PATT 34 ➤2017 Conference Program

Technology & Engineering Education
Fostering the Creativity of Youth Around the Globe

July 10-14, 2017
Philadelphia, PA – USA

Millersville University
Applied Engineering, Safety & Technology
Monday, July 10
5:00 p.m.  Registration
6:00 p.m.  Cocktail Hour

Tuesday, July 11
9:00 a.m.  Welcome and Opening Statements

- Len Litowitz, PATT 34 Conference Chairperson
  Professor, Applied Engineering, Safety & Technology
  Millersville University of Pennsylvania (USA)
- Mike Jackson, Dean
  College of Science & Technology
  Millersville University of Pennsylvania (USA)
- Steven Barbato, Executive Director
  International Technology & Engineering Educators Association

Block 1 Sessions
Chairperson – Joseph McCade

9:20  - PATT and the Amish: Values in Technology Education
  Marc J. deVries
  The Netherlands

9:40  - A Critical Examination of Engineering Design Processes and Procedures
  Greg Strimel
  USA

10:00 - Technology Design Process in Quebec Secondary Schools – Implementation and Assessment
  Brahim El Fadil
  Canada

10:20  Coffee & Tea Break

Block 2 Sessions
Chairperson – Scott Warner

10:40  - Integrative STEM for Teachers of Young Students (iSTEM4ToYS): Engaging Future Elementary School Teachers
  Sharon Brusic
  USA

11:00 - Fostering Creativity in Youth through an Examination of the Socio-Cultural Approaches to Learning in Technology Education Classes in Australia from a Feminist Perspective
  Vicki Knopke
  Australia
Tuesday, July 11 (continued)

11:20 ♦ Education Student Perceptions and Primary Teacher Preparedness to Teach Design and Technology in a Western Australian Context
Jeremy Pagram
Western Australia

11:40 ♦ Tools and Materials in Primary Education: Examining Differences Among Male and Female Teachers’ Safety Self-Efficacy
Tyler Love
USA

12:00 p.m. Lunch Break

Block 3 Sessions
Chairperson – John Williams

1:20 ♦ ACJ: A Tool for International Assessment Collaboration
Scott Bartholomew, Eva Hartell & Greg Strimel
USA & Sweden

1:40 ♦ Learn Better by Doing Study Results
Johnny Moye
USA

2:00 ♦ The Effects of Ideation Assessments on College Student Confidence and Motivation in Creativity
Tanner Huffman
USA

2:20 ♦ Robotics, STEM and Project-Based Learning: Using the P3 Task Taxonomy to Make the Myth Real
Moshe Barak
Israel

2:40 Coffee & Tea Break

Block 4 Sessions
Chairperson – Len Litowitz

3:00 ♦ Unleashing Cognitive Processes via Materialization of Creative Thinking Using Fablab Technological Infrastructures
Vomaranda Joy Botleng
France

3:20 ♦ STEAM Education Professional Development Practicum and Research
Georgette Yakman
USA
Tuesday, July 11 (continued)

3:40 ♦ Does LEGO Robotics and the Universal System Model Provide a Useful Tool for Understanding Brain Processing?
   Hilde van Gijssel
   USA / The Netherlands

4:00 Break for the Day

Wednesday, July 12

Block 5 Sessions
Chairperson – Marc de Vries
9:00 a.m. ♦ Mitcham Score - A Method to Assess and Quantify Students’ Descriptions of Technology
   Johan Svenningsson
   Sweden
9:20 ♦ Enhancing Teachers’ Understanding of Young Students’ Learning in Technology
   Wendy Fox-Turnbull
   New Zealand
9:40 ♦ Illustrating Educational Development Through Ipsative Performance in Design Based Education
   Niall Seery, Donal Canty, & Jeffrey Buckley
   Ireland

10:00 Break

Block 6 Sessions
Chairperson – Joseph McCade
   Joachim Svärd
   Sweden
10:30 ♦ Learning by Doing and Creating Things with Hands: Supporting Students in Craft and Technology Education
   Sonja Niiranen
   Finland

10:50 Prepare for Cultural Experience
Wednesday, July 12 (continued)

Cultural Experience (Afternoon & Evening)
11:15 a.m. Cultural Experience, Lunch, & Tours

Departure
- Lunch at Picnic Area at Longwood Gardens (12:00 p.m.)
- Depart Longwood Gardens (2:15 p.m.)
- Tour of Millersville University’s Department of Applied Engineering, Safety & Technology (depart at 3:45 p.m.)
- Arrive at The Amish Experience (4:15 p.m.)
- Visit Riehl’s Quilts and Crafts (5:30 p.m.)
- Dinner at Plain & Fancy Farm (7:00 p.m.)
- Return to hotel (approximately 9:30 p.m.)

Thursday, July 13

Block 7 Sessions
Chairperson – Wendy Fox-Turnbull

9:00 a.m. The Vocational Goals of STEM Education: Is That Enough?
P. John Williams  
Australia

9:20 Talking with Avatars: The Potential and Impact of Design Dialogue with an On-Screen Avatar on the Development of Learner’s Design and Technology Project Work
Kay Stables  
United Kingdom

9:40 Exploring the Use of Digital Tablets in Preschool Technology and Science Education
Anna Otterborn  
Sweden

10:00 An Exploratory Analysis into the Relationships between Spatial Factors, Domain-Free General Capacities and General Fluid Intelligence
Jeffrey Buckley, Niall Seery & Donal Canty  
Ireland

10:20 Coffee & Tea Break
Thursday, July 13 (continued)

Block 8 Sessions
Chairperson – Sharon Brusic

10:40  ♦ Engaging Students in Hands-On Adaptive Technology Design Projects
       Michele Dischino & James DeLaura
       USA

11:00  ♦ A Proposed Research Agenda for Investigating the Nature of
       Designerly Thinking in Action
       Joseph Phelan, Jeffrey Buckley, Donal Canty, & Niall Seery
       Ireland

11:20  ♦ School Subject Advocacy Work as Policy Enactment: Making the Case
       for Design and Technology Education in England
       Terry Wilkinson
       Canada

11:40  ♦ International Technology & Engineering Educators Association
       (ITEEA)
       Steven Barbato & Edward Reeve
       USA

12:00 p.m.  Lunch Break

Block 9 Sessions
Chairperson – Vicki Knopke

1:20  ♦ Attitudes of Kindergarten Student Teachers towards Technology: The
       Impact of a Technology Thinking Course
       Osnat Dagan
       Israel

1:40  ♦ The Collaborative Activities of Learning Design: “Inserting”
       Partnerships in Engineering and Technology Teaching with
       Novice Teachers
       Éric Tortochot
       France

2:00  ♦ Impact of Long-Term Design Problems in a Team Based Context on
       Student iSTEM Associational Fluency
       Michael de Miranda
       USA

2:20  ♦ Technology and Engineering Education: Fulfilling Its Promise
       Michael Hacker
       USA

2:40  Coffee & Tea Break
Thursday, July 13 (continued)

Block 10 Sessions
Chairperson – Greg Strimel

3:00 ♦ Technical Systems in Technological Education: How French Pupils Aged 13-14 Understand Them
   Fabrice Gunther
   France

3:20 ♦ Child Imagination, A Talent Worth Keeping: How Children Learned to Stream Their Playfulness Into Their Adult Roles
   Alexandra Antonopoulou
   United Kingdom

3:40 ♦ Preview of PATT 2018 in Athlone, Ireland
   Niall Seery

4:00 Break for the Day

6:00 Formal Dinner at City Tavern Restaurant

Friday, July 14

Block 11 Sessions
Chairperson – Kay Stables

9:00 a.m. ♦ Professional Continuity: Investigating the Alignment of Technology Teachers’ Internal Capability Constructs
   Andrew Doyle, Niall Seery, & Donal Canty
   Ireland

9:20 ♦ Rhetoric and Interpretation: The Values Students and Special Interest Groups Attribute to Design & Technology
   Alison Hardy
   United Kingdom

9:40 ♦ Design Heuristic Use to Overcome Similarity or Fixation of Design Ideas
   Keelin Leahy
   Ireland

10:00 ♦ “It is Mainly About Problem Solving...”: Knowledge of Instructional Strategies Expressed by Swedish Technology Teachers
   Birgit Fahram
   Sweden

10:20 Break
**Friday, July 14** (continued)

**Block 12 Sessions**  
Chairperson – *Alison Hardy*

10:30  ♦  Integrating Peer Assessment in Technology Education through Adaptive Comparative Judgment  
*Donal Canty, Niall Seery, Eva Hartell & Andrew Doyle*  
*Ireland*

10:50  ♦  Teaching Algebra through Functional Programming: An Analysis of the Bootstrap Curriculum  
*Geoff Wright*  
*USA*

11:10  ♦  Closing Remarks  
*Len Litowitz*  
PATT 34 Conference Chairperson

11:30 a.m.  **PATT 34 Conference Concludes**

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Thank You  
for Participating in PATT 34!
PATT and the Amish: Values in Technology Education

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Abstract

Part of the PATT-2017 conference program in Philadelphia is an excursion to Lancaster and the Amish people. The Amish have a reputation of being technophobic. In reality they have an intriguing way of assessing new technologies based on family values. Rather than adapting their values to technology, they want to adapt technology to their values. The Amish have been the object of several studies with a focus on their technologies. Donald B. Craybill, Martine Vonk, Stephen Scott and Kenneth Pellman wrote monographs on this topic. They have shown how the Amish have developed an ability to get all commodities that technology offers without becoming entangled in what philosopher of technology Albert Borgmann calls the ‘device paradigm’. By comparing the Amish’ attitude towards technology and current debates in the philosophy of technology, we can understand why the Amish can be an interesting example of a society that has found a way in between technophobia and technocracy. This will be illustrated for some technological domain that used to be the curriculum organisers in the USA: transportation, communication, production/energy and construction.

Keywords: technology assessment, values in technology, Amish technology, device paradigm

Introduction

Technology education aims at helping young people understand the nature of technology. An important element in that nature is the presence of values in technology and engineering. In technology education debates, the role of values has gradually become more explicit. Values such as sustainability, safety, privacy, respect for life and the like have also become an explicit concern for engineers and designers. The attention for values in technology education can become rather vague and abstract as these values themselves have a certain level of abstraction. One way of looking for ways in which these values can be turned into practice is to search for role models that show how these values can serve as concrete guidelines for designing, making and/or using technology. The Amish can be such a role model, but only when we first get a proper understanding of how they make decisions about the position of technology in their society.
Uninformed images

Superficial observation of Amish life easily leads to numerous misunderstandings. This is a danger when an excursion to a place where the Amish live is not accompanied by an introduction into their way of reasoning about technology in terms of values that need to be protected and maintained. When only observing Amish people while sitting in a coach that rides through Amish country, one could easily think that they are a kind of strangely dressed people, riding in old-fashioned horse-drawn buggies, that they have no cars, no telephones, no television, no e-mail and thus have isolated themselves entirely from the rest of the world, that they are inwardly-directed, over-religious and living in a sort of social prison. In reality, however, the have a very interesting way of dealing with values and technology that can inspire many in a time when technology sometimes seems to be overwhelming and captivating.

Amish reality

Amish do have technology (Wetmore, 2007). Although the buggies in which they ride seem to be way from up-to-date, they do contain the most advanced polymers that are currently available. They may not have landline telephones, but several Amish communities do have mobile phones. They also have electricity, which is locally produced (in that respect, the title of Scott and Pellman’s 1990 book on the Amish’ use of technology is incorrect). Ironically, this is seen as the future by many energy experts with a particular interest in sustainable energy production. The Amish have developed special technologies for local energy production that have attracted the attention of several non-Amish companies. They have also shown to be successful entrepreneurs (Ems, 2014) Computers also feature in some Amish communities, although not with Internet connections. The Amish are excellent house builders. In other words: the Amish are no techno-phobes, but they are selective in what they allow to enter their society. There is variation between different Amish sub-cultures and between the Amish and similar communities such as the Hutterites, Mennonites, and Brethren (Kraybill and Bowman, 2001). Even within Pennsylvania there are differences. In Somerset county, most traditional technologies are used, while the Nebraska Group is much more careful in allowing the use of technologies (http://amishamerica.com/amish-technology-friendliness). They, for instance, do not have inside flush toilets, which is rather exceptional for Amish communities.

The Amish have their origin in the Anabaptist movement in the time of the great 16th Century church reformation out of which the Protestant churches emerged from the Roman-catholic church (Craybill, 2001). The Anabaptists were a group that differed from both in that they rejected child baptism and were opposed to formal church regulations, as well as secular governments. They were often associated with the churches of the Reformation and by their liberalistic behavior often caused a lot of trouble for those churches as they constantly had to explain the differences in order not to be persecuted for improper reasons.

The Anabaptists strived for a perfect society in which religious values were the only ones to determine daily life. For the Amish, the family values became the main focus. Close community and mutual respect for each other are further concretizations of these family values. A basic value for the Amish is what they call with an old German term: “Gelassenheit”. “Modesty” is probably the most appropriate translation for this complex term, or alternatively, “humility” (Dana, 2007). In a family, you do not want to show off with property or knowledge. Luxury is therefore not appreciated in Amish societies, nor is acquiring too much knowledge. For most Amish primary school is enough to provide basic knowledge and skills and everything above that conflicts with the primary value of “Gelassenheit”.
The Amish find it important that adhering to these values is a voluntary decision. For that reason, their young people are sent out to what they call the “Rumspringa”: a period of time in which Amish youngsters go into the non-Amish part of the world to experience how life is there. After some months, they can make a decision either to return to the Amish community and become full-fledged members, or stay in the non-Amish world to spend the rest of their lives there. Intriguingly enough, most Amish youngsters decide to return to the Amish community from which they came.

The Amish and deciding about technology

How do the Amish make choices between technologies? There are a couple of criteria that are used. Three of them are discussed here.

Whatever disturbs family life on a regular basis, is expelled. Television is seen as an example of that. When the television is on, everyone has his or her attention directed toward the device instead of toward one another. In fact, there is no escape from that, as the television noise dominates in the room. A conversation is hardly possible. For the same reason landline telephones are banned. When a conversation between family members is constantly disturbed by a ringing telephone, this decreases the quality of community between the family members. A solution to this is to have the phone outside the house in a phone booth. One has to make appointments for calling beforehand of course, but this allows the Amish the have contact with distant relative and this the phone enhances rather than disturbs family connections. Mobile phones can be allowed as they can be turned off and thus are similar to the outside phone.

Whatever makes you completely dependent on the non-Amish world is banned. This is the reason why Amish do not use the electric grid. The use of energy is crucial for a normal family life and if this provision can fall away due to reasons beyond your influence, you want to avoid that. Instead the Amish have technologies for producing energy locally, either on the basis of fossil fuels, but also with contemporary more sustainable technologies such as solar (photovoltaic) cells and panels. Another example of quite advanced technology being used by the Amish.

Whatever stimulates family life is welcomed. This can be seen in the way Amish houses are designed. Amish houses reflect a preference for large public rooms over small private rooms. Amish want their houses primarily to offer opportunities for being together, not for being on your own. Amish houses are a nice example of the fact that buildings can reflect the values of the builders, similar to the way a Gothic cathedral reflects religious value such as being a small creature compared to a great God, or the gracious light from above that touches the earth through the stained-glass windows. In a similar way, Amish houses reflect their view on human life.

Albert Borgmann and his device paradigm

How is this way of dealing with technology to be appreciated? Surprisingly perhaps, it directly reminds of the ideas of an American contemporary philosopher of technology, Albert Borgmann. Borgmann is a good example of how philosophy can develop ideas as critique on society (de Vries, 2017). He developed the concept of a ‘device paradigm’ ruling our use of technology (Borgmann, 1984). This paradigm means that devices provide commodities in such an easy way that we both lost direct and intense contact with reality, and also the understanding of the device. Microwave ovens provide an easy way to ‘prepare’ a meal but at the cost of loss of quality both of the meal itself and of the way it was prepared. Preparing a meal from basic ingredients is a much more intense and rewarding activity in which variety is allowed that the ‘standard’ microwave meal lacks. In a similar way, we can listen to music
in an easy way by using an mp3-player, but this does not in any way give the reward of being able to produce those sounds yourself by playing an instrument. What Borgmann finds most concerning is that we do not ask ourselves anymore why we use these devices. They are there therefore we use them. Currently in the Netherlands there are advertisements by a phone company with texts like: “I want to draw everything there is from the web, because it is possible”. Apart from the fact that this seems to be a fairly ambitious goal, the fact that the motive given is not that there is something useful for me to be gained from that effort, but only the fact that I have “unlimited data”. If we believe advertisements, un-limitedness seems to have become a value in its own right. The term represents a sort of technological utopia, but it can be questioned if it really is an ideal world. Those who try to realize the offer of ‘unlimited eating’ in a Chinese restaurant, during night find out that the utopia has turned into a dystopia. Humans are not made for un-limitedness, yet this is what the advertisements promote.

Compare this device paradigm with the Amish value of “Gelassenheit”. Enough can be enough and probably you appreciate more what is limited than what is not. Particularly in an era in which sustainability has become a concern in most societies, the Amish attitude towards technology use can be an inspiring alternative for a materialist consumer attitude that has no other aim than to get one’s own interests served (Vonk, 2011). Interestingly, Borgmann also warned against the danger of television disturbing our social life: “Television is just like making a hole in the wall. All kinds of stuff come in, on the screen, that we would never allow to come in through the door.” This is precisely what the Amish also dislike about television. One could question why a philosopher like Borgmann is taken entirely seriously (his writings are well received and quoted), and the Amish are seen as old-fashioned and naïve technophobes.

Borgmann’s therapy is what he calls “focal activities”. These are activities that draw us into reality by providing an intense contact with that reality. One can think of getting one’s wood from the forest for warming the house, rather than just adjusting the thermostat a bit. Interestingly enough Borgmann also mentioned attending a church service, as that draws in even in higher reality. Especially in a Gothic cathedral one can experience a strong feeling of being drawn into a ‘higher’ reality (the many upwardly pointing windows enhance that feeling, as the builders intended they would).

**The limits of the Amish example**

Yet, even those who agree with the Amish values and criticize our materialist consumer society would not quickly adopt their lifestyle. Why not? Probably the reason for this is, that they seem to be too eager to ban new technologies and too quickly see them as potential disturbers of their values. Probably they could easily accept more technologies without seeing their values threatened in practice. If a technology can be used in such a way that family values can be preserved, then why ban it upfront?

Yet, the Amish do provide an interesting example of what we call “technology assessment”: an investigation into the possible consequences of introducing a new technology before it is actually introduced and not afterwards only to find out that there are irreversible negative side-effects. Perhaps the quality of their investigation is such that technologies are often banned without sound evidence that they will threaten certain values, but the attitude of reflection before introduction is one that could appeal to everyone.

**Concluding remarks: Relevance for technology education**

What does all this mean for technology education? Traditionally we have social domains of technology use in the curriculum like construction, production, transportation and
communication. For all those, examples from Amish technologies can be used to show how technology can be shaped according to certain values. This would contribute substantially to an understanding with pupils concerning the nature of technology as value-related. We do not need to promote the choices that the Amish make to our pupils, but they would definitely benefit from seeing how the Amish systematically reflect on how technology can serve real purposes and not just be used because it is there. This certainly seems an element in what we usually call "technological literacy". Blindly adopting each new gadget that presents itself does not seem to reflect genuine "technological literacy", but rather the sort of technological naivety that many young (and adult) people show in their use of technology. A ‘drop’ of Amish culture would give technology education an added value in the promotion of technological literacy. Visiting the Lancaster Amish during a technology education conference like PATT Philadelphia 2017 therefore is a nice combination of the useful and the leisurely. Enjoy!

References


Impact of Long-Term Design Problems in a Team Based Context on Student iSTEM Associational Fluency

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Abstract

The current study was conducted in four high schools that had differing groups of students from STEM classes working together in cross-functional diversity teams to complete a long-term (16 weeks) design problem. The total number of participating students across the four schools was 373. Students were challenged to become designers, innovate, communicate, and utilize project management, leadership skills, and work across disciplinary boundaries.

The investigation was informed by research on teaching and learning in the cognitive sciences, specifically; situated cognition, design engineering, collaborative learning, and project-based learning; and from the Next Generation Science Standards. Second, when instruction promotes cross-disciplinary interaction, critical debate, solution and problem finding without classroom or school boundaries, the ethos of the learning environment is fundamentally changed from knowledge transmission sites to sites of discourse and knowledge sharing.

The research methodology used a pretest posttest design using scales validated and tested in a previously published study. The research questions in this study concerned the change in student content knowledge, self-efficacy, and iSTEM associational perceptions through their involvement in an engineering design challenge. Hierarchical linear modeling (HLM) was used to conduct multilevel paired sample t-tests. The model revealed that iSTEM self-efficacy scores gained 0.64 points from pre- to posttest. The random effects revealed that an extremely large proportion of the variability in gain scores was between classrooms. Specifically, the intraclass correlation coefficient was .48, which indicated that 48% of the variability in gain scores was between classrooms.

Keywords: Engineering Design, iSTEM, Design Problems, Test and Measurement
Introduction

Many science, technology, engineering and mathematics (STEM) concepts, especially those learned in the critical formative years of pre-collegiate education are abstract in nature, often taught in vertically articulated course offerings that are frequently unconnected horizontally with other STEM course content. The lack of concept and content connections to authentic applications makes learning difficult for young learners. In addition, few opportunities exist within K-12 education for students to apply STEM learning in contextually authentic learning-in-doing inquiry and design driven environments in which they are immersed over time greater than a few class periods. Combine these factors with student misconceptions of what engineering and technology practice is and less than optimal instructional models yields a volatile combination for student attrition and low perceived value for learning STEM subjects (Adelman, 1998).

The aversion to learning basic STEM concepts due to their high abstractness, low perceived value, utility, and disconnection from applications has triggered a decrease in confidence in STEM learning (Katehi, Pearson, and Feder, 2009, Atman, Sheppard, Fleming, et al., 2008, Felder and Brent, 2005).

The Next Generation Science Standards (NGSS) in the US marks a significant shift in the core concepts and approaches guiding science, technology, engineering, and mathematics education content in the coming years (Lead States, 2013). Integrating the three dimensions of scientific and engineering practice, crosscutting concepts, and disciplinary core ideas that cover traditional scientific fields of study now includes the addition of engineering, technology, and applications of science. Integrating these three dimensions could prove illusive, however approaches informed by research on teaching and learning from cognitive sciences combined with aggressive methodological approaches to measuring student learning within the three dimensions could yield promising results (Brown, 1992).

Grounding of the Intervention Design

STEM content learning.

The conceptualization and design of this study is informed by two perspectives; the first, teaching and learning from the cognitive sciences; and second from the newly released NGSS. There is consonance between models of classroom learning and teaching informed by research from the cognitive sciences and the new NGSS vision to actively engage students in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields (Lead States, 2013, Brown, 1992, de Miranda, 2004, Roozenburg and Cross, 1991). In addition, the ethos of the learning environment can be fundamentally changed from knowledge transmission sites to sites of discourse, knowledge sharing and coming to know and learn how knowledge is applied and shared.

STEM self-efficacy.

Social cognitive career theory (SCCT) helps to explain why student choose and persist into careers, particularly those in STEM fields. Consistently, self-efficacy has been predictive of career choices, persistence toward a career, and performance. Further, within SCCT, self-efficacy is not static but is rather dynamic and sensitive to interactions with others and with social factors that students encounter. Thus, studies that incorporate opportunities for students
to engage with new material, such as engineering concepts, within a social setting could expect to see increases in student task-specific self-efficacy (Lent, Brown and Hackett, 1994, Bandura, 1986, Atadero, Rambo-Hernandez and Balgopal, 2015 and Lent, Sheu, Singley, et al., 2008).

**STEM associational fluency.**

The integrated approach to STEM education (iSTEM) includes instructional approaches and complex classroom interventions that interweave content and learning experiences among and between any of the STEM subjects or other school subjects. While learning-in-doing through integrated design problems situates the learner to apply the “thinking tools” from varied STEM knowledge structures, e.g. mathematics or physics principles on demand when needed. This STEM “associational fluency” refers to students thinking crosses content borders that mirrors expert engineering practice. Prior research with students indicates that they often view science, technology, engineering, and mathematics as separate fields, and thus perceive relatively low levels of integration across STEM disciplines (Hernandez, Bodin, Elliott, Ibrahim, Rambo-Hernandez, Chen and de Miranda, 2013).

**Research Questions**

The following research questions were central to this investigation.

RQ1: Do students make gains in content (e.g., physics) self-efficacy or knowledge (i.e., quiz scores) over the course of the intervention?

RQ2: Does that pattern of gains in iSTEM scores match the pattern described in prior research (i.e., students with initially low iSTEM scores exhibit the most gains in iSTEM perceptions)?

**Methodology**

**Participants**

Four high schools (grade 9-12) had differing groups of classes that worked together to complete the design problems: school 1, (Anatomy & physiology; engineering and technology; geometry); school 2, (engineering and technology; geometry; general physics); school 3, (biology; statistics; engineering and technology); and school 4, (calculus; general and AP physics; engineering and technology). The total number of valid participants was 300. The final analytic sample for this study consisted of high school students in the 9th (20%), 10th (39%), 11th (19%), and 12th (22%) grades. The sample was nearly evenly split by gender (54% male & 46% female). Further, the sample was primarily White (83%), with a smaller proportion of students being Hispanic/Latino (7%), Asian (4%), multi-ethnic (3%), or Other (3%). Finally, only a small proportion of students (16%) were involved in extra-curricular STEM clubs (e.g., robotics club, web design club, 4-H).

**Procedure and Intervention Organization**

This study examines the impact of a complex classroom intervention that addresses several “game changing” factors that could influence pre-collegiate STEM learning.
1. Mathematics, science, and engineering and technology teachers worked collaboratively to blueprint their individual curriculum and built content matrices that identified content intersections that would reinforce the applications of content in authentic practice.

2. Students worked in design teams made up of students from each of the three content classrooms.

3. The intervention was 16-24 weeks in duration. Teacher teams consisting of math, science, and engineering and technology teachers gathered during the summer prior to the intervention to co-plan and blueprint the subject matter content. The blueprinting process made explicit the specific learning concepts, defined or operationalized the content, identified the level of knowledge learning desired, identified common student misconceptions related to the concept/s being learned, and identified the test item number associated with measuring the content. Teachers then created and shared the assessments used to measure student learning. Subject matter experts using a previously validated content validation protocol reviewed each assessment item for alignment and confidence of content being assessed, relevance and appropriateness of items to content being assessed, accuracy of identified correct answer and distractors within the items that could align with know student misconceptions (Hernandez, Bodin, Elliott, Ibrahim, Rambo-Hernandez, Chen and de Miranda, 2013 and Wilson, 2015). Following the content test review, nine of the best items representative of the major concepts being taught were selected for the content assessment after pilot testing and confirmatory factor analysis.

The design problem intervention.

The intervention used in this study translated the activities from an active interdisciplinary biomedical engineering research program. The research consisted of activities in silicon nano scale sensor design. To mirror the practice of this interdisciplinary research, students participating in this study were challenged to design and test “sensing” related problems of their choice. For example, teams made up of math, anatomy/physiology, and engineering and technology students designed bicycle helmets fitted with sensors to test impact absorption and collect data related to helmet materials and design to reduce force transfer to the head as shown in figure 1. Students were required to conduct research, design experiments and engineer test beds that enabled them to execute their experiments and collect data.

Prior to the intervention implementation, teachers administered pretests. Following pretesting, the intervention was implemented in each classroom. After the completion of the intervention, teachers administered posttests. Finally, and concurrent with posttests, the student design teams developed and presented final research posters at a school-wide research symposium.

Measures

Content knowledge quiz.

Student content knowledge was assessed with a teacher made nine-item per subject multiple-choice quiz. Students scale scores on the content knowledge quiz were produced by taking the
proportion of correct answers at pretest and posttest. Therefore, individual scores could range from 0 (no correct answers) to 1 (all correct answers).

Self-efficacy.

Task specific self-efficacy was assessed through a nine item measure. Specifically, after each multiple-choice question on the quiz students responded to the question “How confident are you in your answer to question X?” (where “X” was 1, 2, 3, ..., 9). The response options were scored from 1 (“Not at all confident”) to 5 (“Completely confident”). Students scale scores on the self-efficacy instrument were produced by taking the mean across responses. Therefore, individual scores could range from 1 to 5, with higher scores indicating higher self-efficacy, see Table 1 for descriptive statistics.

iSTEM perceptions.

Participants responded to a nine-item scale developed and validated in a previously published study, to measure student perceptions of the interconnections between mathematics, science, and engineering (Wilson, 2005). In validating the iSTEM scale in a previous study similar to the one reported here, a single factor Confirmatory Factor Analysis (CFA) model was fit to the data based on the model identified through Exploratory Factor Analysis (EFA) at pretest (Hernandez, Bodin, Elliott, Ibrahim, Rambo-Hernandez, Chen and de Miranda, 2013 and Wilson, 2015). The CFA analysis was conducted using maximum likelihood estimation in AMOS version 18 (Arbuckle, 2009). The analysis of the single factor model revealed excellent model fit ($\chi^2_{(df = 20)} = 29.11, p = .08$; comparative fit index = .98; and root mean square error of approximation [RMSEA] = .05, 90% CI [.00, .09]). Further, an inspection of the factor model revealed that all items exhibited high factor loadings, see Figure 2. A reliability analysis of posttest scores indicated highly similar findings to those found at pretest (i.e., Cronbach’s alpha = .85, N = 170, M = 3.50, SD = 0.69, KS z = .05, p = .20).

![Figure 2. CFA factor structure of STEM Connections scale](image)

Note: Q9 had been set as the marker variable. Factor loadings values in the figure are standardized.

Students responded to statements, such as “I have applied connections between mathematics, science, and engineering to help me solve problems outside of school”, on a five-point Likert
scale from 1 (Strongly Disagree) to 5 (Strongly Agree). Students scale scores on the iSTEM instrument were produced by taking the mean response across items. Therefore, individual scores could range from 1 to 5, with higher scores indicating higher iSTEM perceptions, the descriptive statistics for this study is shown in table 1 in the results section.

STEM clubs.

Participants responded “Yes” (1) or “No” (0) to the question regarding their involvement in extracurricular STEM clubs: “Do you participate in any Math, Science, Engineering, or Technology clubs inside or outside of school?” If the student indicated “Yes,” s/he was asked to specify the name of the STEM club, see descriptive statistics in table 1 in results section.

Results

Descriptive Statistics

At the student level, consistent with expectations, participants’ self-efficacy and quiz scores showed positive gains from pretest to posttest, see table 1. Further, consistent with prior research and our expectation, iSTEM scores show no mean level gain from pretest to posttest. Regarding associations, efficacy, quiz, and iSTEM scores exhibited moderately positive correlations (i.e., moderate stability) from pre- to posttest. Further, consistent with theory, self-efficacy and quiz scores were moderately and positively correlated at both pre- and posttest.
Table 1.
Intercorrelations and Descriptive Statistics of Demographic Characteristics, Self-Efficacy, Quiz, and iSTEM Scores at Pre- and Post-test (N = 300)

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
<th>9.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Self-Efficacy (Pretest)</td>
<td>.88</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Quiz (Pretest)</td>
<td>.63***</td>
<td>.67</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. iSTEM (Pretest)</td>
<td>.06</td>
<td>.06</td>
<td>.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Self-Efficacy (Posttest)</td>
<td>.60***</td>
<td>.40**</td>
<td>.16**</td>
<td>.82</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5. Quiz (Posttest)</td>
<td>.48***</td>
<td>.62***</td>
<td>.10</td>
<td>.57***</td>
<td>.61</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. iSTEM (Posttest)</td>
<td>.04</td>
<td>.08</td>
<td>.71***</td>
<td>.26***</td>
<td>.17**</td>
<td>.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Female (0 = male, 1 = female)</td>
<td>-.12*</td>
<td>.07</td>
<td>-.17**</td>
<td>-.07</td>
<td>.06</td>
<td>-.22***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. White</td>
<td>-.01</td>
<td>.05</td>
<td>-.06</td>
<td>.03</td>
<td>.05</td>
<td>.03</td>
<td>.04</td>
<td>.07</td>
<td></td>
</tr>
<tr>
<td>(0 = non-White, 1 = White non-Hispanic)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. STEM Clubs</td>
<td>.14*</td>
<td>.03</td>
<td>.31***</td>
<td>.15**</td>
<td>.02</td>
<td>.25***</td>
<td>.00</td>
<td>.07</td>
<td></td>
</tr>
<tr>
<td>(0 = did not participate, 1 = participated in STEM clubs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>3.07</td>
<td>0.55</td>
<td>3.83</td>
<td>3.71</td>
<td>0.64</td>
<td>3.82</td>
<td>0.46</td>
<td>0.83</td>
<td>0.16</td>
</tr>
<tr>
<td>SD</td>
<td>0.97</td>
<td>0.25</td>
<td>0.64</td>
<td>0.67</td>
<td>0.24</td>
<td>0.68</td>
<td>0.50</td>
<td>0.37</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Note: Cronbach’s alpha coefficient reported in italics on the diagonal.

* p < .05, ** p < .01, *** p < .001
Self-efficacy and Quiz Scores

The main research questions in this study concerned the change in student knowledge, self-efficacy, and iSTEM perceptions through their involvement in an engineering design challenge (i.e., intervention). The most direct method of assessing such changes was a paired samples t-test (i.e., posttest score – pretest score) to test for statistically significant gain in scores. Unfortunately, the design of this study (i.e., the students were nested within classrooms) made it inappropriate to use a standard paired samples t-test, as such a test would underestimate the standard error of the statistical test (Raudenbush, 1999). Hierarchical linear modeling (HLM) is a more appropriate statistical method in nested designs because it distinguishes variability in scores at the student-level (i.e., level-1) from variability in scores at the classroom level (i.e., level-2), which results in correctly estimating standard error. Therefore, HLM v. 7.01 was used to conduct multilevel paired sample t-tests. Further, all analyses were conducted with Restricted Maximum Likelihood estimation (Raudenbush and Bryk, 2002). More specifically, first, we derived gain scores (i.e., posttest score – pretest score) for each construct (i.e., quiz, efficacy, & iSTEM). Second, we entered the gain scores into HLMs as the dependent variable.

To formally test research question-1, a null model (i.e., intercept only with no predictors) was fit to self-efficacy the gain scores. An examination of the fixed effects indicated that the intercept (i.e., mean gain) was positive and statistically significant, see table 2 (Self-Efficacy Gain). The model revealed that self-efficacy scores gained 0.64 points from pre- to posttest. Finally, an examination of the random effects revealed that an extremely large proportion of the variability in gain scores was between classrooms. Specifically, the intraclass correlation coefficient was .48, which indicated that 48% of the variability in gain scores was between classrooms. A further analysis, regressing self-efficacy gain scores on the control variables revealed that none of the factors were significant predictors of gain.

Next, a null model was fit to quiz gain scores. An examination of the fixed effects indicated that the intercept was positive and statistically significant, see table 2 (Quiz Gain). The model revealed that the proportion correct on the quiz increased by 9 percent from pre- to posttest. Finally, an examination of the random effects revealed that a large proportion of the variability in gain scores was between classrooms. Specifically, the ICC was .18, which indicated that 18% of the variability in gain scores was between classrooms. A further analysis, regressing quiz gain scores on the control variables revealed that none of the factors were significant predictors of gain.


Table 2. Summary of Fixed Effects for Self-Efficacy Gain Scores, Quiz Gain Scores, iSTEM Gain Scores and Participation in Poster Presentation from Final Models

<table>
<thead>
<tr>
<th>Fixed Effect</th>
<th>Self-Efficacy Gain</th>
<th>Quiz Gain</th>
<th>iSTEM Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b (SE)  t (df)</td>
<td>b (SE)  t (df)</td>
<td>b (SE)  t (df)</td>
</tr>
<tr>
<td>Model for Key Outcomes ($\beta_0$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept ($\gamma_{00}$)</td>
<td>0.64   4.89</td>
<td>0.09     3.58</td>
<td>-0.01    -0.44</td>
</tr>
<tr>
<td></td>
<td>(.13) (17)***</td>
<td>(.03) (17)***</td>
<td>(.03) (17)</td>
</tr>
<tr>
<td>iSTEM – Pretest ($\gamma_{10}$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.26   -5.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.05) (280)***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>iSTEM$^2$ - Pretest ($\gamma_{20}$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.14    2.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.05) (280)**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Level-1 predictors (iSTEM & iSTEM$^2$) were group mean centered and Level-2 predictor (MEAN iSTEM) was grand mean centered.

* p < .05, ** p < .01, *** p < .001
iSTEM

A series of models were conducted to formally test RQ-two. First, a null model was fit to iSTEM gain scores. The ICC revealed that little between class variability in iSTEM scores (ICC = .00007) was present, which indicated that less than 1% of the variability in gain scores was between classrooms. Second, the non-linear hypothesis was tested by regressing iSTEM gain scores on iSTEM and \( iSTEM^2 \) pretest scores. As expected, iSTEM pretest was significantly and negatively associated with gain scores, while \( iSTEM^2 \) was significantly and positively associated with gain scores. To make these finding more concrete, model predicted iSTEM gain scores were plotted against pretest iSTEM scores, see figure 3. As shown in the figure, low pretest iSTEM scores were associated with higher gain, while moderate to high pretest iSTEM scores exhibited no gain. A further analysis, regressing iSTEM gain scores on the control variables revealed that none of the factors were significant predictors of gain.

\[ \text{Figure 3. Model Predicted iSTEM Gain Scores for Students from Low to High iSTEM Perceptions at Pretest (with 99\% Confidence Bands)} \]

Note: Solid line indicates model predicted iSTEM gain score; dashed lines indicate the upper and lower limit of the 99\% confidence band.

Discussion

Pre-collegiate students engaged in long-term team-based engineering design problems that emphasize, inquiry, design, testing, and making activities is a natural platform for the integration of iSTEM content into classrooms. In the current study, we report on an engineering design based interventions that bridges the gap between the new integrated science standards that include engineering design and well researched models of teaching and learning from the cognitive sciences. One of the primary goals of this project was to transform student
understanding of the co-dependent nature of STEM content knowledge; however, the measurement of such knowledge has been elusive.

A key finding from this study indicated that the measurement of student perceptions were consistent with our expectations. Specifically, we had hypothesized that our instrument would measure a single factor related to perceptions of the interrelated nature of STEM content knowledge and our analysis supported that hypothesis. A single factor emerged from the EFA to explain the pattern of student responses. A second psychometric validation was conducted on the posttest data using confirmatory factor analysis. Once again, the results indicated that the single factor model provided the good fit to the data. Together, these findings provide incremental evidence of the structural validity of the scale, as well as evidence for the stability of the structural model over time.

A second, more important, finding from the current study concerned the positive change in student perceptions of the co-dependent nature of STEM content knowledge. We addressed this issue by comparing student perceptions at pretest with their perceptions at posttest. Our analysis indicated that overall, students did not exhibit significant change in their perceptions; however, probing our data further indicated a surprising pattern of results. More specifically, our data indicate that the intervention was most effective with students who started with low perceptions of the interrelated nature of STEM knowledge. It appears consistent across two studies conducted by the authors that long-term participation in an authentic engineering design problem cultivated connections for those students who initially saw the fewest connections and benefits of STEM content knowledge. Although far from conclusive, this finding is promising in that interventions such as this may help to spur student understanding of the utility of, interest in, and engagement in STEM knowledge for those students who are initially the least engaged. Future studies of similar interventions should closely examine the initial STEM connections at different levels of the continuum.

References


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Attitudes of Kindergarten Student Teachers towards Technology:
The Impact of a Technology Thinking Course

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Abstract

Technology education is part of the formal kindergarten curriculum in Israel, but it is rare to find it in the actual curriculum. The main reason explaining its absence is that technology education is not included in the pre-service training that future kindergarten teachers receive. A Technology Thinking course based on six strands (the designed/artificial world, problem solving, design and making, notations, smart artefacts, and the whole-kindergarten final project), coding, and robotics (Mioduser, 2009; Mioduser et al. 2008; Dagan, 2015) was developed and offered to students in their fourth year of training at Beit Berl College. During the course, the students studied technology concepts and skills as well as ways to implement them in the kindergarten. The courses and the seminar were taught three times between 2014 and 2016, with some modifications made over the years. In the first year, it was in a seminar format and the students dealt with technology thinking, coding, and robotics and were required to submit a seminar research paper. In the second and the third year, the courses dealt with the same subject without the research. The primary objective of the courses and the seminar for pre-service student teachers was to help them formulate their perceptions, beliefs, and philosophy regarding technology and technology education so they would later apply them in the kindergarten.

This paper reports the findings from a survey that used the PATT questionnaire (Raat, de Klerk Wolters & de Vries, 1987) and was conducted twice: before and after the Technology Thinking course. Use was made of a mixed linear model to ascertain if differences exist between the pre- and post-course responses. The findings show differences only in some of the categories. The paper describes the three courses that were taught, the survey findings, and the conclusions, and offers some recommendations for future teacher training.

Keywords: Technology education, pre-service teacher education, kindergarten teachers, attitudes towards technology
Introduction

Isn't it an ambitious aim, to teach a one-semester course or even a whole year seminar and think that the students’ attitudes towards technology would improve? We cannot be sure. However, after teaching a year-long seminar I felt that the students use the word technology with different meanings (problem solving more than computers) (Dagan, 2015) and that brought me to this study.

This paper presents the finding of a research study related to changes in attitudes towards technology throughout a) a one-year seminar and b) a course that lasted a semester on technological thinking, for fourth year kindergarten student teachers. The seminar delivered once and the course twice. In this paper we focus on a) technology education in the kindergarten; b) pre-service teacher training in technology education, and c) pre-service teachers’ attitudes towards technology and technology education.

Theoretical background

Technology Education in the Kindergarten

Early childhood is when the foundation for effective learning is built, and is an opportunity to teach and experience technology, among other subjects. However, it is rare to find technology education in preschool, and few research studies focusing on this age group have been conducted (Fleer, 1999; Mioduser, Levy, Kuperman & Rudolf, 2008). Technological content geared to the kindergarten level has been integrated into curricula developed and implemented in different countries (for example; in the United Kingdom, New Zealand, Australia, the United States, and countries in continental Europe – see in Compton and France, 2007; ITEA, 2000). Despite the differences between them, common sets of content categories and target skills can be identified, including technological awareness and literacy, relations with the world of artifacts in which we live, acquisition of materials manipulation skills, and even design process skills (Mioduser, Levy, Kuperman & Rudolf, 2008; Dagan, Kuperman & Mioduser, 2012).

The technology elements of the Israeli kindergarten curriculum are rarely implemented. This can be attributed to the fact that technological knowledge and relevant pedagogies are not part of most teachers’ background or formal formation in their pre-service professional development. A “new” science and technology curriculum for this age level is currently under development (Ministry of Education, 2009). Beit Berl College decided to develop a course to address the topic of technological thinking in the kindergarten that was included in the preschooler program five years ago.

Fleer (1999) discovered that five-year-old children could design, make, and evaluate in an iterative process when she gave them open-ended problems and assistance during the process. Resnick (2007) claims that a spiraling process in which children imagine what they want to do, create a project based on their ideas, play with their creations, share them with others, and reflect on their experiences, leads the children to imagine new ideas and new projects. Through this non-distinct or sequential process the young children develop their creative and thinking abilities.

The Beit Berl seminar and the course syllabus is based on the concepts and program developed by Mioduser in Tel Aviv University (Mioduser, 2009). This program addresses technological thinking in the kindergarten, with an emphasis on the cognitive process involved and requirement for understanding, interacting with, and designing the artificial world: the human-mind-made
world. It is based on a cognitive and epistemological model that enhances teaching and learning technology as part of a human being’s thinking and intellectual development. Thus, learning technology is learning about thinking, about learning, about the invented world, and about the results of the co-evolution of the designed and the designers’ worlds (Dagan, Kuperman & Mioduser, 2012).

The courses program is based on these six main strands: 1) the designed/artificial world; 2) problem solving; 3) design and making; 4) notations; 5) smart artifacts, which include analyzing observed robot behaviors and design of adaptive behaviors while coding); and 6) kindergarten-wide final project (Mioduser, 2009).

Pre-Service Teacher Training in Technology Education

Despite the many differences in technology education training programs around the world, the programs for pre-service teacher training world-wide focus on technology knowledge, processes, values, and attitude on the one hand, and pedagogical knowledge and skills on the other (Pool, Reitsma & Mentz, 2011; Baskette & Frantz, 2013; Forret, Edwards & Lockley, 2013). Research studies indicate that pre-service teacher training in technology education must focus on the development of teacher subject matter knowledge, pedagogical content knowledge, and teachers’ attitudes towards the subject. The studies claimed that an increase in confidence related to technology teaching combined with a more positive attitude could contribute to an improvement in the quality of teaching (Ginns & Stein, 2000; Koski & de Vries, 2011; Rohaan, Taconis & Jochems, 2012; McRobbie, McGlashan & Wells, 2012; Chikasanda, Otrel-Cass, Williams & Jones, 2013).

Pre-service teachers need to be encouraged to dare to integrate theory and practice as a tool to deal with unanticipated situations in technology education in the classes (Koski & de Vries, 2011).

There is consensus that pre-service teacher training programs not only prepare teachers for teaching the curriculum but also concentrate on building the student teachers’ own beliefs and perceptions (Forret, Edwards & Lockley, 2013; de Vries, 2012 Rohaan, Taconis & Jochems, 2012).

Pre-Service Teachers’ Perceptions of Technology and Technology Education

Volk & Dugger (2005) were interested in comparing the understanding and knowledge of technology as well as attitudes and thinking about technology education between adults in America and Hong Kong. One question in their questionnaire was, "What comes to mind when you hear the word ‘technology’?” Their findings indicated that both groups of adults think about computers first (47% HK and 68% US) and then electronics (5% in both groups). The group from Hong Kong indicated to a greater degree that they also thought about new inventions and advancements.

In order to teach technology effectively the teachers must develop an understanding of technology (de Vries, 2012). The goal of pre-service technology teacher training is to help student teachers develop their conception and knowledge of technology that will influence their perceptions of technology education and shape their curriculum materials (Forret, Edwards & Lockley, 2013).

Research indicates that student teachers changed their perceptions towards technology education and the nature of technology during their training. Initially they thought of technology as use of computers and later expanded their perception of technology to include problem solving, creativity, and thinking processes (Forret, Edwards & Lockley, 2013; Baskette & Fantz, 2013; McGlashan & Wells, 2013; Dagan, 2015).
A survey focusing on the ability of one course to change students' technological literacy and their perception of the importance of technology asked the following open-ended question: “What is technology?” Pre-test responses from the students included the words computer, electronics, and cell phones. Post-test responses included the word computers but also included statements such as "anything that makes life better" (Baskette & Fantz, 2013).

Our study was designed to gauge the ability of a one-semester course or two-semester seminar to change kindergarten student teachers' attitude toward technology and technology education.

**Research question**

Are there any differences in kindergarten student teachers’ attitudes towards technology after participating in a technology-thinking seminar or a course?

**Methods and Materials**

**Study sample**

Kindergarten student teachers who studied technology thinking course or seminar during 2014-2016 at Beit Berl College, Israel, including 77 female students. Twenty-three participated in a one-year seminar during 2014, and 54 students participated in a course that lasted one-semester twice, during 2015 and 2016 (n=77).

Table 1 presents the student demographics. All were women (as most of the kindergarten teachers in Israel). More than 50% were 26-30 years old, and 38% of the students' fathers worked in a job that is connected strongly to technology. Less than 15% of their mothers, more than 40% of their spouses, and 38% of their siblings worked in those types of jobs. The percentage of the students that owned technology toys is 61% (Table 1).
Table 1: Demographic characteristics of the study sample

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>Absolute number (n)</th>
<th>Relative number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>male</td>
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<td>0</td>
</tr>
<tr>
<td></td>
<td>female</td>
<td>77</td>
<td>100%</td>
</tr>
<tr>
<td>Age</td>
<td>20-25</td>
<td>10</td>
<td>13%</td>
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<tr>
<td></td>
<td>26-30</td>
<td>41</td>
<td>53%</td>
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<td></td>
<td>31-35</td>
<td>13</td>
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<tr>
<td>Father tech. work</td>
<td>week</td>
<td>21</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>medium</td>
<td>13</td>
<td>17%</td>
</tr>
<tr>
<td></td>
<td>strong</td>
<td>29</td>
<td>38%</td>
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<td></td>
<td>missing</td>
<td>14</td>
<td>18%</td>
</tr>
<tr>
<td>Mother tech. work</td>
<td>week</td>
<td>29</td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td>medium</td>
<td>18</td>
<td>23%</td>
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<tr>
<td></td>
<td>strong</td>
<td>14</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>missing</td>
<td>16</td>
<td>21%</td>
</tr>
<tr>
<td>Spouse tech. work</td>
<td>week</td>
<td>5</td>
<td>6%</td>
</tr>
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<td></td>
<td>medium</td>
<td>15</td>
<td>19%</td>
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<td></td>
<td>strong</td>
<td>33</td>
<td>43%</td>
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<td>31%</td>
</tr>
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<td>Tech. toys</td>
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<td>27%</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>47</td>
<td>61%</td>
</tr>
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<td></td>
<td>missing</td>
<td>9</td>
<td>12%</td>
</tr>
<tr>
<td>Sibling tech. work</td>
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<td>40</td>
<td>52%</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>29</td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td>missing</td>
<td>8</td>
<td>10%</td>
</tr>
</tbody>
</table>

Abbreviations: Tech. = technology.

Instruments of Evaluation

In this research, the Pupils’ Attitudes Towards Technology (PATT) questionnaire (Raat, de Klerk Wolters, & de Vries, 1987) was used twice; before and after the ‘Technology Thinking’ course (pre-post), and three times (pre, mid, and post) in the two semester-long seminar. This validated questionnaire was developed and used in many countries around the world while the participants were mostly pupils (Ankiewicz & Van Rensburg, 2001; Becker & Maunsaiyat, 2002; Chikasanda, Williams, OtreICass, & Jones, 2011; Ardies et al., 2014). In the current study, this questionnaire was used with student teachers in Beit Berl College (Power, Buckley, Seery & Canty, 2016). The questionnaire contains one hundred questions/statements in four sections: a) open-ended questions (short description of what is technology, and what you will do with technology in the kindergarten); b) individual demographic information in ten questions; c) fifty-seven statements with five possibilities of answers (Likert scale items) d) thirty statements with three possible answers.

The 57 statements from the third section were divided into six categories by the questionnaire’s developers (a) general interest in technology; b) role pattern (gender); c) consequences of technology; d) the difficulty of technology; e) school and technology; and f) career and technology. The thirty other statements were divided into four categories: (a) society and technology; b) the
influence between science and technology, c) technology skills, and d) technology is built from materials, energy, and information.

Thus, the dependent factors in the current study were: a) General interest in technology (‘Interest’); b) Role pattern; c) Consequences of technology (‘Consequences’); d) The difficulty of technology (‘Difficulty’); e) School and technology (‘School’); f) Career and technology (‘Career’); g) Society and technology (‘Society’); h) The influence between science and technology (‘S&T’), i) Technology skills (‘Skills’), and j) Technology are built from materials, energy and information (‘Materials’). Descriptive statistics together with reliability coefficients are presented in Table 2.

Six of these factors—‘Interest’, ‘Role pattern’, ‘Consequences’, ‘Difficulty’, ‘School’, and ‘Career’—had satisfactory coefficient reliability in all the measuring points. Four other factors (‘Society’, S&T’, ‘Skills’, and ‘Materials’) had low coefficient reliability and did not continue to the mixed-linear-model analysis.

Table 2: Reliability of the variables

<table>
<thead>
<tr>
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<th>Pre</th>
<th>Mid</th>
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<tr>
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To know if a half-year course and a whole year seminar (independent factors) change the students’ attitudes (dependent factors), we used the mixed-linear-model method. This method is useful in a wide variety of disciplines and particularly where repeated measurements are made
or where measurements are made on clusters of related statistical units. We also used it because of its advantage in dealing with missing values.

Using the Mixed-linear-Model method, the seminar (that lasted one year) mid-post are equal to course (that lasted one semester only) post. It was done only for the factors whose reliability was higher than 0.5.

The intervention – course and seminar characteristics

The seminar "Kindergarten Student Thinking and Doing Technology" lasted two semesters. During the first semester, the student teachers studied concepts of technology education and how they can teach them in kindergarten (6 Strands). The seminar subjects included technology content knowledge, pedagogical content knowledge, and attitudes and values. Some of the lessons were hands-on, learning by doing (designing), and some of their knowledge was studied in a flipped classroom by collaborating in teamwork and by teaching each other. During the second semester, each pair of student teachers conducted their action study in a kindergarten and wrote a report. Examples of a research topic are "Gender differences in building with blocks and drawings in kindergarten children" and "The differences in designing between age 4-5 and 5-6". During the action study, they had meetings with their mentor, and at the end of the year they presented their results to their classmates (Dagan, 2015).

The Technology Thinking course lasted only one semester and the students learnt the same subjects via the same methods as in the seminar but they did not experience the research process. They had to write a theoretical summary paper instead of a research report.

Results

The impact of the intervention type on student-teacher attitudes is presented in Figures 1-6.

Significant main effects for time-point were found for Interest (p=0.002), Consequences, and School factors (Figures 1, 3, and 5, respectively), indicating that the attitudes related to these factors improved between pre- and post-intervention, collapsed over groups. Significant main effects for the group were found for Consequences (p<0.001) and School factors (Figures 3 and 5, respectively), indicating more positive attitudes within the course group compared to the seminar group, collapsed over time. No significant time-point x Group interactions were found. Post-hoc analysis reveals that for the Interest factor there was a significant difference between the post time-point and the pre and mid/post time-points (p=0.003), only within the seminar group. A similar pattern was found for the School factor, where a significant difference was found between post and pre time-points (p=0.002), also only within the seminar group. No significant effects were found for the entire factor.

In all the variables, the course group attitudes towards technology were always higher than the seminar groups. However, these differences were statistically significant only for Consequences and School factors (Figures 3 and 5, respectively).
Figure 1: Interest

Fixed Effects: Time- F(2,24)=8.3, p=0.002; Group- F(1,20)=3.4, p=0.07; Interaction- F(1,50)=0.2, p=0.64

Figure 2: Role Patterns (gender)

Fixed Effects: Time- F(2,26)=2.6, p=0.09; Group- F(1,66)=1.8, p=0.2; Interaction- F(1,57)=0.07, p=0.8

Figure 3: Consequences

Fixed Effects: Time- F(2,26)=11.5, p<0.001; Group- F(1,63)=11.6, p=0.01; Interaction- F(1,52)=0.00, p=0.99

Figure 4: Difficulty

Fixed Effects: Time- F(2,26)=2.01, p=0.152; Group- F(1,60)=0.2, p=0.66; Interaction- F(1,49)=0.15, p=0.7

Figure 5: School

Fixed Effects: Time- F(2,23)=7.3, p=0.003; Group- F(1,67)=17, p<0.001; Interaction- F(1,50)=0.44, p=0.51

Figure 6: Career

Fixed Effects: Time- F(2,26)=1.86, p=0.176; Group- F(1,68)=0.9, p=0.35; Interaction- F(1,53)=0.075, p=0.79
Summary and conclusions

During the seminar, the students’ attitudes improved in the following factors: Interest in technology, Consequences of technology, and technology in Schools. During the course, only the Interest in technology, and technology in Schools improved. The differences were significant. We could see that the length of the seminar as well as the seminar/course subject and activities help to improve the student teachers’ attitudes in these variables.

There are no significant differences between the groups and the time in Difficulty, Career, and Role pattern factors. In other research, differences between men and women in their attitudes towards technology were found (Rohaan, Taconis & Jochems, 2012; Forret, Edwards & Lockley, 2013; Ardies et al., 2014). All the participants in this research were women, which could explain why the mean scores were high and that no significant differences were found over time and groups in many factors and especially in Role Pattern.

The seminar and even the course had an impact on the student teachers’ attitudes that could be helpful when they teach technology in the kindergartens – when the integration between conceptions, attitudes, and technology knowledge is important, as found in other research (Forret, Edwards & Lockley, 2013; Baskette & Fantz, 2013; Mc Glashan & Wells, 2013).

In our research, there was the impact of time on the attitudes of the students in School, Interest, and Consequences. In those factors, we also found an impact on the type of the group, and their attitudes improved. The impact of the seminar on the attitudes of the student teachers in those three factors could be due to the doubled length of the seminar and from the content’s highlights. During the seminar, the students needed to be involved in a small study in which they had to analyze the content knowledge, synthesize a research question, deliver the study, and evaluate the results. The use of all these capabilities enabled them to construct better attitudes towards technology even if only in the three Interest, Consequences, and School factors. Similar results shown in Ardies et al. research (2014), on 12-15-year-olds’ attitudes towards technology that found that a greater time spent learning about technology correlated with a higher interest and that it positively influences the level of interest, career inspirations, and perceptions of technology consequences, and decreases the boredom felt towards technology.

The declarations of the Israel Ministry of Education for the need for technology education K-12, and especially coding and robotics, will force the teaching colleges to include these subjects in the student teachers’ curriculum. The importance of integrating knowledge, concepts, and attitudes to improve the quality of teaching is known (de Vries, 2012; Forret, Edwards & Lockley, 2013). According to research (including this work), there is a need to lengthen the duration of the courses, and to include students’ research processes. More research in this subject matter, including student teachers’ attitudes towards technology, is needed.

References


Integrating Peer Assessment in Technology Education through Adaptive Comparative Judgment

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Abstract
Advocates of assessment ‘for’ learning argue for its use as a diagnostic tool to support direct and meaningful feedback in a way that is a pedagogical feed-forward. Implementations and interpretations of assessment for learning have begun to push the boundaries of educational transactions to actively include the learner in the process of assessment (Black & Wiliam, 1998; Orsmond, Merry, & Reiling, 2000; Sadler, 2009; Yorke, 2003). Critically, assessment ‘as’ learning encourages self and peer appraisal as a self-regulatory act.
With design and technology education requiring a disposition of enquiry and critique it is critically important that appraisal as a self-regulatory act is developed as a central element of practice. Recognising the impact assessment has on shaping the learning experience (Orsmond et al., 2000), the role and position of the student in assessment activities becomes increasingly important when the outcomes of learning are value laden. The goal is to lead students away from uncritical indoctrination in the technology education discipline to a space where they can conceive and imagine the subject for what it should be. This study looks at how assessment practise can be augmented to support ITTE (Initial Technology Teacher Education) students in developing a disposition appropriate to the goals of technology education.

This study utilised the Adaptive Comparative Judgment (ACJ) method of assessment (Kimbell, 2008) as the medium for the integration of peer assessment in a Technology based ITTE programme. Students (n= 136) presented their own conception of capability through an e-portfolio and holistically assessed the work of their peers using non-explicit assessment criteria.

This paper presents the findings from a study that implemented a student-centred approach to assessment in design and technology education. Both qualitative and quantitative methods were employed to evaluate the impact of the initiative on student behaviour, values and capability. Results present student reactions to holistic peer assessment and examine the impact that the integration of the assessment method had on student learning.

**Key Words:** Peer Assessment, Holistic Judgement, Adaptive Comparative Judgement.

**Introduction**
It is of critical importance that student teachers develop understanding of the value and role of their subjects in the broader context of the curriculum and society (Teaching Council, 2011). For ITE providers this highlights the need for students on ITE programmes to develop their conceptual understanding of their subject domain as well as the acquisition of declarative and procedural knowledge and related skills. Banks et al. (2004) outline the importance of reflective practice in teacher education programmes but cautions about its effectiveness when rigidly structured and completed with insufficient breadth of knowledge and experience. They strongly encourage that students experiment with reflection on their practice to help them internalise the purpose and role of their subject domain. Kimbell and Stables (2007) present the complexity of technology education highlighting critical elements of capability being a combination of speculation and critique. These are difficult dispositions to teach or explain to novice teachers, yet it is critical that they are developed. Developing these insights involves self-monitoring and awareness of how and when to use particular skills and knowledge. The design-based approach in technology education provides fertile ground for the honing and development of these skills where the iterative nature of designerly activity requires the use of “thought in action” (Kimbell, Stables, Wheeler, Wosniak, & Kelly, 1991). Mawson (2003), Barlex (2007), and Kimbell (2008) have all identified the negative impact that rigid structured approaches to design activities have on learning and outcomes of design based education. They encourage a more flexible functional approach, valuing individuality over conformity, where the student and their decision-making processes are at the centre of the activity. Assessment has a critical role to play in shaping the learning environment to provide for such outcomes. This study examines how assessment practices can be augmented to support the development of such outcomes.
Literature Review

Fox-Turnbull and Snape (2011) outline how the constructivist approach to teaching and learning successfully leads to the development of student teachers’ understandings of technology education and technological practice. When embracing a constructivist approach to learning, formative assessment becomes a central issue. Yorke (2003) details the formal and informal nature of formative assessment and presents the potential of formative assessment to promote self-regulation in students. Yorke (2003), Orsmond et al. (2000), Sadler (1998, 2009), and Black and William (1998) present the teacher, peers and the student themselves as potential contributors to the formative assessment process, and outline the importance of strategic planning for the integration of formative assessment into any learning activity. The complexity of learning and assessment documented by Orsmond et al. (2000), Sadler (2009), and William (2010) identifies the need to integrate assessment at the heart of the learning activity. However, the difficulties relating to assessment practice indicate the negative impact of over-defined assessment criteria on the nature of student engagement in any design activity, resulting in convergent solutions to open ended problems. Such an approach leads to a convergent and restricted exploration of the subject domain resulting in a construct of capability that is overly regulated by assessment. The result may be a solution that indicates how well the criteria were addressed but may be devoid of meaning for the student. It may also endorse a more teacher centred approach to the development of what may be considered as prerequisite knowledge and skills to successfully engage in the learning task. This is of critical importance when considering learning and assessment practice in ITTE where a disposition of enquiry and critique is a desired learning outcome. Unpacking this learning outcome is predicated on understanding how this disposition manifests during the learning and assessment processes. This is critically underpinned by developing the associated appraisal skills that enable a student to critically evaluate their practice.

Sadler (2009) presents holistic judgement as a means of developing key skills that will enhance the learning potential of students. These skills are determined as demonstrating sophisticated cognitive abilities, integration of knowledge, complex problem solving, critical reasoning, original thinking, and innovation (Sadler, 2009). The holistic judgement should not be atomised to a set of individual measurements driven by mandated criteria, but rather should be based on the intellectual processing of the relationship between qualities observed as a whole to arrive at the correct appraisal. These qualities must be internally processed by the judge, based on implicit (externally influenced) criteria and standards.

The role of appraisal in holistic judgement is outlined by Kimbell et al. (1991) and indicates the potential benefits of integrating holistic student judgement as a central facet of the learning approach. The need for students to be able to identify levels of quality in contextually related work is seen as being critical to students monitoring the quality of their own work while it is being developed (Sadler, 2009). This requires students to develop a set of values on which to base their judgement, which leads to the question of what should they value. Establishing value on the elements of capability in a task can principally be achieved in two ways. Students can align their values with those presented externally, or they can endeavour to try and work it out for themselves. Formative assessment will aid students in internalising such criteria, but if the former approach is taken, the process gets limited to checking the boxes, which rarely satisfies the conditions for learning (Sadler, 2009). Either way the establishment of criteria is necessary and critical to the learning activity. The critical point of note is that formative assessment is an integral part of learning but developing students’ ability to process assessment information is also of significant importance. If teacher centred instruction and feedback is to give way to peer learning and assessment, then some of what the teacher brings to the learning task must in itself become part of the curriculum for the student and not an accidental or inconsequential adjunct to it (Sadler, 1998). Student teachers need to be inducted into the role of teacher through inbuilt
strategies and supports in the learning environment. This in essence means that the learner must begin to develop a construct of what it means to be capable within the learning activity and establish a sense of quality of the learning intentions.

To develop a concept of quality, Sadler (2009) promotes the use of student evaluation “without necessarily being bound by tightly specified criteria” (p. 47) mimicking the way that experienced teachers make multi-criterion judgements of student work and ability. A student teacher’s pool of criteria is developed over time on an individual basis and through engagement and interaction with peers and teachers. These are stored in the mind of the assessor and brought to the fore as a working set of manifest criteria when making judgements on the quality of student work. When student evidence exhibits something noteworthy, latent criteria get temporarily added to the set of manifest criteria to inform the assessor’s judgement. Such flexibility is critical to the student teachers’ conception of quality where value and meaning is created and built through students’ experience and engagement in assessment related activity (Sadler, 2009). To aid the student in this process, it is recommended to use relevant or guiding criteria in the induction process, highlighting that properly implemented, criteria act as enablers for appraisal of the substance of the work (Sadler, 2009). Having to develop criteria is preferred to having them externally imposed. Establishing what to value leads to complex appraisal and reflection on the knowledge and skills at the core of the task domain.

Operationalising an assessment activity that can embrace the critical elements outlined above poses a significant challenge. The use of Adaptive Comparative Judgement (ACJ) as presented by Kimbell (2009) was explored in this study as a medium that could both support and enhance the learning of student teachers as they try to establish what it means to be capable. Therefore, a significant challenge was supporting students to learn about the disposition required to be a teacher of the design based approach at the same time that they are enacting it.

Methodology
A mixed methods research approach was chosen for the study as the nature of the analysis focused on both qualitative and quantitative data. An electronic portfolio was used as the medium to capture and present evidence of student capability. The infrastructure supported the capacity to capture, manage, record and order information in an attempt to communicate the design journey experienced by each individual student. Utilizing accessible technologies (the students’ mobile phones) and a data repository, students constructed their evidence of capability and learning throughout the activity facilitated by the real-time capturing of evidence of the student experience as they navigated their way through the design activity. The participants (n = 136) in this study were undergraduate ITTE students.

The study was delivered through two modules of study over a 12 week period in the second semester of year one of the student’s programme of study. The learning activity was structured with an initial six week period focusing on the development of core knowledge and skills in the area of study. The second six weeks of the modules provided opportunity for the execution of a design based task building on the initial skills developed, giving a context to the learning and resulting in an exercise in ‘near’ and ‘lateral’ transferability of knowledge and skills. The brief was designed to align with specific learning outcomes of the relevant modules (decorative craft and processing techniques) and to provide scope for individual design input. Students were required to design and manufacture pictorial scene with the composition of the scene being of the students own choosing, but portraying a dominant feeling or emotion. In addition, students were required to create a second artefact, a flower (without facial expression) to express or reflect the emotion or feeling conveyed in their
pictorial scene. The task was designed to provide students with a medium to explore and develop new knowledge and skills in the production of a coherent set of artefacts, that enabled students to transfer their new knowledge and skill into a project that embodied their creative expression and capability.

Following the completion of the artefacts and associated portfolio the students engaged in a peer assessment activity where they generated a rank order of the portfolios using the Adaptive Comparative Judgement (ACJ) method of assessment (Pollitt, 2012). This was completed to elicit their construct of capability by making judgements on the qualities and standards of the work that they observed in their peers portfolios. The findings from this study look at how the integration of peer assessment through the ACJ approach had an impact on student teachers.

**Findings**

**Consensus**
The internal reliability of the ACJ model is presented through the Cronbach Alpha reliability coefficient for the judging session. The reliability coefficient for the judging session in this study was 0.98. This is considered to be a high reliability (Kimbell, 2009) indicating a low level of inter-assessor variability in the judging process. The real significant point of note is that this level of reliability was achieved using holistic judgement and without providing explicit criteria to the assessors. The consensus of the individual judging decisions presented through the portfolio and judging misfit statistics is also extremely high with less than 5% of misfit in either category. The democratic nature of the model assumes that judgments by individuals are equitable if the misfit is not high. This indicates that the judges were making similar decisions about similar pieces of work through the synthesis of qualities observed in the portfolios. The consensus achieved indicates a coherency in the capacity of the novice assessors to analyse and appraise the work and rate it in terms of quality. This gives an insight into the collective values exercised by the group and presents the potential of ACJ in making explicit their implicit beliefs. It is hypothesised that the social dialogue that evolved as a result of the assessment approach was a factor in the consensual outcome of the peer assessment. Students were sharing interpretations of criteria and standards in a bid to establish what was of value and quality. The validity of the student judgments was also examined but is beyond the scope of this paper. For further information on the validity and reliability of the ACJ ranks and the judge and portfolio misfit see Seery, Canty, and Phelan (2012).

**Disposition of Enquiry**

*Gaining perspective:* The approach to this study placed the student at the centre of the learning and assessment activity. This challenged the student to personally consider what constituted capability in the subject domain and develop a strategy to communicate that capability to others through the means of an electronic portfolio. The approach also required the student to holistically judge the quality of their peers work based on their own conception of capability developed throughout the task. Student reactions showed 81% agreeing that this overall approach made them think about the role and value of their subject in a new light. An average of 80% of students agreed that the approach helped them develop their own personal value for the subject area. Both of these findings highlight the effectiveness of the approach in engaging students with more than just subject content, presenting them with the need and opportunity to explore the subject domain for themselves.

When surveyed, over 75% of the students agreed that the lack of rigid assessment criteria and reporting guidelines allowed them to explore a wide range of solutions to the brief. Students also indicated (70%) that this approach to assessment and reporting prompted them to think more deeply about what constituted capability in the subject area as they did not have the “comfort” of a set of rubrics to align with. This was a key factor in students...
developing their own values in relation to the subject domain. On average 80% of students agreed that having to generate their own criteria for assessment made them take responsibility for their own learning. Seventy percent of the students also indicated that this had a positive effect on their learning experience. The findings indicate that the removal of explicit assessment criteria had a positive impact on the student groups in terms of developing an understanding and value for the subject domain of study. This is a critical finding indicating the positive impact of the research approach on the epistemological development of the student teacher cohorts.

Reflections:
The learning and assessment task was designed to create an environment that stimulated the students to develop and establish their views on learning through design based activities. The following are examples of the students’ reflections that indicate how the learning and assessment approach supported them in critically evaluating their practice:

“It was great to get the opportunity to have such complete autonomy in a module, it was refreshing because often I find I feel that very particular things are being sought by a lecturer whereas here I was allowed to decide myself what I wanted to show - this would likely never be shown with a more strictly formed brief and assessment.”

“The task didn’t suit me, but that’s because I like having a structured brief and assessment where it can be shown for what marks are going for. But many others I’ve talked to about the task loved it. Thinking back it is really brilliant in most aspects and I just didn’t take full advantage of the freedom we had.”

“I thought that by thinking outside the box too much in my design, the concept would be lost on people. Therefore I kept the theme stark but simply communicated. If I was doing the project again and was aware of the high level of creativity in the class group that I saw in the ACJ session, I would increase the level of abstract creativity in my project.”

“Having completed the ACJ assessment I am more confident in my ability to think for myself and produce work to a fairly high level of workmanship that is also creative and interesting.”

“I think the fact that we were given the freedom to make whatever we wanted and to use our imagination as much as possible enabled a lot of positivity amongst us as students, and for us as teachers it will allow our students to develop their own thoughts, goals and aspirations, through our guidance and link imagination and thought with a set of workshop skills and problem solving skills”

Looking at the impact of the ACJ judging process, 72% of students agreed that having completed their paired judging session, it broadened their perspective of capability. Having completed the ACJ assessment 79% of the students agreed that they re-evaluated their own performance in the module as a result of judging other students work with 77% of students surveyed agreeing that the judging session was a valuable educational experience.

Engaging in dialogue
Collaboration between students also provided them with the opportunity to view, discuss, and appraise the quality of other student’s work. This also provided the opportunity for the student to interpret other appraisals of their own work through peer feedback in the ACJ activity. This engagement in formative assessment practice was seen as mutually beneficial by students with the findings indicating that students placed significant value on collaborative practice in the development and progression of their learning. Students’ willingness to
engage in collaborative practice indicates their confidence in their ability to positively communicate and contribute to the learning environment. Such interactions are identified by Sadler (2009) as critical to developing skills of appraisal. The culmination of the development of appraisal skills was through the holistic judgement of peer work using the ACJ assessment model. The high levels of reliability and consensus are strong indicators that students developed an ability to judge and appraise the relevant qualities of work based on their personal construct definition. The evident social dialogue throughout the design task provided opportunity for the students to collectively explore what constituted capability and presented significant opportunities of formative feedback from the teaching team. Completing the judging activity also caused students to reflect and appraise their personal standards and performance. Overall the approach employed in the study provided opportunity for students to develop and exercise their skills of appraisal leading to meaningful learning and personal development.

Conclusion
This study highlights the positive affect of the integration of peer assessment in a learning activity. Students reacted positively to the removal of explicit assessment criteria and indicated that this empowered them to be innovative and creative in their learning. The uncertainty and risk introduced by this approach saw the development of autonomous and collaborative learning creating a rich and supportive educational setting. The study presents the efficacy of the ACJ model of assessment in developing sophisticated levels of skills in appraisal to validly discriminate quality of capability in the subject domain. The holistic assessment activity broadened students’ conception of quality, helping them to establish a sense of their own capability and future direction for their learning.

References


38.

Abstract
The inception of psychometric research concerning individual differences in cognition was grounded in explaining and enhancing performance in education (Spearman, 1904). This work established the construct of a single general intelligence often described as IQ. The aim of enhancing educational practices continues to underpin much of psychometric research, however Cattell (1943) postulated the potential for general intelligence to comprise of two separable entities; fluid intelligence ($G_f$) and crystallised intelligence ($G_c$).

Fluid intelligence is defined as “a facility in reasoning, particularly where adaptation to new situations is required” while crystallised intelligence is defined as “accessible stores of knowledge and the ability to acquire further knowledge via familiar learning strategies” (Wasserman & Tulsky, 2005, p.18). Within education the development of crystallised intelligence ($G_c$) is arguably more visible as content knowledge is more easily assessed. The development of novel problem solving capacities is less discernible, however it can be supported by pedagogical strategies such as problem based learning (PBL).

This paper aims to afford an approach to the development of fluid intelligence ($G_f$) through the identification of cognitive aptitudes aligning with this construct. It is envisioned that having a greater understanding of the cognitive faculties which support novel problem solving that pedagogical interventions such as the one described by Sorby (2009) could be scientifically developed and refined.

An exploratory analysis was conducted to identify associations between cognitive factors and fluid intelligence ($G_f$). A cohort of initial technology teacher education (ITTE) students ($N = 85$) completed a battery of 17 psychometric tests selected as indicators for various cognitive constructs. Results illustrate an alignment between working memory capacity, spatial ability and inductive reasoning with fluid intelligence. Stemming from this, a discussion is presented discussing the potential for the translation of cognitive factors into STEM educational practices specifically focussing on technology education.

Keywords: Cognition, Problem solving, Fluid intelligence, Technology education.
Introduction

Broad educational aims vary between different cultures and levels of education. They also vary within these contexts at an individual discipline level however these differences are often more discrete. Considering technology education, there are many conceptions regarding the aims of the discipline. For example, Ritz (2009) describes essential goals of technological literacy programmes and the International Technology Education Association provides a list of goals for technology education which are similar but have minor variances (ITEA, 1990). A common aim found in these frameworks is one concerning the development of problem solving capacities. This is further exemplified in models of technological capability such as those offered by Black and Harrison (1985) and Gibson (2008). Operationalised through the integration of pedagogical strategies such as problem-based learning (PBL) (Williams, Iglesias, & Barak, 2008), there is a clear value in the development of these skills. A problem exists in the achievement of educational goals concerning these skills as while other aims of education, such as the acquisition of content knowledge, are visible and arguably more easily taught and assessed, the development of problem solving skills is more difficult to objectively identify. To assist in pertinent educational agendas, the body of research concerning cognitive development through applied psychometrics presents an auspicious approach which can be adopted.

The origin of psychometrics in education

The inception of psychometric research concerning individual differences in cognition was grounded in explaining and enhancing performance in education (Galton, 1879; Spearman, 1904). Through his early work, Spearman (1904) developed a conception of a single general intelligence which he termed ‘g’, a construct now commonly known as IQ. Spearman’s early work attempted to ascertain if “abilities commonly taken to be ‘intellectual’ had any correlation with each other or with sensory discrimination” (Spearman, 1930, p.322). The empirical evidence ultimately resulted in the formulation of his two-factor theory, a theory of intelligence containing the postulates of g and s (Spearman, 1927). In this theory, g was defined as “not any concrete thing but only a value or magnitude” (p.75), identified as representative of a general ability which is “common to all abilities that are interconnected by the tetrad equation” (p.76). Specific factors, denoted as ‘s’, referred to factors of intelligence which emerged from specific tests or subtests but were not common to all tests in a battery. Spearman posited that the interaction between a person’s general intelligence and a specific factor of intelligence was responsible for test performance. In essence, g described a level of domain general or independent ability while s referred to domain specific abilities.

Over time, Spearman’s two-factor theory was developed to make explicit some of the specific factors contained within it (Holzinger & Harman, 1938; Holzinger & Swineford, 1939). At the same time, similar work was conducted by Thurstone (1938) who identified a series of primary mental abilities devoid of a g factor. These specific factors and primary mental abilities were the foundation for what are now referred to as second-order factors of intelligence and included constructs such as ‘space’, ‘perceptual speed’, ‘number facility’, ‘verbal relations’, ‘word fluency’, ‘memory’ and ‘induction’ (Thurstone, 1938). Within the Cattell-Horn-Carroll theory of intelligence (CHC theory) (Schneider & McGrew, 2012), these second order factors describe cognitive faculties comprising of groups of similar first-order factors which have emerged within the pertinent literature subsequent to the early work of Spearman and Thurstone.
The theory of separable fluid and crystallised intelligences
The theory of separate fluid and crystallised intelligence (Gf-Gc theory) was first theorised by Cattell (1941, 1943) as an advancement of Spearman's (1904) idea of a single general intelligence. Cattell (1943) conceived his theory of fluid and crystallised intelligences from observations of intelligence tests designed for children and their lack of applicability to adult populations. Synthesising the observations of the adult dissociation of cognitive speed from power and the diminished g saturation in adult intellectual performances with neurological evidence identifying localised brain regions as effecting children generally while a corresponding legion effecting adults more in terms of speeded tasks, abstract reasoning problems, and unfamiliar performances than in vocabulary, information and comprehension (e.g. Hebb, 1941, 1942), Cattell (1943) postulated the potential for general intelligence to comprise of the two separate entities. Fluid intelligence is defined as “a facility in reasoning, particularly where adaptation to new situations is required” while crystallised intelligence is defined as “accessible stores of knowledge and the ability to acquire further knowledge via familiar learning strategies” (Wasserman & Tulsky, 2005, p.18). Within education, this dichotomy is easily transferable with fluid intelligence being synonymous with novel problem solving and crystallised intelligence being synonymous with the acquisition and application of discipline specific content knowledge.

An agenda to synthesise factorial research within technology education
Considering the clearer visibility of crystallised intelligence within education and the aims concerning problem solving in technology education, it is currently more prevalent to construct a framework to support the development of fluid intelligence. Substantial research has investigated the association between fluid intelligence and education and with other cognitive factors. Lohman (1996) for example notes how fluid intelligence is a particularly good indicator of general education performance in many disciplines. As this correlation is well-established, pertinent correlations between cognitive factors may aid in its pragmatic synthesis within educational practices.

Specifically within Science, Technology, Engineering, and Mathematics (STEM) education disciplines, spatial ability has been shown to be a significant predictor of success (Lubinski, 2010; McGrew & Evans, 2004; Wai, Lubinski, & Benbow, 2009). Interestingly, spatial ability has also been shown to correlate significantly with fluid intelligence (Colom, Contreras, Botella, & Santacreu, 2001). Building on this, there has been a substantial degree of evidence showing a correlation between working memory and fluid intelligence (Kyllonen & Christal, 1990). The strength of this correlation led cognitive scientists to believe general intelligence and working memory were the same construct (Conway, Kane, & Engle, 2003), however they have since been dissociated as separate cognitive faculties (Ackerman, Beier, & Boyle, 2005). Considering the amalgam of this evidence, it may be possible that fluid intelligence within education can be developed by targeting aligning faculties such as spatial ability and working memory. Corresponding with this agenda, interventions have been developed for spatial ability (Sorby, 2009) and working memory (Harrison et al., 2013) and have been shown to have significant positive effects.

The current study
The ultimate goal of the previously described agenda is to enhance practice in technology education by virtue of the incorporation of cognitive training within traditional educational practices. Currently, operationalising this requires developing fluid intelligence and novel problem solving skills within students. However, fluid intelligence is a second-order factor and therefore is not directly measureable or targetable through intervention. Instead, the
first-order factors associated with it must become the focus of interventions. While constructs such as spatial ability and working memory have been shown to correlate with fluid intelligence, research does not illustrate the full remit of first-order factors within these faculties that are important to this agenda. Furthermore, there are a number of domain-free general capacities which have not been examined to date. Therefore, the intent of this study is to examine the relationships between fluid intelligence and a broad array of domain-free general first order cognitive factors from a psychometric perspective to determine which cognitive faculties should become the focus of future work.

**Method**

**Participants**

A cohort of 3rd year undergraduate students (N=85) enrolled in an Initial Technology Teacher Education (ITTE) programme participated in this study. The cohort consisted of 80 males and five females. Their ages ranged from 19 to 31 with a mean of 21.19 and a standard deviation of 2.41. Participation in this study was voluntary.

**Tests**

Participants were invited to take a total of 17 psychometric tests with each one representing a unique first-order factor of human intelligence. These tests were predominantly adopted from the Educational Testing Services’ (ETS) Kit of Factor Referenced Cognitive Tests (Ekstrom, French, Harman, & Derman, 1976), however additional tests were utilised to reflect advances in psychometric research. The second order factors included in this study were visual processing (spatial ability), long-term memory, short-term memory, general reasoning, and processing speed. Table 1 provides a detailed description of each test utilised within this study.

Participants engaged with the tests in five groups of approximately 17 people. The tests were administered over a course of four test sessions with one week passing between each session. No session lasted longer than 60 minutes in duration and tests were administered in a different order to each group to remove the potential for an order bias within the data.

**Table 1. Descriptions of psychometric tests utilised in the study.**

<table>
<thead>
<tr>
<th>Test (second-order factor: first-order factor)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ravens Advanced Progressive Matrices Test</strong> (fluid intelligence)</td>
</tr>
<tr>
<td>For each problem, participants were presented with a 3 x 3 matrix containing eight abstract figures and one empty space. Participants had to select one of nine multiple choice answers which would fit the pattern of the matrix. The 32 items from part two of the test were used. A total time of 40 minutes was afforded for the test.</td>
</tr>
<tr>
<td><strong>ETS Paper Folding Test</strong> (visual processing: visualisation)</td>
</tr>
<tr>
<td>For each problem, participants were presented with a series of illustrations showing a piece of paper being folded up to three times and having a hole punched in it. Participants had to select one of five multiple choice answers which would identify the piece of paper after it had subsequently been unfolded. The 20 items across parts one and two of the test were used. A total time of three minutes was afforded for each part of the test.</td>
</tr>
<tr>
<td><strong>Mental Rotations Test</strong> (visual processing: spatial relations)</td>
</tr>
<tr>
<td>For each problem, participants were presented with an abstract stimulus constructed of an arrangement of cubes. Participants had to select two of four multiple choice answers which identified the original stimulus but in a different orientation with the remaining two being different (mirror images). The 24 items across parts one and two</td>
</tr>
</tbody>
</table>
ETS Card Rotations Test (visual processing: speeded rotations)
For each problem, participants were presented with an abstract 2-dimensional stimulus. Participants had to identify if eight successive stimuli were the same or different (mirror images) to the original stimulus. The 160 items across parts one and two of the test were used. A total time of three minutes was afforded for each part of the test.

Perspective Taking Spatial Orientation Test (visual processing: spatial orientation)
For each problem, participants were presented with an array of images represented real life objects (e.g. a tree, car and house), and instructions telling them which object they were to imaging being their location, which object they had to image they were facing, and which object they had to mentally point to. Participants had to identify which direction they were pointing in on a chart immediately below the array of objects. The 12 items from the test were used. A total time of five minutes was afforded for the test.

ETS Gestalt Completion Test (visual processing: closure speed)
For each problem, participants were presented with an incompletely drawn image of a real life object (e.g. a flag or hammer). Participants had to identify what the object in each image was. The 20 items across parts one and two of the test were used. A total time of two minutes was afforded for each part of the test.

ETS Hidden Patterns Test (visual processing: flexibility of closure)
For each problem, participants were presented with a 2-dimensional array of lines. Participants had to identify if a common line diagram was or was not present within the array. The 400 items across parts one and two of the test were used. A total time of three minutes was afforded for each part of the test.

ETS Shape Memory Test (visual processing: visual memory)
For each problem, participants were presented with an array of abstract visual stimuli which they had to memorise. Participants had to identify if a selection of abstract stimuli were or were not present within the memorised array. The 32 items across parts one and two of the test were used. A total time of eight minutes (four memorising, four answering) was afforded for each part of the test.

ETS Maze Tracing Speed Test (visual processing: spatial scanning)
For each problem, participants were presented with a 2-dimensional maze consisting of 24 adjoining sections. Participants had to identify the correct path through the maze. The 48 items across parts one and two of the test were used. A total time of three minutes was afforded for each part of the test.

Transformation Test (visual processing: imagery quality)
For each problem, participants were presented with verbal information describing instructions of how to mentally manipulate simple figures (e.g. letters, numbers and shapes). Participants had to identify the final figure after all instructions and illustrate this through a sketch. The 12 items across parts one and two of the test were used. A total time of 12 minutes was afforded for the test.

ETS Picture Number Test (long-term memory: associative memory)
For each problem, participants were presented with an array of images of real life objects and a number associated with each of them which they had to memorise. Participants had to identify the number associated with each object after the numbers were removed and the order of the images changed. The 32 items across parts one and two of the test were used. A total time of eight minutes (four memorising, four answering) was afforded for the test.
**Test (second-order factor: first-order factor)**

Answering) was afforded for each part of the test.

**ETS Toothpicks Test (long-term memory: figural flexibility)**

For each problem, participants were presented with an image showing a pattern constructed of straight lines representing toothpicks and instructions describing a final pattern and how many lines must be removed. Participants had to identify a final pattern which conformed to the given rules in up to five unique ways. The 50 items across parts one and two of the test were used. A total time of six minutes was afforded for each part of the test.

**ETS Auditory Number Span Test (short-term memory: memory span)**

For each problem, participants were presented verbally with sequences of between four and 12 numbers with one second between each number in the sequence. Participants had to identify the exact sequences once all numbers in them had been announced. The 24 items in the test were used. A total time of eight minutes was afforded for the test.

**ETS Figure Classification Test (general reasoning: inductive reasoning)**

For each problem, participants were presented with either two or three groups of abstract visual figures where each group had a specific rule or condition regarding the figures within it which differentiated it from the other group(s). Participants had to identify which of the groups a series of additional figures belonged to. The 224 items across parts one and two of the test were used. A total time of eight minutes was afforded for each part of the test.

**ETS Nonsense Syllogisms Test (general reasoning: deductive reasoning)**

For each problem, participants were presented with a written statement, constructed with nonsensical content, which was exemplary of either good or poor reasoning. Participants had to identify if the statements illustrated good or poor reasoning. The 30 items across parts one and two of the test were used. A total time of four minutes was afforded for each part of the test.

**ETS Finding A’s Test (processing speed: perceptual speed – letters)**

For each problem, participants were presented columns of 41 words, five of which contained the letter ‘A’. Participants had to identify which of the words contained the letter ‘A’. The 200 items across parts one and two of the test were used. A total time of three minutes was afforded for each part of the test.

**ETS Identical Pictures Test (processing speed: perceptual Speed – images)**

For each problem, participants were presented with an abstract 2-dimensional stimulus. Participants had to identify the identical stimulus within a set of five stimuli to its immediate right. The 96 items across parts one and two of the test were used. A total time of 1.5 minutes was afforded for each part of the test.

*Note.* All ETS tests came from the Kit of Factor References Cognitive Tests (Ekstrom et al., 1976), additional tests include the Ravens Advanced Progressive Matrices Test (Raven, Raven, & Court, 1998), the Mental Rotations Test (Vandenberg & Kuse, 1978), the Perspective Taking Spatial Orientation Test (Hegarty & Waller, 2004), and the Transformation Test (Finke, Pinker, & Farah, 1989).

**Data preparation and screening**

Due to participants missing scheduled test sessions for various reasons, 12.60% of the data (182 test scores) was missing from the complete dataset. In addition, eight participants did not finish the Perspective Taking Spatial Orientation Test within the allocated time limit and due to the approach taken in scoring this test this imposed a significant impact on the normality of the results. These test scores were therefore omitted from the dataset. Combined, these missing scores corresponded to a total of 13.15% of missing data leaving
a total of 1255 test scores in the dataset. The missing data was computed with a full-information maximum likelihood (FIML) estimate within the AMOS software (v.21, IBM SPSS Statistics). This approach was selected to avoid the randomness introduce by imputation techniques (Dong & Peng, 2013).

The dataset which included only the 1255 original tests was used to determine the descriptive statistics (Descriptive statistics of the raw scores from each of the tests are illustrated in Table 2. Skewness and kurtosis values for all tests are within acceptable limits of between ±2 (Gravetter & Wallnau, 2014; Trochim & Donnelly, 2006). Despite some of the α values being below the recommended value of .7 (Nunnally, 1978), as all of the tests utilised in the study are well-established and have been previously validated this was deemed acceptable.

To determine relationships between each of the cognitive factors being examined within this study, correlations were computed between each test and an EFA was conducted. The correlation matrix is presented in Table 3.

Table 2) and correlation matrix (Table 3) and the dataset with missing values computed was used for the exploratory factor analysis (EFA). As EFA’s assume multivariate normal distributions and are sensitive to extreme outliers, the data was screened for both univariate and multivariate outliers prior to the conduction of these tests (Kline, 2016). Univariate outliers were identified as results which exceeded three standard deviations from the mean. Seven test results (0.48% of the dataset) were identified as univariate outliers under this criterion and were transformed to the value equal to three standard deviations from the mean (Kline, 2016). Data was then screened for multivariate outliers using both the Mahalanobis D and Cook’s D statistics. The criterion for identifying outliers with the Mahalanobis D statistic was $p < 0.001$ (Kline, 2016) and for the Cook’s D statistic it was any instance greater than 1 (Cook, 1977). No data was identified as a multivariate outlier.

Results
Descriptive statistics of the raw scores from each of the tests are illustrated in Table 2. Skewness and kurtosis values for all tests are within acceptable limits of between ±2 (Gravetter & Wallnau, 2014; Trochim & Donnelly, 2006). Despite some of the α values being below the recommended value of .7 (Nunnally, 1978), as all of the tests utilised in the study are well-established and have been previously validated this was deemed acceptable.

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<table>
<thead>
<tr>
<th>Task</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>Range</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>α</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Paper Folding</td>
<td>72</td>
<td>12.11</td>
<td>3.13</td>
<td>16.00</td>
<td>-.26</td>
<td>.13</td>
<td>.73</td>
</tr>
<tr>
<td>2. Mental Rotations</td>
<td>79</td>
<td>13.33</td>
<td>4.43</td>
<td>18.00</td>
<td>.13</td>
<td>-.85</td>
<td>.81</td>
</tr>
<tr>
<td>3. Card Rotations</td>
<td>65</td>
<td>114.29</td>
<td>24.33</td>
<td>95.00</td>
<td>-.04</td>
<td>-.66</td>
<td>.97</td>
</tr>
<tr>
<td>4. Perspective Taking</td>
<td>71</td>
<td>152.97</td>
<td>14.83</td>
<td>67.17</td>
<td>-.04</td>
<td>.68</td>
<td>.63</td>
</tr>
<tr>
<td>5. Gestalt Completion</td>
<td>72</td>
<td>14.63</td>
<td>2.71</td>
<td>11.00</td>
<td>-.93</td>
<td>.45</td>
<td>.61</td>
</tr>
<tr>
<td>6. Hidden Patterns</td>
<td>72</td>
<td>217.65</td>
<td>55.75</td>
<td>286.00</td>
<td>-.49</td>
<td>.22</td>
<td>.98</td>
</tr>
<tr>
<td>7. Shape Memory</td>
<td>68</td>
<td>24.99</td>
<td>3.19</td>
<td>14.00</td>
<td>-.52</td>
<td>-.07</td>
<td>.56</td>
</tr>
<tr>
<td>8. Maze Tracing</td>
<td>82</td>
<td>30.35</td>
<td>6.58</td>
<td>33.00</td>
<td>.25</td>
<td>.42</td>
<td>.93</td>
</tr>
<tr>
<td>9. Transformation</td>
<td>82</td>
<td>20.56</td>
<td>2.94</td>
<td>13.00</td>
<td>-1.21</td>
<td>1.38</td>
<td>.63</td>
</tr>
</tbody>
</table>
Table 3: Correlation matrix

<table>
<thead>
<tr>
<th>Task</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>Range</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>α</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Picture Number</td>
<td>75</td>
<td>25.13</td>
<td>9.35</td>
<td>34.00</td>
<td>-.38</td>
<td>-.91</td>
<td>.91</td>
</tr>
<tr>
<td>11. Toothpicks</td>
<td>74</td>
<td>10.07</td>
<td>5.27</td>
<td>21.00</td>
<td>.28</td>
<td>.74</td>
<td>.63</td>
</tr>
<tr>
<td>12. Auditory Number Span</td>
<td>82</td>
<td>10.01</td>
<td>2.75</td>
<td>14.00</td>
<td>.25</td>
<td>.02</td>
<td>.71</td>
</tr>
<tr>
<td>13. Figure Classifications</td>
<td>75</td>
<td>130.49</td>
<td>32.88</td>
<td>145.00</td>
<td>-.18</td>
<td>-.58</td>
<td>.98</td>
</tr>
<tr>
<td>14. Nonsense Syllogisms</td>
<td>73</td>
<td>14.53</td>
<td>4.16</td>
<td>20.00</td>
<td>.06</td>
<td>-.16</td>
<td>.80</td>
</tr>
<tr>
<td>15. Finding A’s</td>
<td>63</td>
<td>50.94</td>
<td>12.67</td>
<td>59.00</td>
<td>.63</td>
<td>.39</td>
<td>.92</td>
</tr>
<tr>
<td>16. Identical Pictures</td>
<td>77</td>
<td>83.05</td>
<td>10.50</td>
<td>43.00</td>
<td>-.91</td>
<td>.31</td>
<td>.93</td>
</tr>
<tr>
<td>17. Ravens Advanced Matrices</td>
<td>73</td>
<td>23.43</td>
<td>4.97</td>
<td>25.00</td>
<td>-.61</td>
<td>.25</td>
<td>.87</td>
</tr>
</tbody>
</table>
EFA was selected over a principle component analysis (PCA) as the intent of this analysis was to determine underlying relationships between the variables in the dataset (Byrne, 2005). Specifically, the maximum likelihood method of extraction was selected as in the data screening stage assumptions of normality were not violated (Fabrigar, Wegener, Maccallum, & Strahan, 1999). An oblique rotation was selected as it was hypothesised that the factors would correlate (Osborne, 2015) with both promax and direct oblimin methods being examined. As no significant difference was observable between the two methods the promax solution is described below.

For the EFA, 14 of the 17 variables correlated at least .3 with at least one other variable. The Kaiser-Meyer-Olkin measure of sampling adequacy was .71, above the recommended value of .6, and Bartlett's test of sphericity was significant ($\chi^2 (136) = 353.48, p < .000$). These criteria suggest a reasonable level of factorability within the data. A scree plot (Figure 1) was examined to determine the number of factors to extract. The scree plot suggested a three factor model. The initial eigenvalues showed that the first factor explained 25.137% of the variance, the second factor 9.527% of the variance, and a third factor 8.953% of the variance. Four, five, and six factor solutions were also examined but the three factor solution was preferred because of its theoretical support.

![Figure 1. Scree plot and extracted eigenvalues suggesting a three-factor solution](image)

The results from the EFA are presented in Table 4. An examination of the three factors reveals interesting underlying relationships which aid in their interpretation. The primary tests loading on the first factor are predominantly speeded tests (e.g. Identical Pictures,
Mental Rotations, Card Rotations, and Maze Tracing). Interestingly, the Toothpicks test also loaded on this factor despite having little in common with the primary loading tests. The Transformation and Gestalt Completion tests require the construction of a mental image and are arguably perceptual tests more than speeded tests. However, the statistically significant correlation ($r = .347, p < .01$) between the Toothpicks Test and Transformation Test illustrates that mental imagery has a role in figural flexibility which is theoretically sound. Synthesising the correlations with the factor loadings, this first factors appears to represent a factor associated with cognitive speed.

The second factor is of particular interest to this study. The Ravens Advanced Progressive Matrices Test was of significant interest due to its representation of fluid intelligence and is the highest loading variable on this factor. Also loading on this factor are the Shape Memory and Picture Number tests, the Figure Classifications Test and the Paper Folding Test. Examining all of these, and the tests not loading on this factor, suggests that this factor is associated with cognitive power. Perhaps more interestingly, it suggests that memory span, inductive reasoning, and visualisation are the primary cognitive factors associated with novel problem solving. The Hidden Patterns Test also loaded on this factor and it was theorised that this test would load on the first factor due to the speeded nature of the test. Considering the nature of the problems within the test, it may load on this factor as it requires more than observation of the stimuli and the act of decoding the information within the distracting array of lines may require a higher degree of cognitive power than other speeded tests.

The third factor has loadings from the Mental Rotations Test, the Paper Folding Test and the Perspective Taking Spatial Orientation Test. Despite each being associated with a different spatial factor, they all involve dissociable elements of mental rotation. Combined with the moderate negative loading from the Identical Pictures Test this factor appears to represent cognitive action more than just observation. It appears to be a factor describing spatial skills independent of perceptual and memory factors within the faculty. This is interesting as the evidence shows it as dissociable from the other two factors, aligning with the prominent understanding that spatial ability is a unique cognitive domain. The additional loading from the Auditory Number Span Test illustrates that working memory span also has a bearing on spatial skills.

Finally, an observation of the correlations between factors shows a moderate correlation between factors one and two ($r = .496$), with only small correlations between factors one and three ($r = .112$) and factors two and three ($r = .239$) which suggests that while separable, cognitive speed and power do share a moderate degree of variance in cognitive performance.

Table 4. Factor loadings for the maximum-likelihood EFA factor solution

<table>
<thead>
<tr>
<th>Measure</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identical Pictures</td>
<td>.925</td>
<td>.044</td>
<td>-.453</td>
</tr>
<tr>
<td>Mental Rotations</td>
<td>.593</td>
<td>-.162</td>
<td>.567</td>
</tr>
<tr>
<td>Card Rotations</td>
<td>.584</td>
<td>-.206</td>
<td>.243</td>
</tr>
<tr>
<td>Toothpicks</td>
<td>.422</td>
<td>-.016</td>
<td>.212</td>
</tr>
<tr>
<td>Maze Tracing</td>
<td>.411</td>
<td>.223</td>
<td>-.077</td>
</tr>
<tr>
<td>Transformation</td>
<td>.367</td>
<td>.186</td>
<td>.133</td>
</tr>
<tr>
<td>Gestalt Completion</td>
<td>.366</td>
<td>.210</td>
<td>.047</td>
</tr>
<tr>
<td>Ravens Matrices</td>
<td>-.020</td>
<td>.723</td>
<td>.087</td>
</tr>
<tr>
<td>Shape Memory</td>
<td>-.081</td>
<td>.641</td>
<td>.117</td>
</tr>
<tr>
<td>Measure</td>
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**Discussion**

The results of this study provide a substantial contribution in terms of identifying suitably targetable cognitive faculties to enhance problem solving abilities in technology students. Cognisance should be taken however within this approach to the dichotomy of the problem space and the task environment (Newell & Simon, 1972; Simon & Newell, 1971), constructs which are analogous to the Assessment of Performance Unit (APU) model describing the interaction between mind and hand (Kelly, Kimbell, Patterson, Saxton, & Stables, 1987). This approach aims to directly target the capacities of the mind, which can affect people’s external actions but may not directly affect their tacit capacity to physically manipulate the environment or objects within it.

The findings of this study, both the correlations and EFA results, suggest three predominant cognitive faculties which should be targeted by future interventions. These include working memory span, inductive reasoning and spatial ability. It is posited that the strength and significance in the association between working memory span and fluid abilities stems from the increased capacity to hold relative information in the working memory while problem solving. In terms of the association with spatial ability, it is posited that this supports the ability to generate and manipulate the information within the working memory. Finally, inductive reasoning is posited to provide people with the capacity to make inferences from pertinent information. Ultimately, the amalgam of these cognitive skills is postulated as foundational in supporting a person in problem solving from a cognitive perspective.

Future work on this agenda should involve a more extensive analysis of the data and a rigorous investigation into the causation underpinning the associations between spatial ability, working memory and inductive reasoning with fluid intelligence. Ultimately, this information could then be used for the further develop existing interventions or to create a bespoke intervention suitable to technology education.

**References**


Integrative STEM for Teachers of Young Students (iSTEM4ToYS):
Engaging Future Elementary School Teachers

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Abstract

The iSTEM4ToYS project was launched in 2016 with support from the National Science Foundation in the United States (U.S.). Project investigators are exploring how to prepare Pre-kindergarten to grade 4 (PK-4) teachers for iSTEM teaching and learning. The project is based on the premise that educators who are enthusiastic and confident in integrating STEM into their teaching are crucial to engaging students early and motivating them along a path to become the next generation of STEM innovators and knowledgeable citizens.

This iSTEM4ToYS project is using five research-based programmatic features to enhance teacher candidates’ integrative STEM skills, understandings, and perspectives. These include: an iSTEM Laboratory and Resource Center, a structured sequence of coursework that engages learners in problem-based and design-based learning experiences that build deeper understandings of concepts, STEM focused fieldwork with young children, STEM professional development opportunities, and access to STEM-related community resources. The overarching goal of this project is to determine which component(s) of the iSTEM program that prepares these preservice teachers has the greatest impact on them, which may increase the likelihood that those who complete the program will effectively integrate iSTEM techniques in their future classrooms. By evaluating which features have the maximum impact, researchers will be able to make recommendations on how to replicate these initiatives at other teacher preparation institutions, thereby contributing to an understanding of how to better prepare PK-4 teachers as iSTEM educators.

Researchers are using survey data to gather evidence of iSTEM students’ engagement in STEM and their STEM perspectives. Some students will participate in semi-structured interviews to gather further details about their participation and engagement in STEM. Researchers are using the Critical Incident Technique methodology (e.g., Butterfield et al., 2005; Flanagan, 1954) to investigate which research-based features of MU’s iSTEM program are the most significant transformational elements.

Keywords: STEM, Integrative STEM, Integrated STEM, Early Childhood Education, Elementary Education, Pre-service Teacher Education, STEM Perspectives, Critical Incident Technique
Introduction & Rationale for the Study

Many educators and researchers have developed an increased interest in science, technology, engineering, and math (STEM) education. Since the 1990s, and particularly during the past decade, STEM education has become increasingly popular in American school curricula and as a focus topic for educational researchers (e.g., Brown, 2012; Honey, Pearson, & Schweingruber, 2014; Mizell & Brown, 2016; Sanders, 2009). This interest in STEM has been spurred by a number of factors including concerns about U.S. students’ performance in math and science, students’ lack of interest in science and math, and estimates that there are not enough people entering the STEM pipeline to meet the demands for American workers in these areas (NRC, 2011).

STEM education efforts have been targeted at every level from early childhood through adult education and they can take on many different forms. Some STEM programs place emphasis on just one or two areas of the STEM acronym. Programs specifically described as integrative STEM or integrated STEM (iSTEM) education generally place emphasis on the interconnectedness of all areas – science, technology, engineering, and math (Sanders, 2009). Despite the growing interest in advancing iSTEM education, there is a dearth of research available that helps educators identify the best methodologies, curricula, or approaches that can ensure the desired outcomes (Honey et al., 2014).

There is one area of research, however, that points to a significant concern at the early childhood education level in regards to iSTEM education. The vast majority of early childhood educators are prepared as generalists who can navigate the full range of content areas addressed at the Pre-K (PK) to grade 4 level (e.g., English language arts, mathematics, social studies). In the United States, this is known as early childhood or elementary education. However, there is also a pool of research which indicates that this population is either underprepared or lacks confidence and/or interest in teaching math and science (e.g., Bencze, 2010; Bergman & Morphew, 2015; Bursal & Paznokas, 2006; Westerback, 2006) and that teachers’ anxiety negatively affects their students (e.g., Beilock et al., 2010, Vinson, 2001). While there is little known about this population’s perspective on teaching STEM, one must presume that there would be equal or greater challenges for these educators in iSTEM given that it subsumes two areas for which there is evidence of concern. Furthermore, there are few early childhood educators who are prepared directly for technology and engineering education or iSTEM in their teacher training programs (Rose, Carter, Brown, & Shumway, 2017). There is, however, some initial support to show a positive effect on preservice teachers’ attitudes toward STEM teaching when provided with STEM mentoring in a problem-based learning setting (Caliendo, 2016).

How can we expect to motivate the next generation of Science, Technology, Engineering, & Mathematics (STEM) workers if their introduction to these subjects in the early grades is through teachers who lack enthusiasm and confidence in teaching iSTEM? While there is a growing effort to improve and expand iSTEM education in elementary schools, there are still few opportunities in our U.S. teacher education institutions for pre-service teachers to develop the skills, expertise, and confidence in iSTEM teaching at the PK-4 grade level, as most early childhood teacher education programs offer little or no exposure to technology and engineering education or to iSTEM coursework specifically (Rose, et al., 2017). This is a significant missed opportunity that imposes long-term effects on children’s development of iSTEM concepts and on the STEM workforce pipeline.
**Background and Purpose of the Study**

With support from the National Science Foundation (NSF) (Grant No. DUE-1611652), researchers initiated the Integrative Science, Technology, Engineering & Math (STEM) Education for Teachers of Young Students (iSTEM4ToYS) project in 2016 which aims to address this issue. The iSTEM4ToYS project targets Millersville University (MU) of Pennsylvania undergraduates enrolled in an integrative STEM (iSTEM) education minor as part of their early childhood education (ERCH) or early childhood education and special education (ECSP) teacher preparation program. The minor, which was approved in June 2015, engages these teacher candidates in building their knowledge, skills, and confidence to effectively integrate STEM concepts throughout the PK-4 curriculum. This is accomplished through a required sequence of six courses (18 credits) that is intended to better prepare these future educators to plan, implement, and assess integrative STEM education programs at the PK-4 grade level using a problem-based, design-based, and inquiry-based approach. Students who complete this minor are eligible to apply for an additional Integrative STEM Education endorsement on their Pennsylvania teaching certificate. The iSTEM minor consists of six required courses that are sequenced as shown in the flow chart (Figure 1).

![Flow Chart](image)

*Figure 1. Sequence of six courses required for students choosing the Integrative STEM Education Methods (iSTEM) minor.*

The iSTEM4ToYS project, and MU’s iSTEM minor upon which it is based, reflects the definition of iSTEM as described by Sanders (2009) and defined by Wells and Ernst (2015/2012). Integrative STEM is defined as:

>The application technological/engineering design based pedagogical approaches to intentionally teach content and practices of science and mathematics education through the content and practices of technology/engineering education. Integrative STEM Education is equally applicable at the natural intersections of learning within the continuum
of content areas, educational environments, and academic levels. (Wells & Ernst, 2015/2012, para. 2)

Over the course of three years (August 2016-July 2019), the iSTEM4ToYS project staff will investigate selected research-based components of the iSTEM program. The overarching goal is to determine which component(s) have the greatest impact on undergraduates’ ability to integrate iSTEM concepts and skills in non-iSTEM education courses, their motivation to seek out STEM opportunities in their personal and professional lives, and their perspectives on STEM in general. On certain criteria, undergraduates in the iSTEM minor will be compared to ERCH and ECSP undergraduates who did not choose the iSTEM minor. Current enrollment in MU’s iSTEM minor is more than 80 undergraduate students from freshman through senior year and there are roughly 650 students majoring in ERCH and ECSP on the MU campus.

To that end, researchers are focusing upon the following research questions:

1. What experiences in the iSTEM program prompt undergraduates to include iSTEM concepts in education courses that are not part of the iSTEM minor (e.g., literacy, teaching of reading, math pedagogy, science pedagogy, field experiences, student teaching)?
2. To what extent do undergraduate iSTEM students seek out STEM opportunities in their personal and professional lives?
3. How do iSTEM undergraduates’ resulting STEM perspectives differ from non-iSTEM undergraduates’ perspectives?

Phase One: Establishing Research-Based Programmatic Features

During Phase One of the iSTEM4ToYS project (August 2016-July 30, 2017), iSTEM4ToYS researchers established five essential features for its iSTEM program which will be the focus of the project’s investigation. These features are specifically designed to enhance integrative STEM skills, understandings, and perspectives for the teacher candidates. They include:

1. An iSTEM Laboratory and Resource Center (iSTEM LRC),
2. iSTEM Coursework,
3. iSTEM-focused fieldwork with young children (practicum experiences),
4. iSTEM Professional Development Opportunities, and
5. Access to STEM-related Community Resources.

iSTEM LRC. The National Science Teachers Association (NSTA, 2014) position statement on early childhood science education (and endorsed by the National Association for the Education of Young Children) validates that education for young children must:

...emphasize the learning of science and engineering practices, including asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information (NRC 2012, NGSS Lead States 2013). (para. 17)

The iSTEM Laboratory and Resource Center (iSTEM LRC) is designed with these tasks in mind, and is the primary space used for teaching some iSTEM courses. Additionally, the iSTEM LRC is available during selected hours as an open after-hours space for all iSTEM students to use for investigation, practice, and curriculum development. During phase one of the project (and throughout the grant period), the iSTEM LRC is being refined and improved to better meet
the needs of PK-4 teacher candidates. New tools, materials, kits, and curriculum materials are being acquired and organized for iSTEM teacher candidates’ use.

**iSTEM Coursework.** Also in line with the NSTA position statement, the iSTEM minor (described previously) was designed to engage teacher candidates “…in learning science principles in an interactive, hands-on approach, enabling them to teach about science principles appropriately and knowledgeably and that help them understand how children learn science and engineering practices” (NSTA, 2014, para. 22). During Phase One of the project, iSTEM-specific courses have been continually refined based on faculty members’ experiences and feedback they’ve gathered from students enrolled in their courses. Project researchers gather information about the types of activities, experiences, and resources that are used in each iSTEM course in order to better document what occurs. The iSTEM4ToYS principal investigator brings these faculty members together once per semester to discuss the courses and the minor and to determine if any modifications are needed.

**iSTEM-Focused Fieldwork.** Pre-service teachers in teacher preparation programs across the United States are involved in field experiences to some degree and there are numerous studies that reinforce the value of these activities (e.g., Aiken & Day, 1999; Cooper & Nesmith, 2013; Darling-Hammond, 2010). A field experience with young children is required as the culminating experience for iSTEM minors. This practicum experience is designed in collaboration with a local school district or informal education provider to enable the iSTEM teacher candidates to have an authentic STEM teaching experience with PK-4 students. During Phase One of the project, the project’s principal investigator established new collaborations. The Practicum experience was refined and implemented during May-June 2017. It provided all enrolled students with the opportunity to develop, implement, and evaluate an after-school STEM program for children in grades K-4.

**iSTEM Professional Development (PD) Opportunities.** During Phase One, the project researchers established a plan to engage iSTEM candidates in extracurricular PD opportunities to enhance their engagement in iSTEM teaching and learning. As noted by Power, Short, & Landes (2002), “The combination of effective curriculum implementation and transformative professional development yields powerful learning for all” (p. 135). During Fall 2016, the iSTEM4ToYS project researchers implemented a review system where iSTEM students can apply for PD support to attend and/or present at various national state, and regional conferences related to iSTEM. Some of these venues include conferences such as the Virginia Children’s Engineering Convention (VCEC), National Science Teachers Association (NSTA) STEM Expo, International Technology & Engineering Educators Association (ITEEA) Conference, National Council of Teachers of Mathematics (NCTM), Technology & Engineering Education Association of Pennsylvania (TEEAP) sTEm Conference, Pennsylvania Council of Teachers of Mathematics (PCTM), and the local STEMathon (collaborative conference by numerous education agencies in PA). In February 2017, nine STEM students accompanied the iSTEM4ToYS principal investigator to the VCEC for an inspiring PD experience. In addition, iSTEM minors are invited to join one or both university-based student organizations with STEM connections.

The iSTEM4ToYS project staff plan periodic offerings of colloquium speakers and/or workshops with the goal of building interest and expertise in topics of interest to PK-4 STEM teacher candidates. With funding through the NSF grant, these events are free for students and put iSTEM students in face-to-face contact with experts. During Phase One, two of these types of programs were offered and additional ones are planned during Phase Two and Three.
Access to STEM-related Community Resources. Communities are filled with STEM-related resources that have the potential to enhance students’ understandings of concepts and help them to build deeper understandings. According to Behrendt & Franklin (2014), “Field trips offer an opportunity to motivate and connect students to appreciate and understand classroom concepts, which increase a student’s knowledge foundation, promoting further learning and higher level thinking strategies. With understanding comes confidence and intrinsic motivation” (p. 242). Community resources can take many forms and they are a valuable addition to any educator’s teaching toolbox.

In order to prepare teachers to meet the challenges of a rapidly changing human landscape, we, as teacher educators, need to provide authentic, and meaningful experiences that are situated in place, build community, and show pre-service teachers that they have resources and partners eager to support the educational mission of community schools beyond the walls of their school buildings. (Adams et al., 2014, p. 18).

During Phase One, the project researchers began creating a network of community resources that would be of interest to PK-4 STEM educators and that have the potential to positively impact their understanding of STEM content and pedagogy. Where appropriate, these resources are incorporated into required iSTEM courses. But, they are also promoted through communications with iSTEM minors, including a dedicated online learning management system “course” for iSTEM minors to access resource information. Some examples of community resources that are promoted include local learning centers such as the Lancaster Science Factory, North Museum, and Hands-On House. STEM-related programs offered through the local park system and open houses at a regional makerspace are other examples of events promoted to iSTEM students.

Methodology

Researchers are using survey data to gather evidence of iSTEM students’ engagement in STEM and their STEM perspectives. In addition, some students will participate in interviews which enable researchers to gather further details about their participation and engagement in STEM. Researchers are using the Critical Incident Technique methodology (e.g., Butterfield et al., 2005; Flanagan, 1954) to investigate which research-based features of MU’s iSTEM program are the most significant transformational elements in preparing graduates to integrate STEM in their future classrooms. Research suggests that a critical incident is “any observable human activity that is sufficiently complete…to permit inferences and predictions to be made about the person performing the act” (Flanagan, 1954, p. 327). Understanding the attributes of the program that prompt critical incidents related to iSTEM may increase the likelihood that graduates who complete the iSTEM minor will effectively integrate iSTEM in their future classrooms. By evaluating which features have the maximum impact, the researchers will be able to use this information to consider program modifications that could improve the experience for iSTEM minors in the future. In addition, researchers expect to make recommendations on how to replicate these outcomes at other teacher preparation institutions and thereby provide guidance on how to better prepare teachers of young students as iSTEM educators.

Students will be surveyed in two ways during this study. One is the end-of-semester survey created by project staff and disseminated to all iSTEM minors to gather information specific to STEM minors such as their comfort level in iSTEM, the frequency with which they have integrated STEM concepts and activities in non-iSTEM courses or field experiences, and information about their engagement in other STEM-related or professional experiences (e.g., attended workshops or presentations, participation in conferences, involvement in the iSTEM LRC, engagement in
STEM-related organizations, and visits to STEM-related places). Information is also gathered at this point about any volunteer or work-related experiences. This survey is disseminated to all iSTEM minors once per semester.

Once per academic year, a second survey is disseminated to all STEM minors and a sample of ERCH and ECSP majors who are not in the STEM minor. This survey is a slightly modified version of the Teacher Efficacy and Attitudes Toward STEM Survey-Elementary Teachers (T-STEM) (Friday Institute for Education Innovation, 2012). The T-STEM survey was originally designed “…to measure changes in teachers’ confidence and self-efficacy in STEM subject content and teaching, use of technology in the classroom, 21st century skills, leadership attitudes, and STEM career awareness” (p. 1). The original survey contained nine sub-sections with a series of statements to which respondents indicated their level of agreement from strongly disagree to strongly agree, or for certain sections, from never to every time. The iSTEM4ToYS researchers modified the survey in the following ways:

- Using only four of the nine sub-sections,
- Replacing “science” or “math” with “STEM” on all statements related to teaching efficacy and beliefs and teaching outcome expectancy,
- Rewording in a few places to change the focus from a practicing teacher to a pre-service teacher, and
- Changing the STEM Career Awareness section to focus on STEM in general instead of careers specifically.

Data collection will also take place through interviews with selected students in the iSTEM minor based on a review of survey data. These interviews will follow an established semi-structured interview protocol in order to gather more detailed information about students’ experiences with STEM integration.

During Phase One of the project, project researchers prepared the instruments and did an initial dissemination during May 2017. Data analysis from this first round of data collection is still being conducted and is not expected to be ready for release until Phase Two of the project between August 2017-July 2018.

Conclusion

The iSTEM4ToYS project was established in August 2016 with support from the National Science Foundation to explore how to prepare PK-4 teachers for iSTEM teaching and learning in the United States. This 3-year research effort aims to gather evidence to better understand iSTEM pre-service teacher candidates’ engagement in STEM and their STEM perspectives. Project investigators are completing Phase One of this project, which included establishment of five research-based programmatic features and some preliminary data collection. At this point in the study, findings and conclusions are not at a stage where they can be shared broadly. The project researchers anticipate being able to release this information during Phase Two of the project.

Credits

The author of this paper, Dr. Sharon A. Brusic (Technology & Engineering Education), serves as the principal investigator of the iSTEM4ToYS project. Three co-principal investigators from Millersville University of Pennsylvania are significantly involved in this effort as project researchers and include Dr. Nanette Marcum-Dietrich (Science Education), Dr. Jennifer Shettel (Early Childhood Education), and Dr. Janet White (Math Education). All of these individuals collaborate on every aspect of this research project.
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References


Abstract

Creativity, an important cognitive process that dominates the early stage of a design process, involves a collection of new and unique ideas, innovative, imaginative, divergent and possibly outrageous ideas to produce new productive solutions to problems (Ankiewicsz & De Swardt 2002). These creative ideas can be materialized, (virtual to reality or, expressed another way, concept to product) using the fablab’s technological infrastructures. The materialization of these ideas in turn unleashes embedded cognitive processes (Bloom’s domains). This paper discusses findings from research into cognitive processes in design at a University-based Fablab (Ub-Fablab) in France. The researcher closely followed a group of students doing a group project involving a range of wood, stone and synthetic material technologies to produce a rock-milling machine. The activities were recorded using field notes, video recording and still photography. To keep track of the activities as students iterate through the stages of design an iterative design process model, the ‘Nawita Design Process Model (NDPM)’, introduced at the PATT-32 conference, was utilized. Data was analysed using an adapted protocol analysis and results were graphed using bubble-chart graphing. Results showed that materializing the creative ideas incubated in stage 1 of the NDPM unleashed a stunning peak of cognitive, affective and psychomotor skills (inclusive of mechanical, electrical, electronic end embedded software operation skills) in stages 2, 3 and 4 of NDPM.

Keywords: Creativity, NDPM Iterative Design Process, Cognitive processes (Bloom’s domains: cognitive, affective and psychomotor).
Introduction

Creativity or creative thinking, a cognitive process dominating the initial stages of a design process, involves the incubation of a virtual representation of a product, which, can be materialized using the technological infrastructures in a fablab. Fablabs are physical spaces equipped with specific low-cost technological infrastructures for digital fabrication where people meet face-to-face to invent and make (almost) anything together (Gershenfeld, 2005). The machines in the fablabs are standardized machines proposed by the Massachusetts Institute of Technology Center for Bits and Atoms (MIT CBA). The production machines include CNC milling, laser cutters and etchers and vinyl cutters (subtractive machines) and the 3D printer (additive machine). Such production machines are able to print, cut or mill objects from data files. Initially targeted at communities as a prototyping platform for local entrepreneurships, the concept of fablabs is slowly finding its way into educational settings and is used as a platform for learning and innovation. This study focuses mainly on unleashing creative thinking using the technological infrastructures of fablabs established in universities. The term University-based Fablabs or Ub-Fablabs for short will be used throughout this paper.

The fablabs, however, are often loosely referred to as just, ‘a place where people have access to low-cost digital production tools and meet face-to-face to create anything’ (Gershenfeld, 2005; Grothaug, 2011; the Fablab website, to quote a few). This loose definition of fablabs often leads people to focus on mainly the social aspects of fablabs and the final prototype or product. The cognitive processes (inclusive of cognitive, affective and psychomotor domains) generated during the design process itself are often overlooked and undermined. It is important to capture the cognitive processes that occur between the stages of conception of ideas (virtual) and the final product (reality). The realisation and documentation of these cognitive processes will not only bring to light the cognitive processes involved in the design process, but this study will show that the realization of the creativity process at the early stage of a design process in fact produces a stunning peak of cognitive, psychomotor and affective skills throughout the stages of the design process.

Because design process in the fablabs involve what Eastman (1968) described as ‘self-taught’ and ‘intuitive design processes’ coupled with the usage of production machines with intuitive interfaces, this study used an adapted model of human cognitive-behaviour to interpret processes involving the brain’s information processing mechanisms (stimuli) and behaviour (response) (Eastman, 1968) to observe the processes that are embedded in the design process in a fablab. To track and align cognitive activities mediating between stimuli and response throughout the design process in fablabs, observable behaviour outlined in Bloom’s Taxonomy of cognitive, affective and psychomotor domains of learning are used to align with the design process of the Nawita Design Process Model (NDPM) (Botleng, Brunel & Girard, 2016) (see Figure 1). The NDPM has been introduced in PATT-32 conference in Utrecht, Netherlands.
2 THEORETICAL BACKGROUND

The relationship between conceptual and procedural knowledge in technology, creativity, creative thinking and problem-solving

It is important for one to know that the design process that fablab users iterate through to finally come up with their finished prototype/product can be viewed as a type of problem-solving activity (Eastman, 1968). Reiman (1963; as cited in Eastman 1968) described the problem solving activity in places like the fablab as a ‘transformational problem-solving activity’. The activity begins with an initial information state and requires the task to transform into an acceptable solution state. The problem solving tasks alone require high-order thinking skills like creative thinking, critical thinking, problem solving, decision making and design. These complex thinking processes are categorized under the ‘minds-on’ dimension of technological procedural...
knowledge (Ankiewicz, 2015, as cited in Engelbrecht, 2016). The relationship between these thinking processes can be summarised in the concept mapping of the ideas (see Figure 2).

**CREATIVE THINKING**
A process of sifting through information which involves disciplined conceptualization, application, analysis, synthesis and evaluation of information gathered through investigation, observation, experience, reflection, reasoning or communication and then using the results to make progress to a specific end (Ankiewicz & De Swardt, 2002).

**CRITICAL THINKING**
Produces new and unique ideas through application, commitment and perseverance to produce innovative, imaginative, divergent and possibly outrageous ideas to produce new productive solutions to problems (Ankiewicz & De Swardt, 2002).

**DETECTION-MAKING**
- Collect alternatives through Creative Thinking
- Evaluating and finally selecting the most suitable alternative through Critical Thinking

Materializing virtual representations of these creative and critical thinking in the fablab using iterative design processes like the NDPM unleashes a rigorous amount of Bloom’s cognitive, psychomotor skills (inclusive of mechanical, electrical, electronical and embedded software operation skills) and affective skills.

**Bloom’s Taxonomy**

In 1956, Dr Benjamin Bloom and his collaborators: Max Englehart, Edward Furst, Walter Hill and David Krathwohl developed the first version of Bloom’s Taxonomy, which was revisited and revised in 2001 (Anderson & Krathwohl, 2001), to use to promote higher forms of thinking in education. Bloom’s Taxonomy has classified learning behaviours under three domains of learning: cognitive, psychomotor and affective. Other terms used to refer to these three domains of learning include: Knowledge, Skills and Attitudes. There has been a lot of work done on the cognitive domain of learning (Figure 3), but very little on the psychomotor and affective domains of learning (Figures 4 & 5) (McLain, 2016). Simpson (1972) quoted Bloom (1956:7-8) as having found ‘...so little done about [the psychomotor domain]’, and ‘[did] not believe the development of a classification of these objectives would be very useful’ (cited in McLain, 2016).
This research would be one of a few researches which will bring into light the two dormant domains of learning, the psychomotor and affective.

3 METHODOLOGY

The sample for this research consists of a class of 25 primary school trainees from a university in France. The trainees were working in groups of 5 on several projects including creating i) stringed and percussion instruments, ii) honey boxes, iii) tree name-tags, iv) bird houses, v) catapult, vi) rock grinding mills, vii) artificial arm. For the purpose of this study the researcher
observed very closely the group working on the rock milling machine (RMM for short), which, involved a range of wood, stone and synthetic material technologies, skills and knowledge.

The researcher took a non-participant observer role in this study. The frequency with which psychomotor, cognitive and affective ‘observable behaviours’ occurred throughout the NDPM design stages were documented in field notes and captured using still photography. Using an adapted protocol analysis method, the documented observable behavior are analyzed and then aligned with Bloom’s taxonomy of cognitive, psychomotor and affective domains of learning.

The percentage occurrences of the cognitive, psychomotor and affective skills are calculated and displayed in Table 1 and graphed using a bubble graph. The researcher chose to use a bubble graph over the others as a bubble graph allows one to see three variables on the graph unlike the other graphs where only two variables can be shown. In this research, the bubble size gives the magnitude of the cognitive, psychomotor and affective skills at each stage of NDPM.

4 RESULTS

Due to the word limitation of this paper, the details of observable cognitive, psychomotor and affective skills could not be included, but a summary of the occurrences of observable behaviour and the magnitude of each skill at each stage are outlined in Table 1 and depicted in graph 1 below.

Table 1: A summary of the occurrences of the observable behaviours during Stages 1-4 of NDPM.

<table>
<thead>
<tr>
<th>NDPM Stage #</th>
<th>Cognitive Skills</th>
<th>Psychomotor skills (inclusive of mechanical, electrical and embedded software application skills)</th>
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<td></td>
<td>Number of observable behaviour</td>
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</tr>
<tr>
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</table>

The frequency at which each of the cognitive, psychomotor and affective observable behaviour at each stage is graphed using bubble-graphing (Graph 1).
Graph 1: Graph showing the occurrences of cognitive, psychomotor and affective ‘observable behaviour’ in stages 1-4 of NDPM.

In NDPM stage 1, graph 1 shows a high peak of 55% occurrence of cognitive skills, a 9% occurrence of psychomotor skills and a 36% occurrence of affective skills. Stage 2 of NDPM showed a rise in psychomotor skill to 35% occurrence, a 30% of cognitive skills and 35% of affective skills. In Stage 3 of NDPM, there is a tremendous rise of psychomotor skills to 47%, a 35% of affective skills and an 18% of cognitive skills. Stage 4 of NDPM sees a rise in cognitive skills (46%) while psychomotor skills decline to 15% occurrence and affective also rises to a 29% occurrence.

5 DISCUSSION

In stage one (1) of NDPM, creative thinking and critical thinking, which fall under the cognitive domain, dominates this early stage of the design process. It is a stage where students begin to think about new concepts/ideas to solve problems therefore a lot of mental representations of the design process (Martinez & Stager, 2013) are incubated. This mental process evolves as the problem solving process progresses. Retrieved from the long-term memory (LTM) to the working memory (WM) is mainly declarative knowledge where users define and categorize problems right through to brainstorming ideas to solve problems (Blooms Taxonomy). Retrieval of procedural and metacognitive knowledge from LTM to WM is also evident at this stage as is reflected by the psychomotor and affective skills performed at this stage. The psychomotor skill at this stage is a complex reflex response action where it involves operating a computer quickly to look up information for clarifications and instructions. Affective skills, on the other hand fall within the categories of receiving phenomena and internalizing values where users listen attentively to others in the group, display of teamwork, and display of professional commitment to producing.

In stage two (2) of NDPM, cognitive processes involving the prefrontal lobe (PFL) of the brain and the cerebellum are dominant. Processes such as making decisions, categorizing, analyzing and evaluating the materials to be used for the prototype/product. Retrieval of conceptual and factual information from LTM to WM is reflected by the 30% cognitive observed behavior.

Retrieval of procedural knowledge and metacognitive information from LTM to WM is dominant at this stage as reflected by the 35%, 35% of psychomotor and affective behaviors respectively. The psychomotor observed behavior falls mainly within the categories of sensory perception,
organization and overt complex responses. An important process that took place in this stage involving the three categories and the cognitive skills is the translation and transforming of mental representations done in stage 1 onto paper either using 2D or 3D sketches. The 35% affective observed behavior falls within four (4) categories: Internalizing values; organizing values, responding phenomena and receiving phenomena because they were working in groups, it was possible to observe this domain of learning in the fablab.

Stage three (3) of NDPM is a stage of design best described by Ackerman (2010) as, ‘…breaking loose from habitual ways of thinking and making dreams come true’ (cited in Martinez & Stager 2013, p.39). This dream of arriving at a prototype or product brewed and incubated in stages 1 and 2 of NDPM has come to fruition in this stage. It is no longer a virtual object, but a real one. Retrieval of Procedural Knowledge from LTM to WM is still dominant in this stage while Declarative Knowledge remains constant. This is reflected by a tremendous rise in psychomotor of 47% occurrences and a 35% of affective skills compared to a consistent pace of cognitive skills of 18% occurrence. The psychomotor skills involves the categories of sensory perception; adaptation; complex overt response; mechanism; guided response and set(refer to Figure 4). The affective skills involved in this stage consists mainly the category of internalizing values valuing; responding to phenomena and receiving Phenomena (refer to Figure 5).

In stage four (4) of NDPM, retrieval of Declarative Knowledge from LTM to WM is dominant in this stage compared to Procedural Knowledge. The cognitive skills is dominant in this stage since it is a stage where testing and evaluation of the finished prototype/product is taking place. A lot of judgements and decisions are made in this stage as to whether or not the product requirements are met. A lot of comparison processes also take place to see if the finished product meets what is expected of the prototype/product. Affective skills is also high in this stage since it is a group project so a lot of social thinking and collaborations is needed to make final decisions about the finished prototype/product.

6 Conclusion and recommendations for further research

This study has highlighted the way creative thinking process at the beginning of a design process can unleash a stunning range of cognitive, psychomotor and affective skills in later stages of the design process in anUb-Fablab. This research study findings can therefore lend the support for the use of Ub-Fablab as platforms for learning and innovations in educational settings.

There are, however, some limitations worth mentioning and recommendations for future research into creativity and cognitive processes in Ub-Fablabs. The concept of fablabs, only emerged in 2001, is still a new concept to many. While there are a few publications on the industrial applications and the economic and social benefits of fablabs, there is very little, if any, prior research study into the cognitive processes embedded in the design process in Ub-Fablabs. This research may serve as an exploratory research study to lay some groundwork for future research into the cognitive processes in fablabs.

This research study, also, being carried out into a little-researched field, there are no prior research models to track the activities during the design process or data collection and analysis tools thus the model/tools/instruments used in this research study are either created by the researcher (e.g. the NDPM) or adapted from various sources in related field of research (see works of Crutcher 1994, Simon and Kaplan 1989, Austin and Delaney 1998, as cited in Ericsson, 1993 ; Bloom, 1956 ; Baddeley, 2000; McLeod, 2012; Mastin, 2010; Boettcher, 2008) ). The model and data collection and analysis instruments /tools used in this study could
therefore make a good starting point in developing research instruments for future research into this field. While this study focused mainly on the unleashing of creative thinking in Ub-Fablabs, the approach could also be applied to entrepreneurship-oriented fablabs in communities to compare Bloom’s domains of learning in the two sectors.

REFERENCES


Fablab Website: https://www.fablabs.io/labs


ACJ: A Tool for International Assessment Collaboration

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Abstract:  
Adaptive comparative judgment (ACJ), a relatively new approach to assessment, has proven valid, reliable, and feasible for the assessment of open-ended design problems. The use of ACJ for assessment has shown positive results in various countries around the world. The potential for ACJ, as a tool for international collaboration in assessment, has not yet been addressed. Preliminary findings from a study involving ACJ use in three countries (United States, United Kingdom, and Sweden) and future directions for research are shared.

Keywords: Adaptive Comparative Judgment, Engineering Design, Technology Education, Design Assessment, International Comparison
Introduction

Open-ended design challenges are common in engineering, technology, and design programs (Kimbell, 2007; Reeve, 2015). However, these problems can be challenging to assess using traditional rubrics, which are problematic in terms of subjectivity and reliability (Bartholomew, 2017; Kimbell, 2007, 2012a, 2012b; Pollitt 2004, 2012). This can be especially true when assessing work internationally as student expectations and teacher values often differ from country to country (Becher & Trowler, 2001). Recently, a method of assessment, titled adaptive comparative judgment (ACJ), has become popular for evaluating design challenges as it has proven to be a highly reliable method of assessment for open-ended problems (Bramley, 2015; Kimbell, 2012a; Pollitt, 2004, 2012). ACJ centers on judges making judgments between pieces of student work when comparing them to one another. These comparative judgments are repeated until a rank order of student work has been produced (Pollitt, 2004, 2012). ACJ, as an assessment tool can also provide an opportunity to identify priorities and values of judges as they work through the process of making comparative judgments and providing the accompanying rationale for each decision (Bartholomew, 2017). In this way the values, related to “good design” and “design thinking,” of the judges can be extracted through the ACJ process of assessment. The opportunity to utilize ACJ to identify similarities and differences between groups of judges, located in different regions, appears intriguing and meaningful. For this initial study we intentionally targeted the UK, US, and Sweden based on the similarities and differences in Technology/Design Education programs across the three countries and the recent use of ACJ for assessment.

Statement of the Problem

Despite the success of ACJ in individual settings and scenarios, little has been done to evaluate the impact of ACJ as a tool for international collaboration and comparison in assessment. The nature of ACJ—which can be used with panels of judges in common assessment sessions—situates ACJ as a potentially useful tool for international collaboration, comparison, and discussion in common areas of interest. The following research question was used to guide this study:

Research Questions

1. Are “good design” and “good design thinking” a regional or international phenomenon?
   - What relationship, if any exists, between the rank order, produced through adaptive comparative judgment, of middle school open-ended design products when assessed by panels of judges in three different countries: the United States, the United Kingdom, and Sweden?
   - What relationship, if any exists, between the rank order, produced through adaptive comparative judgment, of middle school portfolios, from an open-ended design problem, when assessed by panels of judges in three different countries: The United States, The United Kingdom, and Sweden?

Literature Review
Technology and Engineering Education (TEE) has a long history in K-12 education in the US and across the world (ITEEA, 2000/2004/2007). Originally known as “Manual Arts,” the field dedicated to the study of technology, design, and engineering principles has undergone several name changes throughout the years (Starkwether, 2015). This evolutionary-process in not confined to the US as other countries have also experienced changes in programs, fields, and naming conventions. While a complete illustration of the differences by country, their educational histories, and respective programs, is beyond the scope of this work, a brief overview of TEE in each of the countries involved in this study will be provided here.

**USA.** Since the formal inception of the school subject in the 1800’s, numerous adaptations have occurred to address the changing needs of society. From Manual Training, to Manual Arts, to Industrial Arts, to Technology Education, and most recently, TEE, the subject in the US has continuously evolved in an effort to provide the proper delivery and content for students to be contributing members of society (Strimel, Grubbs, & Wells, 2016). TEE’s content once emphasized metalworking and woodworking but now stretches to cover topics such as computer-aided design, robotics, and control systems while fostering student abilities to design, make, and innovate (Starkwether, 2015). Additionally, the TEE profession still emphasizes “technological literacy for all” and the use of the Standards for Technological Literacy to help students use, manage, assess, and understand technological products and systems (ITEEA 2000/2004/2007). However, currently the TEE community continues to struggle in communicating its’ role in an evolving STEM education landscape (Lewis & Zuga, 2005; Starkwether, 2015; Strimel & Grubbs, 2016). The result has been TEE being offered as mostly an “elective” and being delivered inconsistently across the country (Moye, Jones, & Dugger, 2015).

**United Kingdom.** While the dynamic study of technology and design in the US has become known as TEE, the comparable subject in the UK is referred to as Design and Technology (D&T) education. With the implementation of the National Curriculum in 1989, the UK became one of the first countries to establish the study of D&T as a statutory requirement for all students (Design and Technology Association, 2017). Since then, D&T has been viewed as a practical and rigorous subject focused on preparing all students to live in the designed world and helping to address current skill shortages in the manufacturing, engineering, and other creative industries (Design and Technology Association, 2017). The D&T school subject specifically engages students in creative and practical activities to teach them the knowledge and skills necessary to participate successfully in an iterative process of designing and making (Department of Education, 2013). This includes topics such as the study of different cultures to understand user needs, identifying design problems, developing design specifications, generating creative ideas, developing detailed plans, modeling, selecting appropriate tools and techniques to produce prototypes, and selecting prototyping materials based on their properties (Department of Education, 2013). However, much like the US, the position of D&T education has recently been challenged in the UK and the value of the school subject has repeatedly come under question by policy makers and politicians (Design and Technology Association, 2017; de Vries, 2015).

**Sweden.** Technology is a mandatory subject in Sweden compulsory school (Year 1 to Year 9). Technology, first introduced as a separate subject in the national curriculum in early 1980’s, was originally grouped together with physics, chemistry, and biology. Although Technology is still included in the same allocated hours as science subjects, in the autumn of 2011, a Technology-specific curriculum was introduced with the overarching aim of “helping the pupils to develop their technical expertise and technical awareness so that they can orient
themselves and act in a technologically intensive world." (NAE 2011/2016, p. 278). The themes of the core contents include (but are not limited to) mechanics, materials, electronics, automatic control, technological systems, product development, and technology’s relation to the sciences, to society at large, and to the fine arts. The implementation of Technology, as a subject, has continuously undergone changes—in March this year, Swedish government launched introduction of programming as part of technology courses (Regeringskansliet, 2017). Although technology is mandatory for every pupil in elementary school; the subject Technology still varies between schools, in content, complexity, pedagogy, and assessment (Hartell, 2015; Teknikföretagen and Cetis, 2013, Skolinspektionen, 2014).

**Design Projects and Design Assessment.** The fields associated with TEE (D&T, Technology, etc.) often includes open-ended problem solving activities with complex goals and non-predefined product outcomes (Dutson, Todd, Magleby, & Sørensen, 1997; Katehi, Pearson, & Feder, 2009; Cunningham, 2009). In many cases, students are presented with an open-ended problem, which requires them to work in groups as they solve, test, modify, and design a solution (ITEEA, 2000/2004/2007). In tandem with the widespread use of design problems and projects, a variety of models, methods, rubrics, and guides have been developed to assist with assessment (Denson, Buelin, Lammi, & D’Amiccom 2015; Diefes-Dux, Moore, Zawojewski, Imbrie, & Pollman, 2004; Kimbell, 2007, 2012b; Kimbell & Stables, 2007; Schilling & Applegate, 2012).

However, despite a wide-range of possible options for assessment, the highly-creative and open-ended nature of these problems has made them traditionally very difficult to assess with reliability, validity, and efficiency (Bartholomew, 2017; Pollitt, 2004, 2012a; Pollitt & Crisp, 2004; Kimbell, 2007) While rubrics and criterion-based approaches to grading have made considerable progress in improving assessment related to design problems (Kimbell, 2007, 2012a; Denson, Buelin, Lammi, & D’Amiccom 2015), teacher bias and subjectivity has continued to lead to difficulty in valid and reliable assessment (Bartholomew, 2017; Pollitt, 2012a).

The Technology Education Research Unit in the UK (Kimbell, 2007; Seery, Canty, & Phelan, 2012) piloted an innovative approach to design assessment based on ideas first set forth by Thurstone in 1927. Thurstone’s (1927) ideas related to ACJ, centered on the argument that human comparative judgments (judgments between two items) are more valid and reliable than decisions based solely on a predetermined rubric (Pollitt, 2004; Thurstone, 1927). By implementing a series of comparative judgments, a rank order of student work may be produced with very high levels of reliability (Kimbell 2012a, 2012b; Pollitt, 2004, 2012a). A host of research related to ACJ, it’s use as a tool of assessment, it’s validity and reliability, and it’s feasibility for implementation have been conducted (Bartholomew et al., 2017; Bartholomew, Strimel, & Jackson, 2017; Kimbell, 2012a, 2012b; Kimbell & Stables, 2007; Rowsome, Seery, & Lane, 2013; Seery, Canty, & Phelan, 2012; Tarricone & Newhouse, 2016)

In an ACJ assessment setting a judge (e.g., the teacher), does not use a rubric to tally a score for each student; rather, the teacher/judge simply views sets of student work and identifies which item is “better” based on a predetermined rubric and/or their own professional expertise. As the teacher/judge repeats this process—identifying the better in a set of two items—a rank order develops for all the student work. The ACJ method of assessment can be undertaken by a single teacher/judge or as a group-effort between teachers/judges. A more extensive and thorough explanation of ACJ can be found elsewhere (Pollitt, 2004, 2012a, 2012b). In addition to the final rank order emerging from the ACJ process, a comment/rationale for each judgment can be collected. The opportunity for judges to justify their decisions for each comparison can prove useful as these comments form a type of formative assessment for
student items which can be provided as a learning tool to students (Bartholomew, 2017, Bartholomew et al., 2017, Hartell & Skogh, 2015).

**Methodology**

Prior to implementation of this research permission was obtained through IRB. Following permission and collection of the required assent/consent forms the design portfolios and products from middle school students (age 12-14, \( N = 706 \)) enrolled in a large suburban school district (over 75,000 students) in the Western US were collected. This school district is comprised of a mainly suburban middle-class population (16% free/reduced lunch). The teachers recruited for this study \( (n = 6) \) possessed similar characteristics (teacher license level, similar years of teaching, similar classes taught, similar school facilities, and recommendation from the district TEE coordinator). Each teacher agreed to implement the study in at least two sections of the *Exploring Technology* class—an introductory TEE course for 7th and 8th graders (age 12-14). The study, involving an open-ended design problem for students to complete in groups (see Figure 1), took place over five 90-minute class periods with a total of 18 classes of *Exploring Technology* forming the population of the study.
The Design Challenge

Context: An elderly individual enjoys traveling internationally. Ideally, this person would like to travel internationally between 2-3 months of the year. This person has a few ailments and allergies that require medication. In addition, this person also takes vitamins.

Challenge: You have been hired to design a new medicine dispenser for this client. Your design should:
1. Be easy to use
   a. Easy to open and close
   b. Easy to fill and take
2. Assist the person in remembering when to take the pills
   a. Day of the week and time of day
   b. Correct amount of pills that should be taken

Criteria & Constraints: Your design should:
1. Remind the person to take each pill (this is time of day and day of the week).
2. Remind the person how many of each pill to take.
3. Be small enough to fit easily in a purse, backpack, or pocket for travel (should fit easily within an 8" x 10"
4. Be childproof (that is, difficult for a child to open)

Resources: The breakdown for when pills should be taken and the quantities is included here:

<table>
<thead>
<tr>
<th>Pill Name</th>
<th>Pill Size</th>
<th>Number taken at each dose</th>
<th>When to take the pill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin A</td>
<td>0</td>
<td>2</td>
<td>Monday (morning)</td>
</tr>
<tr>
<td>Vitamin B</td>
<td>0</td>
<td>1</td>
<td>Friday (morning)</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>0</td>
<td>1</td>
<td>Monday (morning)</td>
</tr>
<tr>
<td>Iron</td>
<td>0</td>
<td>1</td>
<td>Monday (morning)</td>
</tr>
<tr>
<td>Allergan D</td>
<td>0</td>
<td>1</td>
<td>Wednesday (morning)</td>
</tr>
<tr>
<td>Potassium</td>
<td>0</td>
<td>1</td>
<td>Wednesday (morning)</td>
</tr>
<tr>
<td>Sodium</td>
<td>0</td>
<td>1</td>
<td>Thursday (morning)</td>
</tr>
</tbody>
</table>

Supplies:
Students will be provided with tools, materials, and supplies to prototype and build while they are designing. Students should plan carefully to conserve materials as no additional materials will be provided. All materials and tools need to be used in the design. Building items include:

- Plastic bag containing all supplies
- 10 3x5 cards
- 10 pencils
- 2 copies of the engineering design challenge
- 1 pair of scissors
- 2 green pencils
- 1 pair of pointed metal scissors (paper group)
- 1 pair of post-it notes
- 1 pair of plastic
- 1 plastic cup
- Plastic (1 1/2" x 12" sheet - 0.017" thickness)
- Cardboard (two 8.5" x 11" sheets, assorted colors)
- Rubber bands (approximately 25, assorted colors)
- String (polyester thread, 3")
- Tape (brown, 1 roll)
- Net glue gun and glue (1 10 oz stick)
- Scissors (1 pair)
- Paper (8.5" x 11", white)

Evaluation Criteria: Students will complete a design portfolio that documents their process as they design their product. Students will be graded based on their design portfolio and their final prototype using the rubric below:

Portfolio Evaluation

<table>
<thead>
<tr>
<th>Item</th>
<th>Evaluation Criteria</th>
<th>Item Weight Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questions/Answers</td>
<td>Each question or prompt was responded to by the students with an evaluation, picture, or drawing</td>
<td>2</td>
</tr>
<tr>
<td>Figures</td>
<td>Each picture box contains a picture representing student work</td>
<td>1</td>
</tr>
<tr>
<td>Figurine</td>
<td>Figurine demonstrates a logical progression of the product through the design process</td>
<td>1</td>
</tr>
<tr>
<td>Design Process</td>
<td>Steps of the engineering design process are clearly demonstrated in the students in the portfolio</td>
<td>1</td>
</tr>
<tr>
<td>1. Identify the need or problem</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2. Research the need or problem</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3. Develop possible solutions</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4. Select the best possible solution</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5. Construct a prototype</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6. Test and evaluate the solution</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7. Communicate the solution</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8. Redesign</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>9. Finalize the design</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Overall Portfolio</td>
<td>Portfolio is easy to read, follow, and understand</td>
<td>1</td>
</tr>
<tr>
<td>Self-directed Learning</td>
<td>Student demonstrated self-directed learning in their portfolio creation</td>
<td>1</td>
</tr>
</tbody>
</table>

Product Design Evaluation

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Item Weight Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria &amp; Constraints</td>
<td>Designed product satisfies provided criteria and constraints</td>
<td>1.5</td>
</tr>
<tr>
<td>Feasibility &amp; Functionality</td>
<td>Designed product is both feasible and functional</td>
<td>1.5</td>
</tr>
<tr>
<td>Affordability</td>
<td>Designed product is within budget limits</td>
<td>1.5</td>
</tr>
<tr>
<td>Creativity</td>
<td>Designed product demonstrates original thought, insight, and innovation</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Figure 1. Open-ended engineering design challenge.
Following instruction related to the engineering design process and an introduction to the open-ended design challenge, students were placed in groups of 2-3. This challenge involved designing a new container/dispenser for distributing pills to patients in specified quantities and at prescribed times (see Bartholomew, Reeve, et al., 2017). Students designed the product with a specific user in mind and were instructed to adhere closely to the provided criteria, constraints, and scenario (an elderly individual who enjoys traveling internationally). At the outset, groups of students gathered and interacted with a “handling collection” consisting of materials chosen to stimulate idea generation and creativity (e.g., zippers, ties, string, plastic, clay, etc.). Following this brainstorming activity, students were provided materials which they used to construct a solution to the design problem.

**Data Collection.** At the completion of the study all the student portfolios and products were collected and digitized, resulting in 176 images of student design products and 176 pdf files of student portfolios. These files were uploaded to the ACJ engine (titled CompareAssess) in six separate judgment sessions for assessment (one ACJ session for the products for each country and one ACJ session for the portfolios for each country).

A panel of judges was identified and recruited for the assessment of student work in each country (teachers, researchers, teacher educators, and individuals with experience in design, design education, and design assessment). The majority of these individuals had little or no experience with ACJ prior to this study.

Each panel was trained on the CompareAssess ACJ software, introduced to the rubric and the assessment criteria, and provided a login to the CompareAssess online judging platform. Each judge was asked to make 20-30 comparative judgments of portfolios and student products as an initial step. This initial judgment session was done in an effort to ensure all judges were comfortable with the process, understood how to use ACJ, were comfortable with the grading criteria, and had an opportunity to identify a sample of student quality and expectations for the assignment.

Following the initial judgment session, each judge was given the option to ask questions, resolve concerns, and discuss a unified direction in judgment. Subsequently each judge was asked to complete additional judgments until sufficient reliability levels ($r > .9$) were obtained for the resulting rank orders. For the US judges this equated to roughly 175 total comparative judgments of products and 175 total comparative judgments of portfolios (including the initial 20-30 judgments). As there were more judges in both the UK and Sweden, this equated to roughly 88 total comparative judgments of products and 88 total comparative judgments of portfolios (including the initial 20-30 judgments). The resulting rank orders, in addition to the judge comments from both the portfolios and products, were recorded for later analysis. When each group of judges reached reliability levels of $r > .9$ the judges were instructed that no additional judgments were necessary.
Preliminary Findings

The findings presented here are preliminary in nature as the research is still in progress and the analysis of the resulting data has not yet been completed. The initial findings show interesting similarities, and differences, in the preferences of the judges from each location (Figure 1 & 2).

<table>
<thead>
<tr>
<th>Rank</th>
<th>United States of America</th>
<th>United Kingdom</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Group 200</strong></td>
<td>Group 37</td>
<td><strong>Group 192</strong></td>
</tr>
<tr>
<td>2</td>
<td>Group 100</td>
<td>Group 35</td>
<td><strong>Group 18</strong></td>
</tr>
<tr>
<td>3</td>
<td>Group 12</td>
<td>Group 115</td>
<td>Group 76</td>
</tr>
<tr>
<td>4</td>
<td><strong>Group 192</strong></td>
<td><strong>Group 105</strong></td>
<td><strong>Group 200</strong></td>
</tr>
<tr>
<td>5</td>
<td>Group 147</td>
<td>Group 122</td>
<td>Group 130</td>
</tr>
<tr>
<td>6</td>
<td><strong>Group 105</strong></td>
<td>Group 108</td>
<td>Group 68</td>
</tr>
<tr>
<td>7</td>
<td>Group 61</td>
<td>Group 154</td>
<td><strong>Group 122</strong></td>
</tr>
<tr>
<td>8</td>
<td>Group 2</td>
<td><strong>Group 18</strong></td>
<td>Group 190</td>
</tr>
<tr>
<td>9</td>
<td>Group 72</td>
<td><strong>Group 200</strong></td>
<td>Group 112</td>
</tr>
<tr>
<td>10</td>
<td>Group 5</td>
<td>Group 187</td>
<td>Group 9</td>
</tr>
</tbody>
</table>

Figure 1 – Top Products by Location

<table>
<thead>
<tr>
<th>Rank</th>
<th>United States of America</th>
<th>United Kingdom</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Group 122</strong></td>
<td>Group 61</td>
<td><strong>Group 185</strong></td>
</tr>
<tr>
<td>2</td>
<td>Group 12</td>
<td>Group 108</td>
<td>Group 100</td>
</tr>
<tr>
<td>3</td>
<td>Group 129</td>
<td>Group 115</td>
<td>Group 128</td>
</tr>
<tr>
<td>4</td>
<td>Group 192</td>
<td><strong>Group 155</strong></td>
<td>Group 200</td>
</tr>
<tr>
<td>5</td>
<td><strong>Group 185</strong></td>
<td>Group 18</td>
<td>Group 58</td>
</tr>
<tr>
<td>6</td>
<td>Group 182</td>
<td>Group 105</td>
<td>Group 112</td>
</tr>
<tr>
<td>7</td>
<td><strong>Group 155</strong></td>
<td><strong>Group 122</strong></td>
<td>Group 199</td>
</tr>
<tr>
<td>8</td>
<td>Group 62</td>
<td>Group 67</td>
<td>Group 60</td>
</tr>
<tr>
<td>9</td>
<td>Group 114</td>
<td><strong>Group 99</strong></td>
<td><strong>Group 99</strong></td>
</tr>
<tr>
<td>10</td>
<td>Group 52</td>
<td>Group 69</td>
<td>Group 126</td>
</tr>
</tbody>
</table>

Figure 2 – Top Portfolios by Location

**Portfolios.** The top-10 portfolios for the locations demonstrated marked differences as only group 185 was present in at least two of the top-5 ranks. However, there were also a few noticeable parallels between locations. There were four portfolios, which appeared in at least two of the top-10 ranks for the countries (122, 185, 155, 99) but no portfolios appeared in all three of the top-10 rank orders from the separate countries. Comparing the top-ranking portfolios with the top-ranking products we found that a total of 11 groups, out of 26 unique group portfolios in the top-10, appeared in the top-10 products lists as well (122, 12, 192, 61, 108, 115, 18, 105, 100, 200, 112) suggesting that student design performance in both the process (demonstrated by the portfolio) and the outcome (demonstrated by the product) was related.

**Products.** Similar to the portfolios of the top-ranking products, there were five products that appeared in at least two of the top-10 rank orders for products (200, 192, 105, 122, 18). None of these five products appeared in all three of the top-10 rank orders from the countries. In a comparison of the top-ranking products with the top-ranking portfolios we identified a total of
11 groups, from the 26 unique group products in the top-10, which appeared in the top-10 portfolios. Once again this suggests a relationship between success on the final outcome of the design process and the actual process, and documentation, used by the students.

**Discussion & Direction for Future Work**

The findings from this work, preliminary in nature, help shed light on the similarities, and differences, in design values and assessment practices across three countries. Future work into the rationale behind these similarities and differences will aim to explore and illuminate these ideas and the possible implications for TEE. As the world becomes increasingly connected, the emergence of similarities and differences in the judges’ assessments of student work is important and warrants investigation. While many of the same portfolios and products appeared in the top-10 ranks for each country there were marked differences as well. The rationale behind these differences, the cultural implications and ramifications, and the design-values held in various locations are all planned for areas of further investigation. As we prepare students for potentially-global careers the need for an understanding of globally-held preferences, views, and values is vital.

We believe that ACJ, highlighted in this study, is a valuable tool, which may serve to facilitate assessment on a broader-, even global-, scale. The possibilities and implications of connecting various academic ideas, paradigms, and cultures will guide further reflection and investigation of the findings from this research. In order for students to truly be prepared for a global workplace, the values and preferences of a global audience must be taken into account. This study highlights several possibilities for implementing this preparation into TEE programs across the globe.
References


Rowsome, P., Seery, N., & Lane, D. (2013). The development of pre-service design educator’s capacity to make professional judgments on design capability using adaptive comparative judgment. American Society for Engineering Education.


SLIDE 1. Thank you for giving me this opportunity to speak with you today to share a little about ITEEA’s background, current focus, and projects. My name is Steven Barbato - I am Executive Director and CEO of the International Technology and Engineering Educators Association (ITEEA) based in Reston, Virginia, just outside Washington DC. I am here today to share ITEEA’s goals, mission, and vision, while also sharing important information regarding activities that support all STEM Educators, specifically, technology and engineering educators from a national and international perspective.

ITEEA has a strong tradition and extensive 80 year history of supporting technology and engineering educators at all levels. Our research, professional development, curriculum,
and assessment efforts are driven by the unique ability of our educators to utilize technology and engineering content and practices in order to bring STEM to Life for ALL students! Learning STEM through an engaging technological systems and engineering design lens provides all students, preK-12 the vital opportunity to become both technologically and engineering literate.

• SLIDE 2. We, as active leaders in our field, have an opportunity through technology and engineering education, to take advantage and provide a presence that impacts and launches all of our students to embrace technological and engineering literacy – the ability to understand, manage, and assess the world around them and make it better! The key to creating and supporting STEM leaders is to encourage their active participation in their professional development through professional networks like ITEEA. Each member has the opportunity, as well as the responsibility, to access and participate in essential activities to promote Technology and Engineering learning through Integrative STEM Education practices in Pre-k through grade 12, as well as in our teacher preparation programs. <CLICK> https://www.iteea.org/Activities/39081/ITEEAinaBOX.aspx  <Bring STEM To Life infographic> Walk through each infographic/page.
SLIDE 3. The approach is “Integrative STEM Education”! By this, I mean the delivery of technology and engineering design-based learning approaches will intentionally integrate the concepts, content, and practices of science and mathematics aligned with the content and practices of technology and engineering education. Aligning with STEAM, Integrative STEM Education is the interdisciplinary approach that is equally applicable at the natural intersections of learning within the continuum of content areas such as language arts, social studies, art, music, etc. Additionally, delivering technology and engineering education through an I-STEM Education approach allows for interdisciplinary teaching and learning to support all educational environments and academic levels. (Adapted from Sanders & Wells, 2010 and Wells & Ernst, 2015) — The key is delivering first class Professional Development at the early primary grades up through high school and to have world class teacher preparation programs preservicing and in-servicing teachers to be at their best! ITEEA is working to make this happen!

Slide 4: Students who study technology and engineering through an Integrative STEM education approach learn about the
technological world that inventors, engineers, and other innovators have created. The goal is to produce students with a more conceptual understanding of technology and engineering and its place in society. These students are able to fully conceptualize and evaluate new technologies that they may have never before seen. By “doing and making,” children are able to become makers for the future.

Slide 5: Using an Integrative STEM Education delivery for Technology and Engineering Education provides a perfect interdisciplinary integrator of all subject content. It especially excels at connecting the fields represented by the STEM acronym. When taught effectively, technology and engineering is not simply one more field of study seeking admission to an already crowded curriculum, pushing others out of the way. Instead, it reinforces and complements the material that students learn in other classes—Technology and Engineering Bring STEM to Life!

Slide 6: **Technology and Engineering Literacy is a Must for ALL Students!** Technological and engineering literacy is the ability to use, manage, assess, and understand technology and engineering practices. A technologically and engineering literate person understands, in increasingly sophisticated ways that evolve over time, what technology is, how it is created, and how it shapes society, and in turn is shaped by society. A
technologically literate person will be comfortable with learning about technology and engineering, without being afraid or intimidated by it.

Slide 7: Technology and Engineering Literacy paves the way for making a positive difference in the lives of humankind! STEM is an important force in our economy; anyone and everyone benefits from being familiar with it. On the individual level, technological and engineering literacy allows consumers to better assess products and make more intelligent decisions pertaining to purchases and policy, as well as decisions that affect our quality of life.

Technology and Engineering Education through Integrative STEM Education effectively delivers technological literacy and engineering and paves the way for making a positive difference in the lives of humankind!

Slide 8: ITEEA’s mission is to advance technological and engineering capabilities for all people and to nurture and promote the professionalism of those engaged in these pursuits.
Slide 9: **ITEEA Is YOUR Dynamic Professional Association!** ITEEA is the largest professional educational association, principal voice, and information clearinghouse devoted to enhancing technology, innovation, design and engineering through experiences in PreK-12 schools. However, it requires our “Collective Participation”!

Slide 10: **ITEEA represents all preK-12 technology and engineering educators throughout the U.S. and internationally.**

Slide 11: **ITEEA conducts a wide variety of professional development programs and holds an Annual Conference—the largest technology and engineering education showcase of exhibits and educational sessions in the world.**

Slide 12: **ITEEA Publishes Technology and Engineering Teacher, Children’s Technology and Engineering, the Journal of**
Technology Education, STEM Connections, and a variety of other publications that lead the profession by providing teaching directions, instructional ideas, and networking opportunities.

Slide 13: ITEEA leads and engages its members through numerous committees, task forces, and boards that coordinate all aspects of technology and engineering education and sponsor dozens of meetings, conferences, and exhibits annually.

Slide 14: ITEEA sponsors an active honors and awards program that recognizes outstanding teachers and programs (K-12) from states, provinces, and countries affiliated with the Association. ITEEA also presents award certificates and supports other programs that recognize outstanding efforts in the technology and engineering teaching profession.

Slide 15: ITEEA conducts a vigorous public policy program frequently providing information to government, agencies, associations, and other special interest groups concerning technology and
engineering education. The Association strives to provide concerned publics with an understanding of the importance of technological and engineering literacy through technology, innovation, design, and engineering education to the future growth and well-being of all nations.

ITEEA’s Councils, include the Council on Technology and Engineering Teacher Education (CTETE), the Council for Supervision and Leadership (ITEEA-CSL), the Children’s Council, and the Technology and Engineering Education Collegiate Association (TEECA). Each Council recruits the best and brightest in our field in order to lead the movement towards an Integrative STEM Education for all students and build a better future for all. Ostensibly, PATT is like an ITEEA Council and a greatly respected and appreciated international affiliate of ITEEA!

ITEEA and its foundation, the Foundation for Technology and Engineering Educators (FTEE), provide awards, grants, and scholarships to support the advancement of technology and engineering education. FTEE awards support programs that will: make our children technologically and engineering literate; transfer industrial and corporate research into our schools; produce models of excellence in technology and engineering teaching; create public awareness regarding the nature of technology and engineering education; and help technology and engineering
teachers maintain a competitive edge in technology, innovation, design, and engineering.

Slide 18: ITEEA offers individual memberships, pre-K-12 schoolwide STEM memberships, university, and corporate memberships. Our members are classroom teachers, state and local supervisors, college students, college and university faculty, teachers of science, mathematics, and other disciplines such as art, music, social studies, as well as technical and general educators.

Slide 19: ITEEA offers its members a professional forum to exchange ideas, ask questions, and share valuable lessons, tips, and tricks of the trade: ITEEA’s IdeaGarden forum generates real-time dialogue pertaining to educational programs and events, knowledge resources, and new ideas about teaching and learning. Teachers ask questions, share information and ideas, and offer meaningful support.

Slide 20: ITEEA’s STEM Center for Teaching and Learning™ has developed a premier standards-based Integrative STEM
Education curriculum model designed to be flexible, affordable, and accountable.

Slide 21: This teacher-designed and driven Engineering byDesign™ curriculum was developed to address the need for standards-based curriculum using Standards for Technological Literacy as well as the Common Core Standards, the Next Generation science standards, and the national Academy of Engineering’s Grand Challenges. This dynamic curriculum is “engineered” to address and advance the needs for standards-based Technology and Engineering literacy through an Integrative STEM Education delivery system.

Slide 22: An NSF-funded project through Hofstra University and Dr. Michael Hacker’s leadership, have developed two new exciting units that totally exemplify the I-STEM Education approach! This development has positioned EbD™ to better meet the dynamic needs of all learners through Technology and Engineering Education. To preview EbD Courses, simply click on the “Request for EbD Course Review Access” button on the left side menu and complete the online form.
Slide 23: We hope you can join us for ITEEA’s 80th Anniversary Conference, April 12-14, 2018 in Atlanta, GA! There will be special programming for all international attendees and will feature the PATT International Conference #35! This venue provides the international community a very unique and targeted opportunity to collaborate, share, and learn with practitioners at all levels across the globe!

Slide 24: Please take the time to view this “Membership Matters” video highlighting the strengths and advantages of being an active participant in ITEEA. https://youtu.be/ExiGIG3uoxU

Become a new or returning member today by going to ITEEA.org to create an account and then “Manage Profile.” Or use the downloadable Print Form.

Slide 25: Thank for your attention during this presentation. I especially want to thank Marc DeVries for his many years of service to ITEEA and our profession, along with the wonderful job Dr. Len Litowitz has done in coordinating this conference with his colleagues from Millersville University!
Robotics, STEM and Project-Based Learning: Using the P3 Task Taxonomy to Make the Myth Real

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Abstract  
Recently, three main subjects have inspired technology education: robotics, STEM education and project-based learning (PBL). However, a gap exists between the theory or intentions related to each of these subjects and their application in practice. The study presented in this paper aimed at examining the effectiveness of a 30-hour robotics course for junior high school students (n=32) that incorporates STEM studies and project-based learning (PBL). Class activities were designed according to the P3 Task Taxonomy, which comprises: 1) Practice – basic closed-ended tasks and exercises; 2) Problem solving – small-scale open-ended assignments in which the learner can choose the solution method or arrive at different answers; and 3) Project-based learning – open-ended challenging tasks. The research aimed at exploring students’ working patterns, achievements in learning the course, and the impact of this experience on students’ motivation to learn STEM subjects. Evaluation tools included a final exam on factual, procedural and conceptual knowledge in the STEM subject learned in the course, class observations, interviews with the students, and an attitude questionnaire administered before and after the course. Since the experimental class was quite heterogeneous with regard to students’ prior learning achievements and motivation to learn, some of the students completed only the basic exercises, others coped well with the problem-solving tasks, and only a few took it upon themselves to carry out a mini-project. However, all of the students showed high motivation to learn robotics and STEM subjects. In summary, robotics provides a very exciting learning environment for STEM education and PBL. Yet, the realization of this potential depends largely on the careful design of course content and methodology, especially the design of students’ assignments in the class.

Keywords: Project-based learning, Robotics, STEM, Task taxonomy

Introduction  
Recently, three main subjects have inspired technology education: robotics, STEM education and project-based learning (PBL). However, a gap exists between the theory or intentions related to these subjects and their application in practice (Hall and Miro, 2016). The present study, which is derived form a broader paper describing the research in full (Barak & Assal, 2016), examines the effectiveness of a robotics course for junior high school students incorporating STEM studies, PBL and the P3 Task Taxonomy developed for science and technology education.
Literature Review

Robotics in school
Robotics is increasingly becoming a popular platform for teaching science and technology (Toh et al., 2016). Educators and researchers often try to show how engaging students in robotics workshops or competitions fosters learning subjects such as technological design, engineering, problem solving, physics, mathematics, or creative thinking in general (Barker & Ansorge, 2007; Barak & Zadok, 2009). However, in a robotics workshop at school, students are often engaged merely in building and programming robots, with only little explicit learning of mathematics, science or engineering design.

Project-based learning
Robotics and STEM education are often associated with project-based learning (PBL), which is also intensively becoming a preferred instructional approach in all levels of K-12 education, and in teaching STEM in particular. Researchers and educators often present PBL as an instructional method for teaching STEM subjects and developing students’ broad skills, such as independent learning, problem solving, creativity, metacognition and teamwork (Savery, 2006; Barak & Shachar, 2008; Kolmos 1996, Thomas, 2000; Crismond, 2011). The PBL environment places learners in an active role where they can cope with authentic assignments and learn through doing design and problem solving, while applying knowledge in mathematics, physics and programming.

The need for tutor guidance at the beginning of learning a new subject
Despite the wide consensus in the literature about the advantages of PBL over traditional schooling, educators are becoming increasingly aware of the difficulties and limitations of applying these methods in the regular school context. If the problem or project presented to students is not compatible with the learners’ prior knowledge and skills, only little learning is achieved, and students may be busy ‘doing’ with only little significant learning taking place (Blumenfeld et al., 1991; Barron et al., 1998; Barak, 2012). Booker (2007) uses the term “a roof without walls” to describe the desire to develop higher-order thinking skills (according to Bloom’s taxonomy) of children who have not learned facts and gained substantive knowledge in a certain subject. A number of authors (Dolman et al., 2005; Kirschner, Sweller & Clark, 2006; Hushman & Marely, 2015; Hmelo-Silver et al., 2007; Savery, 2006) posit that in order to stimulate students towards constructive and contextual learning, realistic, open-ended and ill-structured problems must fit with the students’ prior knowledge and skills. Lehtinen & Viiri (2017) point out that inquiry-based learning should be guided in order to achieve optimal learning outcomes. The need for guidance is even greater when simulations are used because of their high information content and the difficulty of extracting information from them. PBL curricula should consist more of tutor guidance at the beginning through shared guidance of both the students and the tutor, and move to increased student guidance at the end.

The P3 Task Taxonomy
As noted in the previous section, it is important to design a curriculum and instructional method that help the students gain some basic knowledge and skills related to learning a new subject before dealing with PBL. To this end, we developed the P3 Task Taxonomy, which identifies three levels of students’ assignments:

1. **Practice** – basic closed-ended tasks and exercises;
2. **Problem solving** – small-scale open-ended assignments in which the learner can choose the solution method or arrive at different answers; and
3. **Project-based learning** – open-ended challenging tasks, in which the learner is engaged in selecting or defining the task.

In this study, we show how the P3 Task Taxonomy was used for designing and teaching a robotics course in junior high school.

**Setting and Methodology**
The STEM-oriented robotics course comprised 15 sessions of two school hours each (total 30 h). The participants included 32 students (23 girls and 9 boys) aged 13-14 from a small school in southern Israel, which serves mainly a mid-low income population. The teacher had a background in teaching technology; a physics teacher from the same school also helped in designing the students’ assignments and evaluating their work.

The study adopted the mixed research approach in order to collect rich data on students’ activities in the class, their achievements, difficulties and motivation, either simultaneously or sequentially, to best understand the research problems (Creswell et al., 2003; Creswell & Plano Clark, 2009). The quantitative tools included a **subject matter exam** and an **attitude towards technology and STEM questionnaire**. The qualitative tools included **documenting** all class activities, **interviewing** the students, and analyzing the **assignments and final projects** they submitted. This paper presents only part of the data obtained in this study. More details about the research methodology and tools appear in the Findings section.

**Findings**

**Assignments on the practice level**
In the first part of the workshop, the students dealt with basic closed-ended exercises and tasks in which they learned about the robot’s parts and structure, and the programming method. For example, the students had to program the robot to move forward during 1 sec and 0.5 sec, and measure the distance the robot moves on the floor in each case, as shown in Figure 1. They then had to repeat these measurements when the power of the robot’s motors was reduced to 75% and 50% of the maximum power.

![Figure 1. An example of a Practice task – measuring the distance a robot moves on the floor in one second](image)

In the data analysis, the students calculated the robot’s velocity in cm/s in each case and presented the findings in a table and on a graph.

This example shows how robotics helps in learning a number of STEM aspects: programming the robot, taking a series of measurements with changing parameters, calculating and presenting the findings in a table and on a graph. The assignment was marked as fitting the **Practice level** because this was the students’ entry into the world.
of robotics. They received exact instructions as to what to do and how to present the findings, and by coping with the assignments, they came to know the robot’s working environment. The fact that many students encountered difficulties in completing the above-mentioned assignments and required the teacher’s help proves that this was an essential preparation of the students for the subsequent assignments in the course at a higher level of the task taxonomy, as described in the following sections.

Assignments on the problem-solving level
In the Introduction section, we have seen that problem solving relates to small-scale open-ended assignments in which the learners can choose the solution method or arrive at different answers. One of the assignments at the problem solving level was to program the robot to move in a labyrinth and blow up a balloon at its end, as illustrated in Figure 2.

![Figure 2: An example of a problem-solving task – a robot moves in a labyrinth and blows up a balloon at its end](image)

In coping with the labyrinth task, the students had to deal with a number of design and problem-solving issues, for example: choosing the shape and size of the labyrinth; deciding whether the labyrinth will be a real construction or just lines marked on the floor; choosing whether the robot’s movement will be based on calculations of distances or using sensors; and determining how to make the robot turn exactly $90^\circ$ at the corners. As each group of students tried different methods to solve the problem, a sort of competition was developed in the class – who will achieve the target first?

Assignments on the project level
In the P3 Task Taxonomy, a project is defined as an open-ended challenging task in which the learner takes part in selecting or defining the task. Since the course addressed in this study was relatively short and the students had no prior experience in project work, we engaged them in a short mini-project. Their task was to program a robot to draw a path or route on the floor of their choosing, for example, a geometrical shape or a letter. They could also decide whether this would be a simple, medium, or high-level project for them. The students could also start out with a simple task and move later to a more advanced one, or vice versa. The main idea was that in project work, the students take responsibility for what they want to do. Figure 3 shows examples of a simple, medium and complicated task the students chose for their project. Path c in Figure 3 is indeed more complex because the robot has to move forward and backward in at least one section, which requires turning the robot exactly $180^\circ$ at a certain point. Out of the 10 groups that prepared a final project, five defined their project as being at the simple level, three at the medium level, and two at the advanced level.
<p>| | |</p>
<table>
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<tbody>
<tr>
<td>a.</td>
<td>A simple project</td>
</tr>
<tr>
<td>b.</td>
<td>A medium-level project</td>
</tr>
<tr>
<td>c.</td>
<td>A high-level project</td>
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</tbody>
</table>

Figure 3. Examples of three project levels chosen by the students

**Findings from the final exam**
At the end of the course, the students answered a final subject matter exam that contained seven open-ended questions, each of which comprised 3-4 sub-sections, for a total of 20 items. Among them were five items of factual knowledge, nine items of procedural knowledge and six items of conceptual knowledge, as demonstrated in the following examples.

**Example of items from questions 1 and 2 in final exam (Figure 4):**

a. Prepare a table that displays the robot's distance at points A, B, C and D over time (procedural knowledge).

b. Calculate the robot's mean velocity (procedural knowledge).

c. The intensity (voltage) of the robot's motor is reduced to 50%. Add a graph that shows the robot's distance over time for the four points you choose (conceptual knowledge).

d. Calculate the robot's velocity for sections A-B, B-C and C-D (procedural knowledge).

e. Calculate the robot's mean velocity from points A to D (conceptual knowledge).
Example of items from question 3 in the final exam (Figure 5):

Figure 5 shows three robots A, B and C located in a black/white area. Each robot has two light sensors, L (Left) and R (Right).

a. What are the values obtained from the two sensors for each robot? (factual knowledge).

b. Write a logic condition that returns “True” when the two sensors detect a black color (procedural knowledge).
c. Write a program to move robot A to the black area and stop inside (there are a number of solutions; choose the one best for you) (conceptual knowledge).

The principal investigator and class teacher formulated the exam questions, and the teacher, with the help of a physics teacher in the same school, checked the students’ answers. They first checked six exams together, three of high-achieving students and three of low-achievers, to set exact criteria for scoring the students’ answers. They then checked the rest of the exams independently, compared the scores and discussed cases of gaps between the two scores. This process took place to ensure validity of the exam content and reliability of the scoring process. The girls’ scores (n=23) and the boys’ scores (n=9) on a scale of 0-100 are presented in Table 1.

### Table 1: Students’ mean scores in the final exam (scale 0-100)

<table>
<thead>
<tr>
<th>Type of questions</th>
<th>Girls (n=23)</th>
<th>Boys (n=9)</th>
</tr>
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<tbody>
<tr>
<td>Factual knowledge (5 items)</td>
<td>86.01 (SD=12.43)</td>
<td>78.74 (SD=15.13)</td>
</tr>
<tr>
<td>Procedural knowledge (9 items)</td>
<td>92.0 (SD=9.66)</td>
<td>87.37 (SD=8.51)</td>
</tr>
<tr>
<td>Conceptual knowledge (6 items)</td>
<td>79.58 (SD=16.78)</td>
<td>73.76 (SD=14.57)</td>
</tr>
<tr>
<td>Total (20 items)</td>
<td>86.67 (SD=10.06)</td>
<td>80.67 (SD=10.25)</td>
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**Findings from the interviews with the students**

Towards the end of the course, one of the researchers conducted 10 semi-structured 20-30-minute interviews with small groups of students. The researcher asked the students how they dealt with the different tasks presented to them during the course, and their motivation to learn technology and STEM, with a focus on points from the learning and motivation theories that guided this study. In addition, the students could raise aspects or points that were important to them in learning the course. A data analysis, which combined deductive and inductive approaches, was conducted in three rounds in order to identify the items, sub-categories and main categories in the students’ comments. The main categories that were identified are presented below.

1. **Cognitive domain:**
   - Learning, thinking, discussing, investigating, solving problems, developing ideas, designing, asking questions, understanding mathematics, science and technology.

2. **Affective domain:**
   - 2.1 **Personal** – interest, curiosity, creativity, benefit, self-efficacy
   - 2.2 **Social** – teamwork, collaboration, engaging parents and family
   - 2.3 **Attitude towards technology** – innovation, instrumentation, importance for daily life, future aspirations

The following section presents some examples from students’ comments in the interviews in two categories in the cognitive domain: implications of the course on learning, thinking and problem solving; and understanding mathematics, science and technology.

**Learning, thinking and problem solving**

Since the robotics course was a substantial change from the routine learning method in school, many students related to this aspect, as seen in the following examples:

“Robotics is a very interesting subject because it helps us think… We do not get things ready in advance; we think a little, do the next stages to program the robot to make it complete the task, and this helps us think…”
“When you (the teacher) explain something verbally, we understand it slowly, but when we see it in practice, we understand quickly…”

“Robotics is very interesting because when we work with a robot we become curious as to how to program it to make it move along a certain path.”

“At first, you are unable to solve a problem, for example, how to change (the robot’s) directions… this requires serious thinking to find the solution… this is not easy but also not too difficult.”

**Understanding mathematics, science and technology**

In the interviews and open discussions held with the students, they had many comments on the contribution of robotics activities to understanding basic concepts in mathematics, science and technology. For example:

“I loved the experiment measuring the distance a robot moves on the floor at different velocities and taking measurements.”

“We turn the robot’s wheels and the LED on the robot lights up… electric energy is generated” (conversion of mechanical energy to electrical energy).

“The subject (robotics) includes knowledge of physics, such as formulas and how to use them.”

“Knowledge of physics helps a great deal; it shows us how to use formulas through the activity… I understood what I got when I used the formulas.”

“It helped me understand the subject we learned in mathematics… to know how to make a robot turn at 90° or another angle.”

“I like to know how things work, for example, how a car travels… sometimes I cannot understand from explanations because this has to do with mathematics and physics, but through the activities and experiments in class, I can understand better.”

**Conclusions**

The objective of this research was to investigate the effectiveness of a robotics workshop aimed at teaching students specific concepts and skills related to STEM, developing students’ broad learning competences such as engineering design, problem solving and creative thinking, and fostering students’ motivation and self-efficacy beliefs about learning STEM. Among the major factors that contributed to achieving these goals were engaging the students in a rich and challenging robotics learning environment, and the design of the students’ assignments according to the P3 Task Taxonomy comprised of Practice (exercises), Problem solving and Projects. The findings indicated that the students were satisfied with dealing with mathematics and physics in the robotics course, for example, the first closed-ended task (“Practice”) of making systematic measurements, presenting the findings in a table and on a graph, and analyzing the findings. This was the learners’ useful preparation to cope with higher-level tasks of problem solving and a mini-project.

**References**


Child Imagination, a Talent Worth Keeping: How Children Learned to Stream Their Playfulness into Their Adult Roles

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Abstract

This paper examines a partnership between adult designers and ten-year-old children working together on a future orientated design brief. The brief was assigned to them by an imaginary ‘Future Design Board’ (FDB) and involved the several teams (two children one adult each) in developing future objects, exchanging letters with the fictional characters of the board, and coming together to discuss each other’s outcomes. The study is part of the author’s PhD thesis, which explored the consequences of losing the childhood expertise with the onset of adulthood and highlighted the lack of examples where design is recognized as a valuable everyday process for all.

In particular, this paper discusses how the process facilitated children to acquire capabilities and stream their playfulness into their adult roles as everyday designers, researchers and story-makers. The analysis involves a review on how the children participants recognized that they have a special talent to share with the adult world that must be retained. At the same time, it reviews the ways in which they became conscious of exactly how their child expertise could be injected into design and research. This is followed by an analysis of the cycles between self-esteem and developing capabilities while collaborating with others. The discussion then delves deeper into how the children participants explored the ethics of public opinion and learned how to infuse their beliefs into their creations. As part of this process play and design allowed children to test ideas and ideals, explore the limits of the designer’s power and comment on highly philosophical issues such as ethics of punishment, freedom of choice and the elusive idea of perfection. The paper involves a critical discussion on how the entire process allowed for the evolution of “whole children” and hopefully, in the future, creative whole adults.

Keywords: story-making, design, adult, child, collaboration, agency, skills, play, imagination
Introduction
This paper examines a partnership between adult designers and ten-year-old children working together on a future orientated design brief. The workshop took part in early 2011 and its theoretical grounding and process was presented in the Patt conference the same year (Antonopoulou, 2011). This paper focuses on the children’s learning and discusses how the process facilitated them to recognize that their playfulness is a special talent that must be retained in adulthood. The paper also discusses the sets of capabilities that children gained in order to be able to stream their playfulness into their adult roles as everyday designers, researchers and story-makers.

Activity outline
The three-day activity was based on the fictional scenario of a “Future Design Board” (FDB) who was asking for the children’s help in designing objects for the future. At the same time, I introduced myself to them as a researcher from Goldsmiths who was also asking for their research expertise and that together with the other adults wished to learn from them.

The workshop started with a warm-up activity requesting to imagine the designers of the future and use material to model their accessories. Each team then presented their creations dressed up as future designers, answered questions and talked about how they envisage design and design responsibility (See Figure 1).

During the main activity, the teams had to design the future objects that the Future Design Board had requested. In order to do this, they used a tool I had developed called the “story-making tool for design”. Using the tool, the teams imagined their object as a living character, created illustrated stories about their life and later on, they drew annotated diagrams explaining the functions of their objects. All the materials produced were then “posted” (including imagining the board’s full postal address) to the imaginary “Future Design Board” for critical feedback. This critical feedback consisted of letters from the “Future Design Board” that posed questions about each team’s creations. The communication with the FDB was taking place through personified pda devices, personified Dictaphones and finger characters that the children had drawn in their fingers (See Figure 2). But at the same time the teams knew that they are in the role of a researcher and they collect this material for my research.

Figure 1. Making and presenting the Future accessories, discussing design future and responsibility

Figure 2. Data collection: A conversation between their finger personas and the ‘little computer’ (personified pda service. Communicating with the FDB and collecting data for the research
Using the “story-making tool for design” to come up with personified objects, their illustrated life stories and diagrams of their functions. Imagining the FDB’S address and posting it to them.

We are all fascinated by your splendid story about the crazy robot. We are also amazed by your amazing skills when you made it. We are also very impressed by how you would imagine so though we would also like to see some of the illustrated story about the robot’s life speaking from the robot’s point of view.

1. Why might this robot become a bad design (something that can be used for a bad purpose) and how would you ensure that this won’t happen? Why?... we want to make amends.

2. Why is he having a spy? Don’t you think that this might here people or put him in trouble if he was n’t some people telling what he can become again and see the poor.

Receiving letters from the FDB replying, presenting their proposals and replies and having debates.

Taking into consideration the FDB feedback and the group discussions they create the final stories of their objects and model them.

Presenting their final proposals and receiving the future designer’s certificates.
The teams received and answered the FDB letters in the beginning of the second day. Subsequently, they presented their answers together with their proposals to the other workshop participants who once more challenged the teams with questions (See Figure 4). Seeking explanation from the teams about their design-object features and their ethical – social dimensions pushed the children to add specific functions and features on the spot and shifted the fiction-making towards design conversations including functionality, design identity, critical design concerns and the idea that fictional play can be not merely a method to come up with products but also a medium through which to discuss issues around creation and responsibility as an everyday practice. From here, the teams went on to update the life stories of their objects and create their final design proposals. The children were thus moving slightly towards the pragmatism however, these “factual” elements always remained only a subset of the overarching fiction (See Figure 7). On the last day of the workshops, the teams were set the task of creating models of their personified objects.

Simultaneously my finger persona took interviews from each child’s finger persona. The answers were videoed from the “little computers” who communicated them to the “Future Design Board”. At the end of the day, each team presented their creations and every participant was awarded a “future designer” certificate (See Figures 5 & 6).

Figure 7. the interactions between play and design during the three days of child-adult partnership.

The cycles between confidence, skills and agency

One important outcome of the way in which the design workshops for this study were delivered, was that the children realized they have special expertise that has to be retained in adulthood. At the same time, the fact that they were told that the adult participants, the imaginary “Future Design Board” and the entire “serious” adult university research were dedicated to learning from their “child world” processes seemed to affirm their sense of self-worth and enthused their confidence to have faith in the value of their child expertise. While Heathcote’s “mantle of the expert” concept focuses on the development of the child into an expert (Heathcote and Bolton, 2010, p.36), this case study turns this idea on its head starting with the assumption that children are the experts and adults are the learners. Identifying children as experts not only encourages them to see themselves in this light but also encourages them to develop expertise in other domains.
Children recognized themselves in the role of the researcher and were given an understanding of what research is. For example, Lionee felt, that she was a researcher because as she said they asked “people what they wanted” and she pointed out the importance of interviewing and asking many questions so that you gain a valid insight. “You need to know properly, because if someone says something small you have to understand properly” she said.

Additionally, the children gained agency and skills as designers, were able to articulate what design is for them, and experienced how design interlinks with their playful imagination; for example, while designing their objects, the cardboard and the cracks in the tin foil, appeared alive and whispered to them what the object would be. Linking their make-believe with an activity framed as Design, children were able to “realize something of their inherent design intelligence” (Baynes, 1994). Matt said with enthusiasm that he liked “being a designer because you can make everything in the world”. In this sense, the hands-on experience developed what Bruce calls a “sense of control”, which, “impinges upon self-esteem, self-confidence, autonomy, intrinsic motivation, the desire to have a go, to take risks and to solve problems, and the ability to make decisions and to choose” (1991, pp.82-83). Stephen, not only reflected on his design agency, but was also eager to disseminate its importance, saying that their story was intended to teach “that children can make things as well as adults.”

The collaboration established encouraged a dialogical approach non-typical of the traditional school environment, that operated through informal chatting, tinkering, fiddling and teaching each other, in an environment of “genuine care and respect” (Fitizsimmons et al., 2009). Everyone considered important that they have learned to work with others and felt happy with their teams. Deeper collaboration with imaginary characters allowed for dialogue and critique in the “Future Design Board” case study. For example, Zahret, Stephen and William not only collaborated with one another but also collaborated with the robot they were creating. The robot presented to them “secret” or “magical” feedback, that provided the team with further material to reflect and act upon in the development of him as their design object.

Through this collective approach, each participant recognized that they and everyone else held a “unique point of view” (Edwards et al., 1998, p.94), that their ideas were both similar to and different from those of others but all equally “respected for their uniqueness” (Fitizsimmons et al., 2009). This, in turn, contributed to a sense of freedom and safety in expressing oneself and helped the children (as the well the adults) to continue to freely explore, generate and give voice to new ideas. With the raised status of “expert” and increased sense of self-worth, collaboration with adults enabled the development of new capabilities to emerge. The children began to apply their child expertise to design thinking, to become continually reflective about their learning. At the same time, their sense of responsibility within a broader social
system became evident: that being a designer not only involves realizing one’s own creative ideas but also has social implications and consequences.

**Developing responsibility and linking the child-expertise with the everyday roles as designers, researchers, and storytellers**

Thinking and speaking with their hands wallowing in free flow making and moving in-between fiction and reality dialogues developed children’s ideas and values, and brought about ethical considerations about themselves and the world. The design-research context of the activities helped the children understand that creation “is lodged with sets of ideological values” (Fry, 2011, p.6) and that every form of power comes with responsibility. This promoted further reflection on the implications of children’s ideas that brought about ethical considerations about the “rightness” and the ethics of design’s omnipotent power.

At the start of our discussions about the responsibility of being a citizen-designer-creator-researcher I asked participants to consider what makes a “good” or a “bad” design. Initial responses related to functionality, that is, how far an object performed the task it is designed for, and whether it was "something people use a lot".

However, it soon emerged from the discussion that the terms “good” and “bad” have complex meanings. Ideas about design responsibility re-emerged in relation to the participants’ own designs later during the warm-up activity presentations, and on the second day while the groups presented their answers to the “Future Design Board”. Ideas about responsibility were also addressed on the third day when working on the final versions of their designs and revisited once again in the participants’ interviews with me at the end of the workshops.

Thinking about design responsibility children suggested ways of ensuring responsible use by limiting access to their design objects to trustworthy users. For example, in order to use the Universal Transportation Marble (UTM) that is a device that can transport infinite stuff, you have to be a member without criminal convictions. Other children tried to censor misuse, for example the robot who makes your wishes come true would shut down automatically when it detects bad intention.

Recognizing the human tendency to misuse objects regardless of warnings or risks, all the groups imposed limitations on the use of their designs through thinking of punishing functions for those who would misuse them. This raised extended philosophical dialogue, with revelations amongst the children about the subjectivity of punishment. From here, more fantastical, extreme ideas were suggested, such as submitting the user to “abject” experiences (“it puts a sheep or a dog to do its business on top of this person’s head). Finally, the participants agreed that punishment needed to vary according to individual perceptions of what would be an unpleasant experience. In the case of “cookie biscuit” design, for instance, one participant suggested: “When sensing bad intention, it will give you something that you absolutely hate”.

Furthermore, they also recognized the godly power to see all actions and meet out punishments, and with this, they played out scenarios that pushed the moral boundaries of the adult world. The children who created the robot, for instance, suggested that he had the power to electrocute those who inflicted harm, although in response to moral objections, they “agreed” to reduce the robot’s punishment from permanent to temporary paralysis.
De-commodifying and redefining design

Despite the improbability of the designs, the process was a microcosm of real world design interactions. Within this design structure, children – via their personified objects – expressed their real views as researchers-designers undertaking tasks in “now” time.

Paradoxically, while the Future Design Board studies involved designing products, improving on existing ones, creating brands and deciding where they would be sold, the children moved towards the principle of de-commodification. While they initially focused on the functional aspects of their objects from a consumer’s point of view, in response to the letters they received from the “Future Design Board” and also through their discussions with other participants, their understanding of the value of design became something broader.

By considering design responsibility and its relationship to individual and collective wellbeing, they came to view “good” design as intimately linked to a view of the world in which happiness is not to be measured through the possession of goods but in terms of fulfilment through friendship and fun. They found themselves exploring and testing out personal values and attitudes, and in doing so recognized the power of designing as a self-discovery tool with the power to address socio-psychological issues such as greed, loneliness, tolerance and happiness. One of the many examples of this shift in understanding was the children’s adaptation of the “biscuit cookie” from an object that fulfilled material wishes and desires to a living object-companion that tackled loneliness.

Respecting the human choice

Children re-evaluated their ideas and did not allow them to forcefully or magically change someone’s action intentions, even if that would be illegal ones. They only allowed their living objects to be able to give advice; but at the same time considering that advice is not value free either, they did not design their objects with pre-set mechanical conscience but with the ability to mirror the individual’s conscience and highlight moral dilemmas. As children pointed out, the individual should then decide freely and take responsibility for his actions; succeeding and failing are equally important as opportunities to learn through experience.
On perfection
Replying to Future Design Board’s questions, children collectively decided that since there is not a single design to guarantee a utopian perfect world for everyone, “universal” perfection is not possible. In this sense, according to the children constant perfection is phony and unwanted as life is boring without dramas going on. The children liked this world, as it is, real with its scars and dirt, sometimes naughty, as they are themselves, a place where bad and the good, success and failure co-exist and are appreciated without the need to be repaired in the name of being perfect.
Being truthful to their ideas, children intentionally allowed for imperfection in their designs. For example, the robot who was judging and paralyzed the deviants is not perfect himself; sometimes, even if it is rarely, it swears becoming a bad design”.
Therefore, the robot’s society of disabled deviants that are at some point forgiven is a good analogy for the perfect society that the children propose; a place where constant “perfection” does not exist and all it matters is the journey towards the perfect moments. As Peter said what makes life worth living is “the fighting in between the reward”.

The children’s interactions and instant fictions resulted in what Adams calls “new alliances and forms of action” (2014, p.184). In the process of becoming critical designers, researchers and storytellers in their everyday lives, the children participants learned to co-exist, and communicate with others on multiple levels. The process that the children went through was a unifying mechanism that developed the “whole child”; a child that according to Froebel (1887) has all his/her intellectual, social and emotional aspects developed.

![Diagram of children being recognised for their expertise](image)

Figure 9. Overview of the cycles of gaining skills and confidence with gaining voice, agency and developing themselves responsible, critical and socially competent human beings

Conclusion

The responses to questions posed by the “Future Design Board” at the end of each workshop day, together with the comments gathered later from interviews with the children clearly demonstrated that the children had begun to acknowledge the value of their creative expertise, that their playfulness had an essential function in the
framing of concerns relating to the power, values and social responsibility of the designer. Children experienced exactly how their playful capacity to handle fantasy and reality at the same time can be applicable in their lives as critical young people and future adults. In particular, how enjoying themselves, experimenting without fear, reflecting on their actions, being capable of relating their values to their creation and considering its inherent power and responsibility can be applied in their adult lives as aware citizen designers, researchers and story-makers. They also realized how the agency as designers and researchers deeply relates to life principles such as freedom of choice, subjectivity of perfection, equality and collaboration. In particular, they suggested that the right and capability to be citizen researchers, designers and story-makers of our lives equates with the basic freedom acts. This is the foundation to create empathetic relationships based on respect for divergence. The “death and rebirth” of adult design expertise had created joyful activists, confident independent capable creators - problem solvers and purposeful, aware, self-motivated people.

Of course, we cannot argue that this three-day experience will enable the children to embrace play in their later adult lives but it is hoped that some bits of this experience will stay with them; that they would feel encouraged to engage in the quest for new knowledge in their later adult and be confident to take responsibility for who they are and what they create. It is hoped there will be moments where they will be bold enough, like they were as children, to suspend their reality, live in parallel worlds, bounce their idealistic magic fictions off each other, continue to be ambitious, and to reinvent themselves and the given world around them.

References

A Proposed Research Agenda for Investigating the Nature of Designerly Thinking in Action

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Abstract

The intent of this paper is to discuss the nature of Design and Technology (D&T) education and arising from that the potential contribution of cognitive psychology to further understanding of designerly thinking in action. D&T education is discussed in relation to its purpose and necessity as a discipline in education. A discussion pertaining to how D&T education develops technological capability in students highlights the need for a greater understanding of the nature of designerly thinking. This obligates the discussion for the potential of cognitive psychology to inform the investigation of designerly thinking and its utility in uncovering the nature of the cognitive processes of individuals.

The discipline of cognitive psychology is discussed with relevance to investigating designerly thinking in D&T education. The importance of ecological validity in study design is highlighted regarding cognitive psychology which highlights the difficulties which may be encountered in the application of cognitive psychology methodologies to the investigation of designerly thinking. Taking cognisance of these initial discussions, the warranty for a synthesis of the current body of knowledge surrounding the nature of designerly thinking in D&T education with an approach informed by cognitive psychology is proposed.

Keywords: Design Education, Designerly Thinking, Modelling, Cognitive Psychology

Introduction

Design and Technology (D&T) education aims to develop students’ competencies to effect change on the world (Roberts, 2013). The dualistic synergy potentiated by affording students the opportunity to cognitively and externally model when engaging in design tasks has long been identified (Kelly, Kimbell, Patterson, Saxton, & Stables, 1987; Kimbell & Stables, 2007; Roberts, Archer, & Baynes, 1992; Seery, 2013). D&T education fosters this synergy through tasks which promote the internal development of ideas with simultaneous external realisation. This sees D&T education as prioritising the development of the visionary and revisionary capacities of students as they engage in designerly thinking in response to a design task. Although recognised as integral to D&T education realising its aims, how designerly thinking is enacted requires further investigation (K. Baynes, E. Norman, & K. Stables, 2010). It is posited that investigating designerly thinking with consideration of the potential contribution of cognitive psychology is warranted. This paper proposes:

- the need for a research agenda to further our understanding of designerly thinking,
- the potential contribution of cognitive psychology in achieving this agenda, and,
- the importance of appropriately synthesising these disciplines.

Design and Technology Education

Humans have transcended the evolutionary dependencies of other species for development to fill what has been theorised as the cognitive niche (Tooby & DeVore, 1987). This theory proposes
that humans’ dominance in any ecosystem they inhabit is due to their unique ability to wilfully adapt to meet the needs of their environment in contrast to other species that have adapted through the process of evolution. Pinker (2010) describes the theory of the cognitive niche as being a useful explanation for three uniquely advanced but common traits of humans. These hyper developed traits include technological know-how, cooperation among nonkin and grammatical language. Technological know-how describes how we have and still “use and depend upon many kinds of tools, which involve multiple parts and complicated methods of fabrication” (Pinker, 2010, p. 8994). Without the acquisition of technological know-how surrounding the use and development of tools humans would be bound by their inherent physical capacities.

Technological know-how allows humans to augment their capacities to not only thrive within their environment but also to manipulate it to meet their identified needs. The recognition of technological know-how as a critical contribution to the emergence of a dominant humanity is pertinent to the aims of D&T as “the importance of design education has been fuelled by greater understanding of the propensity for humans to think and act in designerly ways” (Stables, 2008, p. 8). D&T education’s inclusion as a discipline in curricula is justified by its anomalous means of fostering students’ capability to effectuate purposeful change in the made world (Kimbell & Stables, 2007; Roberts, 2013). D&T education clearly aims to develop the trait of technological know-how with contemporary relevance. Educating students to be capable of identifying the need for change, appropriately conceptualising the means to meet that need, and then causing that change to happen in the made world has and still is acknowledged as critical to growth and prosperity of society whilst improving quality of life (European Design Leadership Board, 2012).

Advocating for the conceptualisation of purposeful change and its subsequent realisation establishes a complimentary dichotomy that “involves the active, purposeful deployment of understandings and skills – not just their passive demonstration” (Kimbell & Perry, 2001, p. 9). This highlights the synergy of simultaneously nurturing design and technological capability. Gibson (2008) posits the appropriate development of technological capability as cultivating students’ skills, values and problem solving abilities encompassed by appropriate conceptual knowledge. The recognition of values as being central to capability concurs with the cultivation of the hyper developed trait of technological know-how to extend the capacities of humans as “the concept of improvement is essentially value-laden” (Kimbell & Perry, 2001, p. 5).

It is essential that visionary and revisionary capacities are developed through D&T so that the appropriate and necessary change is identified at the initiation of and throughout the enactment of design and technological capability. Schön (1983) outlines the reflective nature of designing as when engaging in design activity the individual is constantly engaged in a reflective dialogue with their solutions. D&T education’s potential to develop students’ capacity for employing a contemporary technological know-how is evident and manifests itself in the development of students’ design and technological capability.

To fulfil its pragmatic aims D&T education is enacted through ‘task-centred, goal-directed activity’ (Kimbell, 1994). These tasks can vary in the level of autonomy they grant the student; closed tasks may seek to explicitly develop procedural skills and open tasks cultivate the students’ design
and technological capability having acquired the procedural knowledge pertinent to engaging in the prescribed task (Kimbell, 1994). Roberts et al. (1992) highlight the necessity of ‘modelling’ during designerly activity that “is chiefly concerned with ‘ill-defined problems’” (p. 3). Seery (2017) describes the act of modelling as “a natural behaviour designed to support human enquiry into the unfamiliar” (p. 261), affording the representation of envisioned change and results in the construction of physical and/or cognitive models reflecting the proposed change (Roberts et al., 1992).

Designerly activity in tasks in D&T education is mediated through the act of modelling both inside and outside the head. Modelling inside the head may involve the cognitive conceptualisation and development of an idea or mental model whereas modelling outside the head involves the use of the individual's external environment to externally model concepts for development in the form of discussions, sketches and physical models etc. Kelly et al. (1987) illustrate the dichotomy of cognitive and external activity fostered during design tasks which demonstrates the synergistic result of this iterative relationship (Figure 1). Throughout designerly activity students engage in progressive visionary speculation of ‘what could be’ informed by their revisionary critique of ‘what is’. This activity is at the core of developing design and technological capability in students. The benefit of affording a dialogue between the internal and the external is clearly communicated in the pertinent literature and the relevance of this in educating a student capable of implementing their conceived change is evident. What is not evidenced is the cognitive processes which underpin the enactment of designerly thinking as observed by Kelly et al. (1987) (Figure 1).

Figure 1: APU model of the nature of activity in design tasks (Kelly et al. 1987)

As a result of this Stables (2010) highlights the need for a better understanding “of how humans enact designerly thinking” (Ken Baynes, Eddie Norman, & Kay Stables, 2010, p. 8). It is posited that a greater understanding of the interplay between internal and external engagement in designing activity from a cognitive point of view is necessary. Why does the appropriate synthesis of thinking and doing result in the observed activity? How can this be examined empirically? It is
suggested that methodologies developed in cognitive psychology are of relevance in the context of investigating the nature of designerly thinking.

**Cognitive Psychology**

Cognitive psychology aims to understand human cognition and behaviour with the ultimate goal to “help people use cognition in real-life situations” (Sternberg & Sternberg, 2009, p. 23). To develop an understanding of cognition and behaviour cognitive psychologists predominantly employ rigorously controlled experiments in an experimental laboratory setting. A broad view of this process sees the participants' behaviour as an indicative result of their cognitive processes having perceived and interacted with certain stimuli. This approach has proven to be effective in shedding light on the way individuals think and behave. Roediger and Pyc (2012) highlight the benefits of applying cognitive psychology to educational practice due to its capacity to provide empirical evidence of techniques which optimise learning. The cases presented by Roediger and Pyc (2012) show the potential for cognitive psychology to assist in providing empirical evidence for the evidence-based practice advocated for in contemporary educational practice discourse (Slavin, 2002). It is evident that findings in cognitive psychology can function as a useful point of reference to inform practice but methodologies in cognitive psychology can provide just as rich a source to inform the investigation of cognition and behaviour in an educational context.

The approach taken in cognitive psychology to investigate cognition and behaviour has been criticised as lacking ecological validity as applying the results ascertained from an experimental laboratory setting to real life situations is a problematic juncture. Kingstone, Smilek, and Eastwood (2008) put forward the argument that the type of laboratory testing described above is problematic in finding real life applicable discoveries as the control and invariance in the experimental procedure may provide results which only arise in such a situation. Kingstone et al. (2008) propose a ‘cognitive ethology approach’ whereby hypotheses are developed based on the initial observation of real world situations and the subsequent laboratory experiments are designed with cognisance of those observations. It is suggested that such an approach of deriving the development of study design based on real life situations potentiates the heightening of their ecological validity. This movement towards more applicable findings acknowledges the possible situational effects on cognition.

The importance of viewing cognition as a situated process has recently gained significant recognition (Robbins & Aydede, 2009). The concept of situated cognition considers the effects the context of cognitive processes has on the nature of those processes. Robbins and Aydede (2009) select three theses as being particularly central to the concept of situated cognition, namely, cognition as embodied, embedded and extended. The concept of embodied cognition highlights the influence of the brain being situated in the body has on cognitive processes. An appropriate articulation of this happens when an individual engages physically with their task environment through their body. The concept of embedded cognition describes the way an individual can cognitively work within their environment. One explanation of this concept is the way individuals cognitively off-load onto their environment through “epistemic action” (Kirsh & Maglio, 1994). Gedeneryd’s (1998) view of cognition as extended subscribes to the situated view of cognition in contrast to the view of cognition as “intramental” (p. 12) (Figure 2). This proposes a view of cognition as transcending the boundaries of the brain to exist as embodied in action and
embedded in the environment. A situated view of cognition requires these to be considered in the cognitive processes of the individual from the outset of study design.

Figure 2: Gedenryd’s (1998) juxtaposition of views of cognition as intramental and extended

Synthesis of Designerly Thinking Research and Cognitive Psychology
There has recently been emphasis placed on the value of research which simultaneously contributes to theoretical understanding and pragmatic use (Smith, Schmidt, Edelen-Smith, & Cook, 2013). Error! Reference source not found. illustrates the model Stokes (1997) created as a means to position research in reference to its intent on furthering understanding and its consideration of practical application. This quadrant model gives exemplars of pure basic research as concurring to that carried out by Niels Bohr in his quest to understand atomic structure without practical implications of such an advancement. This is contrasted with the pure applied research carried out by Thomas Edison when discovering means of commercialising electrical lighting without the preoccupation of advancing understanding. Research which advances understanding and considers its potential to have pragmatic significance is the result of a commensurate synthesis of pure applied and pure basic research. This quadrant is labelled Pasteur’s quadrant due to his work in developing understanding of diseases to inform the development of vaccines to tackle them. Research aimed at advancing the understanding of a phenomenon such as designerly thinking in the context of the practically enacted discipline of D&T education must position itself in Pasteur’s quadrant to ensure practical consideration.

<table>
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<tr>
<th>Quest for fundamental understanding?</th>
<th>Considerations of Use?</th>
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<tr>
<td>Yes</td>
<td>Pure Basic Research (Bohr)</td>
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<tr>
<td>No</td>
<td>Pure applied research (Edison)</td>
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Table 1: Quadrant Model of Scientific Research (Stokes, 1997)
Cash and Culley (2015) posit that the consideration of other disciplines in design research is beneficial to “the development of greater scientific rigour and the improvement of experimental methods and methodology” (p. 186). Implementing this proposal would enhance the means of developing a theoretical understanding which would complement the pragmatic considerations of “practice-based research that is common in design” (Wensveen & Matthews, 2015, p. 263). To approach the investigation of designerly thinking from a cognitive perspective it is therefore critical to consider the potential contribution of cognitive psychology. The appropriate synthesis of these disciplines is proposed to promote a use-inspired basic research approach to the proposed agenda.

Cash and Culley (2015) allude to the difficulty in executing such a multi-disciplinary synthesis, evidenced by Ball and Ormerod (2000) in reference to the appropriate yet ineffective employment of ethnography in the analysis of engineering design. Providing an example for what Ranulph (2015) describes as “the sometimes uncomfortable marriages of design and research” (p. 9). Coupling these concerns with those raised regarding the appropriateness of laboratory experiments used in cognitive psychology highlights the intricacy of such a synthesis.

As discussed previously, it is imperative that cognitive psychology research is cognisant of the importance of ecological validity. The cognitive ethology approach proposed by Kingstone et al. (2008) highlights how the current body of research into the nature of designerly thinking can inform the effective development of studies which aspire to provide a cognitive perspective. This consideration is posited to aid in the appropriate synthesis of research into designerly thinking with methodologies developed in cognitive psychology. Christensen and Ball (2015) emphasise the heightened ecological validity attained when design cognition is investigated based on observed practices. Within the context of D&T education there is a wealth of research into the nature of designerly thinking which will prove invaluable in informing the research implemented based on the discipline of cognitive psychology.

The acknowledgement of the possible difficulties presented by the proposed application of principles from cognitive psychology highlights some key considerations. One consideration is the need for an ecologically valid study which can uncover the real life means by which designerly thinking is enacted. Another consideration is the utility of the concept of ecological validity in relation to the effectiveness of use-inspired basic research. Use-inspired basic research aims to combine the quest for greater theoretical understanding with a practical use although it is necessary to note that research positioned within Pasteur’s quadrant does not necessarily automatically rate highly in terms of ecological validity because of that trait alone. Research positioned in Pasteur’s quadrant, in the context of the investigation of designerly thinking must ensure that the conditions it is carried out under are conducive to those in which designerly thinking is naturally enacted to further strengthen the applicability of its findings to practice.

**Conclusion**

Subsequently, discussion surrounding the proposed synthesis above substantiates the appropriateness of considering designerly thinking as a situated activity. The role of modelling cognitively and physically during design tasks and the consequential progression through the process of designing this grants has been clearly outlined. The embodiment and embedded
theories of cognition have clear relevance to the enactment of design thinking during design tasks in D&T education as modelling can occur cognitively and physically throughout this process. Models created during the design process such as discussions, sketches or physical models can be viewed as the outcome of the student’s embodied and embedded cognitive interactions with their environment and through their bodies with their environment. The recognition of these theses as being particularly appropriate to the discourse surrounding designerly thinking is can serve to inform the design and analysis of research studies tasked with investigating designerly thinking in D&T education. The view of D&T education as being guided by task-centred activity must not be lost in the synthesis argued for here. The necessity of a research agenda which is; ecologically valid, informed by relevant disciplines, and, use-inspired has been identified.

References


Abstract

School education systems in Australia are very local varying between the six states and two mainland territories. Each State and Territory government runs education at this level. Australia now has (for the first time) a new National Curriculum in which Design and Technology runs from K to year 10. This paper examines the perceptions of Design and Technology of pre-service teachers in this area in Western Australia (WA). The data was gathered at Edith Cowan University in Perth, the only university to train Design and Technology teachers in WA. The number of students studying Design and Technology (D&T) education at Edith Cowan University (ECU) in WA has fallen over the past few years. This is despite an increasing shortfall in the workplace leading to many graduate job opportunities. In addition primary teachers are now expected to teach design and technology in their classes and the researchers wondered how much preparation they receive in their training. In the context of these problems the researchers set out to examine the perceptions of existing ECU School of Education students towards D&T to determine if preconceived views relating to the area of D&T were discouraging study in the area. Two online surveys were developed and delivered via the Qualtrics (Qualtrics, Provo, UT) commercial survey engine. Amongst the findings is a clear indication that before entering university many students’ views towards design and technology are biased and stereotyped based upon school experiences. In particular the perception is that, while seen as creative, design and technology is about men making things. For those training to be primary teachers, just over half of respondents felt comfortable teaching D&T while most had either no formal training in D&T, or half an online unit during their course. This paper discusses these findings and their implications.

Keywords: Teacher education, student perceptions, online surveys, design and technology (D&T).
Introduction

This paper reports upon a small research project carried out in the School of Education at Edith Cowan University (ECU) in Perth Western Australia (WA), that sought to examine the perceptions of existing Edith Cowan School of Education primary and secondary pre-service teachers towards the subject of Design and Technology (D&T) to determine the nature of any preconceived views relating to the area of D&T and, for primary pre-service teachers, how well their course has prepared them to teach D&T.

Perth (pop 2.1m) is located on the western seaboard of Australia and is the second most isolated capital city in the world after Hawaii. It is the capital of Western Australia (pop 2.6m) the largest of Australia’s states and very sparsely populated (see figure 1). Perth is home to 5 universities. Education in Australia at primary and secondary levels is run and funded by the various State governments, and thus there were as many systems and curricula as there are States. This however is undergoing change as States adapt and adopt the new national curriculum called the Australian Curriculum.

![Figure 1. Australia state boundaries and population spread](image)

Edith Cowan University (ECU), situated in the metropolitan area of Perth Western Australia, is a large university with approximately 29,000 students, 17,546 of whom are female. These students are spread over three campuses. Historically, ECU has its foundations in teacher education and training and its School of Education is the largest in Western Australia, with 5617 students and 104 academic staff (ECU, 2016).

Currently Australia is at a point of change as a new national curriculum is being rolled out across the nation. Previously confined to lower secondary school (8-10), Design and Technologies (D&T) will now cover the years K to 10. This is combined with the positioning of home economics and the existing design and technology subjects under the one area of design and technologies. It is in this context that the current research was undertaken.

In this paper the authors will describe the setting and method for gathering the data, followed by a discussion of selected findings. The paper will conclude with the implications for ECU.
Technology education
The major aim of design and technology curricula requires students to fully understand the nature of technology. In order to achieve this aim, it is expected that teachers should be the first ones to understand technology and technology education. Moreover, it has been indicated that teachers’ perceptions of the nature of technology may affect their perceptions of technology education and their way of teaching this subject (Forret, Edwards, Lockley, & Nguyen, 2013). Therefore, it is necessary to investigate teachers’ perceptions and understanding of D&T.

Research has found that many teachers had little understanding of D&T because they had been given little support (Office for Standards in Education, Children's Services and Skills [Ofsted], 1995). Similar results have been concluded from other research, which also indicated teachers’ limited understanding of design and technology (Jarvis & Rennie, 1996; Jones, 1997; Jones & Carr, 1992). In the same way as teachers, school students were also found to have narrow views of design and technology (Rennie, 1987; Rennie & Jarvis, 1995a, b), which suggested that teachers’ perceptions of D&T would affect their students. Furthermore, McRobbie, Ginnns and Stein (2000) found that few teachers had the knowledge to make plans and engage students in a design-process, which resulted in the failure to achieve a major aim of design and technology education.

According to Benson (2013), innovation and authenticity were excluded when teachers were asked to indicate six words or phrases that best describe the nature of D&T, which indicated that teachers did not appreciate core concepts of D&T. Forret et al. (2013) also pointed out the importance of understanding the nature of technology and technology education. From their research, pre-service teachers had a narrow view of technology and technology education before entering university.

Also because of the nature of D&T, teachers are required to use varying pedagogies and often have inadequate knowledge and experience of combining technology with the traditional subjects they teach (Ankiewicz, 2003). This problem can be solved by conducting more professional teacher training to equip teachers with the necessary knowledge and skills (Engelbrecht, Ankiewicz, & Swardt, 2007).

While teaching design and technology is new in primary and early childhood levels, Design and Technology in secondary education in Western Australia is also in a time of flux, with the introduction of the Australian Curriculum that is currently being implemented. Figure 2 shows the change of emphasis from technologies (product and processes) to design, and this tension between practical and theoretical has been an ongoing tension throughout the history of D&T curricula (Williams, 1996). This is combined with the positioning of the subjects of computing, home economics and design and technology under the one area of technologies. This change will lead to a number of existing teachers being uncomfortable as they have never received training in design and also make the teaching of the subject attractive to a different range of potential tertiary students. Changes implemented to encompass design over the past two years in the ECU D&T course have led to resistance from some of the more purely practical of our students, showing how great a paradigm shift this emphasis is for some teachers and potential teachers. Traditionally with previous curricula there has been perhaps a change the name but not what we teach approach to new curricula in the area.
In the light of this the researchers set out to investigate the following questions:
- What are the perceptions of existing ECU School of Education students towards D&T?
- Do preconceived views of the area of D&T held by ECU pre-service teachers discourage further study in the area?

**Method and participants**
The investigation was undertaken via an online survey developed and delivered via the Qualtrics survey engine. Two versions of the survey were developed one aimed at those studying to be secondary teachers of any specialisation and one aimed at those studying to be primary and early childhood teachers who under the Australian curriculum will now have to teach D&T. The two surveys allowed tailoring to answer particular questions relevant to each group while a common set (examined here) allowed overall conclusions to be drawn.

Education students were informed of the survey via a link placed on the ECU Blackboard Learning management system. Figure 3 shows a screen captured from the survey and illustrates how it was designed with an uncluttered layout and utilised radio buttons to facilitate accurate data entry. A progress bar indicated how far participants were through the survey to encourage them to continue through to the end.

![Figure 2. Representation of the recent change in emphasis in D&T education in Western Australia](image)
In all 224 students from the School of Education at ECU completed the surveys. This sample consisted of 160 students enrolled in the Bachelor of Education (Secondary) and 64 students from the Bachelor of Education (Primary or Early Childhood). Twenty one percent of all respondents were male meaning the ratio of male to female students was a reasonable reflection of the actual ratio among Education students at ECU. Seventy four percent of respondents were under thirty years old. Overall the samples were a reasonable representation of the student population under examination.

Additionally of interest to the authors was how many of the sample had studied D&T prior to attending ECU. Seventy five percent of the Secondary and 83% of the Primary students reported having studied D&T at school. This is important because the majority of the B.Ed. intake is directly from the school system and so any preconceptions regarding the subject are likely to have been developed though past study.

**Findings**
Results presented here pertain to the results of interest that emerged from analysing the survey data. For the purposes of this paper only those results with particular relevance to the topic of this paper are presented. Most come from the statistical analysis of data from the closed questions within the survey but some pertain to the results from the interpretation of open-ended questions.
Perceptions of D&T.
The respondents were asked a number of questions relating to their perceptions of the D&T Subject area. The first of these questions was regarding the importance of D&T to Australia and the data this is displayed in Table 1.

**Table 1**
*Student perceptions of the importance of D&T to Australia*

<table>
<thead>
<tr>
<th></th>
<th>Little Imp. (1)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Vital Imp. (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined %</td>
<td>1.3</td>
<td>2.2</td>
<td>17.4</td>
<td>42.4</td>
<td>32.1</td>
</tr>
<tr>
<td>Secondary %</td>
<td>1.9</td>
<td>3.1</td>
<td>18.1</td>
<td>45.6</td>
<td>30</td>
</tr>
<tr>
<td>Primary %</td>
<td>0</td>
<td>0</td>
<td>15.6</td>
<td>34.4</td>
<td>37.5</td>
</tr>
</tbody>
</table>

*Combined (n=224)*

*Secondary (n=160)*

*Primary (n=64)*

*Figure 4. Student perceptions of the importance of D&T to Australia.*

The first of these was: *How important you think Design and Technology is to Australia as a country?* D&T is perceived by the majority of both primary and secondary respondents to be of great importance to Australia (Figure 4). Given the age of the respondents this perception is likely to have come from their experiences in secondary school.

The respondents had the opportunity to give a reason for their response and the most common reasons given were that
- D&T teaches useful skills that are transferable to other areas of life;
- D&T gives students a chance to see if they would like to pursue the subject as a career, particularly for non-academic students.
Primary and early childhood teachers are what as known as generalists in that the one teacher teaches the full curriculum to his or her particular group of students. Secondary teachers on the other hand are specialists and thus tend only to engage with their particular section of the curriculum and this is evident in a number of the areas examined by the survey, with primary students having a better understanding of what the D&T curriculum entails while secondary students (Unless training to be D&T teachers) tended to fall back upon prior knowledge and experiences from their own school days. In Figure 5 primary students perceive D&T as being more creative than secondary students possibly due to exposure to the curriculum through their pre-service teaching course. While when both groups are combined the subject is seen to be neither one or the other.

When asked To what extent is the subject Design and Technology focused on Problem solving, Primary students again had slightly differing views to their Secondary counterparts with Primary students with curriculum exposure seeing the design element as a clear link to problem solving (Figure 6).
Figure 6. Student perceptions of to what level D&T is focused on problem solving.

Figure 7. Student perceptions of to what level D&T is focused on woodwork and metalwork.
When asked *To what extent is the subject Design and Technology focused on wood and metal work*, there is still perception that D & T is focused on these things but less so with the Primary students (Figure 7). There are many reasons for this, including past school experiences and indeed the physical structure of most WA schools, which have wood and metal workshops as separate entities.

When asked *To what extent is the subject Design and Technology masculine or feminine*, Primary pre-service teachers were more likely to perceive D & T more broadly again it is likely because they have engaged with curriculum (Figure 8). Thus, the Secondary graph is a measure of perceptions without any curriculum knowledge and based almost entirely on attitudes developed at secondary school. It should be noted that when the researchers broke the data down by gender the trends did not change, thus gender is not a factor - it is knowledge of curriculum that changes perceptions. This link to curriculum knowledge is particularly poignant as the primary pre-service teachers reported that they received little or no training in their course across the Technologies area and in D&T in particular. This means that ECU primary pre-service teachers are relying on past experiences in school to give them the content knowledge required to teach D&T.

Figure 9 clearly shows that Primary students see that computing and D&T go together (since they have seen the curriculum). Secondary student's still view D&T in its traditional form.
Other findings
The survey has also shown that while D&T is seen as male dominated it is not perceived as too masculine. D&T is seen by many as on a parallel with art as a creative and practical subject and with science as a problem-solving subject. While this finding fits well with the intent of the new curriculum, other findings showed that many participants still see the area as focused upon the process of making, constrained within years 8-12, and boxed into areas defined by material.

Conclusions
It appears from the survey that while all participants had strong perceptions as to what D&T is and how important it is in education, and for secondary pre-service teachers in particular these views were greatly influenced by their experiences at school because, for the majority of pre-service teachers surveyed, this would in all likelihood be their most significant exposure to D&T as a subject. For Primary and Early Childhood pre-service teachers there was a marked difference with views in line with, or close to, those reflected in the new Australian Curriculum. Thus it would seem for these students that it is knowledge of curriculum gained through study at ECU that has changed their perceptions.

However for those training primary and early childhood teachers in Australia and WA in particular, the lack of coverage in training of D&T needs to be addressed quickly for successful adoption of the Australian Curriculum. For school systems and those training D&T teachers, changing the perceptions of those teachers already in schools is important to overcome resistance to change and to encourage a new generation of teachers for the new expanded and reinvigorated subject of Design and Technology defined by the Australian Curriculum.
References


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Exploring the Use of Digital Tablets in Preschool Technology and Science Education

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Abstract The availability of digital tablets in preschools has increased significantly in recent years. Literature suggests that these tools can enhance students' literacy skills, as well as improve student collaboration. Society is becoming increasingly digitized and the Swedish preschool curriculum includes technology and science as priority areas of learning. Preschool teachers' knowledge is of utmost importance in helping carry out this mandate. Since there have been few studies on the use of digital tablets in preschool technology and science education in a Swedish context, there is an urgent need to explore the role and influence of digital tools as teaching tools, in an effort to exploit the potential pedagogical opportunities offered by digital technology. The current study investigates what features and aspects of digital tablet technology preschool teachers use to teach technology and science in preschools. Preschool educators throughout Sweden responded to an online survey consisting of 20 closed and 6 open items that probed teachers' use of digital tablets. Results show that programming, invention, construction, creation, entrepreneurship and designing with the support of digital tablets are emerging technology education activities in preschool. This finding is in line with a revised Swedish curriculum to be completed in 2018. Teacher scaffolding in conjunction with different digital tablet applications could help to develop children's ability and confidence to invent, program, create and design. Future work will consist of conducting interviews with preschool teachers to obtain a deeper understanding of the themes that emerged from the survey.

Keywords: Digital tablets, preschool, technology education, science education, iPads, digital tools, educational technology
Introduction and Aim

The availability and use of digital tablets in preschools has increased significantly in recent years, both in Sweden and around the world. While computers have mostly become tools used by preschool teachers for administrative purposes, digital tablets have in a short time become an integrated part of pedagogical practice at preschools, accepted and used by both preschool teachers and children. Prensky (2001) talks about a generation of “digital natives”, children who have grown up in a digital world and that have adapted to a digital language. Through more accessible digital tools such as tablets, children are exposed to and interact with digital technologies at an earlier age than ever before.

The use of digital tools in education has been a hot topic in education over the last decades, and the availability of these tools in educational contexts has increased significantly (e.g. Neumann & Neumann, 2014). Although there is a strong push toward an increased use of technology in schools, not least from governmental mandates, more empirical work is needed on investigating the actual influences and effects of newly emerging technologies as pedagogical tools. For example, there are signs that the potential benefits of digital technology are not merely “a given”. One example of this is shown in the PISA findings, where ICT use at school and at home has been shown to share a negative correlation with scores in science and mathematics (Spiezia, 2011). In Sweden, a country which has a very high use of ICT - Swedish boys demonstrate the highest use of ICT of all PISA participants - this correlation has been flagged as a potential problem (Skolverket, 2015). The developing use of digital technology in preschools is not only affected by new and more accessible technologies and software, but also by preschool teachers and children's own incorporation of these new tools in daily preschool activities. National and international curriculum policies also highlight digital technology and digital literacy. Sweden has recently engaged in a national overhaul of regulations concerning the use of digital technology in education, and a revised national preschool curriculum with increased emphasis on digital literacy is expected in 2018 (Utbildningsdepartementet, 2017). The current status of the role of digital tools in the Swedish preschool system carries with it both high expectations as well as being in a state of development.

This study aims to contribute to current developments in this area by investigating what features and aspects of digital tablet technology preschool teachers use in Swedish preschools, with particular focus on uses related to children’s learning of technology and science. Preschool educators in different parts of Sweden responded to an online survey consisting of 20 closed and 6 open items that probed teachers’ use of digital tablets. By conducting this study we aim to gain an understanding of how digital tablets can be used in order to support preschoolers’ learning of technology and science.

Method

Study Context and Survey Design

The study was conducted in Sweden with preschool teachers being the target respondents to an online survey on their use and experiences with digital tablets in preschool education settings. The survey was designed to generate information on Swedish teachers’ use of digital tablets (e.g. iPads) as educational resources in preschools, with a focus on technology and science education. Designed items included demographic information on gender, age, respondents’ preschool
location, level of education, number of available tablets, and teachers’ own perceived level of competence in their use. An additional component of the questionnaire asked what programs or “apps” were used, how and why they were used during practice, as well as their opinions about the pedagogical advantages and disadvantages of using tablets in preschool education. A core aspect of the survey design was on the use of tablets in the teaching of technology and science. This included designing items that asked how often tablets were used in relation to technology and science content, what related activities were implemented in praxis, and teachers’ views of the pedagogical advantages of, and potential recommendations for, using tablets in these contexts. The items were designed iteratively over a period of four months and involved at least four cycles of revision and refinement between the first and co-authors. A balance between specific and more general questions was sought as well as corresponding implementation of closed and open item formats on a web-based platform. A final step involved piloting the electronic questionnaire with 16 preschool teachers in further pursuit of face and content validity. Following subsequent adjustments, the final survey consisted of 26 items (20 closed and 6 open items, respectively). Interested readers can access the Swedish survey at https://survey.liu.se/Survey/4080/sv.

Data Collection

The survey was activated from November 2016 to April 2017. An invitation to participate in the survey and accompanying link was emailed out by the first author to 700 preschool directors throughout Sweden, who were requested to forward it to respective preschool educators in their district. The survey invitation and link was also communicated on social media platforms that included multiple Facebook groups in Sweden such as, “iPads in schools and preschools” and Twitter. Aside from exposure on social media, given that each preschool director is responsible for ca. 3 preschools with ca. 15 educators at each school, our estimated potential reach was in the order of 30000 potential survey recipients. The first author monitored the breadth and nature of the received responses as they were obtained, and it was decided that 300 responses would be an adequate sample size for pursuing a reliable analysis (e.g. Nunnally & Bernstein, 1994). The subsequent data subjected to analysis comprised 327 individual survey activations, and serve as the data corpus for this study.

Data Analysis

This paper focuses on analysis of responses to the open-ended item, “What programs and apps do you use in connection with the use of digital tablets in activities with the children (regardless of subject area)? Please describe how you use this software and why you selected it”. An overall qualitative content analysis procedure was used to treat the data (Mayring, 2000). Half of the responses were randomly selected and read by the first author on three separate occasions, while generating notes of any emerging interpretations. These impressions were used to inform a colour scheme to code the individual responses into inductively developed categories. In pursuit of concordance, the two co-authors performed their own individual category development of a smaller sample of responses. After discussing the overall patterns and themes that emerged, the first author continued to induce subcategories for each identified main category. Lastly, the main categories were described in terms of their respective incidence in the data, and also reflected upon in light of the Swedish preschool curriculum (Lpfö 98/16).

Results
Results of the study are structured by presenting the demographic features of the respondent sample, followed by themes of preschool activities with digital tablets identified in the survey responses to the survey item above (see Method). Lastly, examples of technology education activities with digital tablets generated from the same survey item are described in light of the future Swedish preschool curriculum.

**Demographic characteristics and features of survey respondents**

Demographics (gender, age and level of education) and context features (preschool location, pedagogical role and number of tablets) of the respondent sample is summarised in Table 1.

Table 1. Demographic characteristics and context features of survey respondents (n=327).

<table>
<thead>
<tr>
<th>Demographic and Context Features</th>
<th>Proportion of Sample (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>96.0</td>
</tr>
<tr>
<td>Male</td>
<td>3.4</td>
</tr>
<tr>
<td>Other</td>
<td>0.6</td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>20-30</td>
<td>16.4</td>
</tr>
<tr>
<td>31-40</td>
<td>27.2</td>
</tr>
<tr>
<td>41-50</td>
<td>31.3</td>
</tr>
<tr>
<td>51-60</td>
<td>21.1</td>
</tr>
<tr>
<td>&gt;61</td>
<td>4.0</td>
</tr>
<tr>
<td>Pedagogical role</td>
<td></td>
</tr>
<tr>
<td>Preschool teacher</td>
<td>76.5</td>
</tr>
<tr>
<td>Childminder</td>
<td>18.1</td>
</tr>
<tr>
<td>Other</td>
<td>5.4</td>
</tr>
<tr>
<td>Level of education</td>
<td></td>
</tr>
<tr>
<td>Compulsory school</td>
<td>4.7</td>
</tr>
<tr>
<td>Gymnasium (upper secondary)</td>
<td>19.3</td>
</tr>
<tr>
<td>Post-secondary (3 years or less)</td>
<td>21.4</td>
</tr>
<tr>
<td>Post-secondary (&gt; 3 years)</td>
<td>66.8</td>
</tr>
<tr>
<td>Graduate studies</td>
<td>1.2</td>
</tr>
<tr>
<td>Preschool location in Sweden</td>
<td></td>
</tr>
<tr>
<td>Northern Sweden</td>
<td>13.0</td>
</tr>
<tr>
<td>Central Sweden</td>
<td>43.0</td>
</tr>
<tr>
<td>Southern Sweden</td>
<td>44.0</td>
</tr>
<tr>
<td>Available digital tablets</td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>55.0</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>3-4</td>
<td>39.4</td>
</tr>
<tr>
<td>5 or more</td>
<td>6.6</td>
</tr>
</tbody>
</table>

*In some items more than one option could be selected.

Other pedagogical roles mentioned included primary school, Montessori and Reggio Emilia teachers. According to the Swedish National Agency for Education, in 2016, 39% of all preschool pedagogues were in possession of a preschool teacher degree. The agency also reports that there are ca. 46000 tablets in the pre-school system, at an average of 8.2 children per computer or tablet. Furthermore, 23% of staff have access to their own computer or tablet.

*Emerging themes of digital tablet activities with children in preschool education*

Emergent themes from analysis of the focus item (see Method) are presented in Table 2 below.
Table 2. Thematic structure of categories and subcategories of digital tablet activities with response incidence (Incid.) (n=288).

<table>
<thead>
<tr>
<th>Main category description</th>
<th>Incid.</th>
<th>Sub-category description</th>
<th>Example of response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Science and Technology: Hands-on and active exploration of content.</strong></td>
<td>128/288 (44%)</td>
<td>Science: Plants, animals, sustainable development, physics and chemistry.</td>
<td>“To find out facts about the human body and nature, the tablet is taken to the woods and used to search”.</td>
</tr>
<tr>
<td>Technology: Explore technology by creating and constructing.</td>
<td></td>
<td>Technology: Explore technology by creating and constructing.</td>
<td>“Stimulating an interest in programming by using various applications in the subject”.</td>
</tr>
<tr>
<td><strong>Language: Developing the use of Language in different forms.</strong></td>
<td>144/288 (50%)</td>
<td>Developing spoken and written vocabulary, concepts and symbols.</td>
<td>“Working with linguistic awareness and facilitating reading and writing using the Bornholm play app”.</td>
</tr>
<tr>
<td>Communicative forms of expression such as artistic creation.</td>
<td></td>
<td></td>
<td>“Using the app Puffarna, which allows children to express their feelings through colour and shape”.</td>
</tr>
<tr>
<td><strong>Mathematics: Engaging and developing maths concepts and skills.</strong></td>
<td>85/288 (29%)</td>
<td></td>
<td>“To develop and discover mathematics with the children, different maths applications are used”.</td>
</tr>
<tr>
<td><strong>Themes: Thematic approaches engaging focused work.</strong></td>
<td>40/288 (14%)</td>
<td></td>
<td>“Choosing different applications to work with several children at the same time in larger projects based on the curriculum and the children’s interests”.</td>
</tr>
<tr>
<td><strong>Cooperation and values: Engendering different types of cooperation and democratic principles.</strong></td>
<td>45/288 (16%)</td>
<td></td>
<td>“Applications are chosen to promote interaction and socialization, the children work together with the digital tablet and not so much individually”.</td>
</tr>
<tr>
<td><strong>Fact searching: Engaging applications without a constrained focus.</strong></td>
<td>117/288 (41%)</td>
<td></td>
<td>“They are looking for facts about different things with the children”.</td>
</tr>
<tr>
<td><strong>Critical thinking: Knowledge and tools to strengthen children’s critical abilities.</strong></td>
<td>48/288 (17%)</td>
<td></td>
<td>“…sit with the children when working with tablets so to discuss and challenge children’s thoughts”.</td>
</tr>
<tr>
<td><strong>Documentation and reflection: Analysing and developing activities by discussing and reflecting together.</strong></td>
<td>156/288 (54%)</td>
<td>Individual documentation and reflection</td>
<td>“Children photograph freely and document alone”.</td>
</tr>
<tr>
<td>Joint documentation and reflection</td>
<td></td>
<td></td>
<td>“They do the pedagogical documentation together with the children where the parents also get insight”.</td>
</tr>
</tbody>
</table>
Overall, 8 main categories and 6 subcategories emerged from the analysis (Table 2). The main categories were oriented to science and technology, language, mathematics, themes, cooperation and values, factual search, critical thinking and documentation. Subcategories which developed from these were science, technology, spoken and written language, other communication forms, individual and joint documentation and reflection.

**Emerging technology education activities with digital tablets in relation to the new preschool curriculum**

The Swedish preschool curriculum was revised in 2010, and among other foci, states that “preschool should strive to ensure that each child develops their ability to identify technology in everyday life, and explore how simple technology works, and also develop their ability to build, create and construct using different techniques, materials and tools” (Lpfö 98/16). Formal integration of digital skills into a further revised curriculum is expected to be implemented in 2018. Further elaboration of the data from the focus item (see Method) revealed five emerging areas of activity related to technology education content in conjunction with using digital tablets (Table 3).

Table 3. Examples of technology content areas and related activities with digital tablets and apps at the preschool level.

<table>
<thead>
<tr>
<th>Content focus</th>
<th>Examples of activity</th>
<th>Example of app or program used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Programming</td>
<td>Programming real robots that move on the floor by using digital tablet apps.</td>
<td>Bluebot</td>
</tr>
<tr>
<td>Invention</td>
<td>Children build their own inventions using applications.</td>
<td>Pettson’s Inventions</td>
</tr>
<tr>
<td>Construction and Creation</td>
<td>Look for images and movies of construction to inspire children’s building of their own. Also draw them on paper.</td>
<td>YouTube</td>
</tr>
<tr>
<td>Entrepreneurship</td>
<td>Reflect as well as create movies together with the children where they foster their imagination and creativity.</td>
<td>iMovie</td>
</tr>
<tr>
<td>Design</td>
<td>Using a WiFi microscope to explore objects. The magnified images allow children to visualize objects at higher levels of detail.</td>
<td>WiFi microscope together with Ucam</td>
</tr>
</tbody>
</table>

With the support of teachers and different digital tablet applications, children can develop the ability and confidence to program, invent, and design their own constructions. In discussions with peers and teachers, children discover how different forms of technology work by finding solutions to different technical issues.

**Types of scaffolding activities with digital tablets to support and encourage children’s learning**
Analysis of responses to the focus item (see Method) also revealed various scaffolding activities that teachers use to support children's learning with digital tablets. Yelland and Masters (2007) have described three types of scaffolding. **Cognitive Scaffolding** "aids in conceptual and procedural understanding and involves strategies such as modeling and questioning by the adult", and was revealed in the current study as per the following example response:

"Make time lapse movies, children paint and photograph every other second with the tablet. Visualize the process, which can lead to many discussions and discoveries about what the children are targeting".

**Affective scaffolding** "is where the teacher or parent provides positive encouragement to extend children’s learning to higher levels of thinking and operating", and was also a feature of responses obtained in the current study, such as:

"Reading books and "jumping into" the books through the green screen for the children to get one more dimension, in addition to having heard the book, they can also act as the characters in it."

Finally, **technical scaffolding** refers to how interactive features of the tablet scaffolds the child's learning and facilitates understanding and problem solving skills, support also obtained in the survey responses, which included:

"In the app Pettson's Inventions the child will help to complete innovative inventions. At different levels of difficulty."

The data indicates that teachers use digital tools to scaffold problem solving. In this approach, the teacher shows the children that there are many ways of solving problems, which encourages children to tackle new tasks and take risks.

**Discussion and Implications**

Since survey responses were from throughout Sweden, the results serve as a representative snapshot of the current status of digital tablet activities in Swedish preschools. A salient aspect of the responses highlight the possibility of cooperation, participation, co-investigation as well as co-discovery together with children. One advantage of the digital tablet is that while children document a phenomenon as part of a technology activity, the tablet provides a platform for active reflection, which may promote the child’s focus on the task at hand. Results also suggest that in combination with scaffolding, teachers encourage children to conduct various technology activities with digital tablets that include simple robot programming, which could support logical thinking and problem solving abilities (see Yelland & Masters, 2007). In addition, using digital applications in construction and design activities could stimulate inventive and entrepreneurial skills and feed children’s natural curiosity. The data also indicates that digital tablets may support the development of verbal literacy (Neumann & Neumann, 2014).

Although the study indicates that digital tablets could support preschool learning through various activities, potential disadvantages of using tablets also requires future attention. As mentioned, one example of this is shown in the PISA data, where both positive and negative scores are associated with digital tools in school (The Swedish National Agency for Education, 2015). One
possible source for this finding is the notion that digital tools are ‘fragmented communicators’, and children do not read traditional books to the same extent as previous generations, which may induce a less nuanced language ability (Rosén, 2011). There is also a need to find a trade-off between digital literacy and content-specific technology knowledge, and to clarify how pedagogues talk about each of these aspects in preschool education praxis. Sundqvist (2016) sheds light on content knowledge in technology with teachers’ examples such as, “the purpose of the technology, what parts different objects consist of and how they are assembled, and about different technical systems, such as how water gets from a lake to the tap and how it is cleaned on the way there”. Future work will comprise analysing the entire corpus of survey responses, followed by conducting interviews with preschool teachers to attain a deeper understanding of the emergent themes from the survey.

References


Abstract
Learning by doing and creating things with hands have always been key elements in Finnish craft and technology education. Tacit knowledge (i.e., understanding how various materials behave and knowing how to manipulate them) is knowledge that can be gained only through individual and concrete experiences. Finland’s new National Core Curriculum for Basic Education 2014 (NCCBE 2014), which came into effect in August 2016, emphasizes pupils’ ownership of ideas and learning through meaningful and concrete experiences. The hands-on nature of the subject provides pupils with the possibilities to both conceptualize scientific and technological knowledge as well as multiple strategies to put that knowledge into practical uses. In Finland, there is no independent subject called technology education. Rather, technology education is decentralized and taught through various subjects. Craft, however, is a subject that supports technology education because it is a practical subject with hands-on activities. In craft, pupils actively practise experimentation, investigation, invention, problem solving and designing skills. The NCCBE 2014 represents a major change in craft. It now becomes a multi-material, integrated subject involving technical and textile craft for all pupils during compulsory lessons in grades one to seven. This paper will explore and discuss how learning by doing and creating things with hands will be fundamental aspects of an evolving craft and technology education. A qualitative, theory-oriented content analysis was first performed to examine the extent of the learning by doing approach in craft and technology education in the NCCBE 2014 document. Meaningful sentences or themes and manifest content were chosen as the analysis units. Second, a case study method was utilized to examine the learning by doing approach in craft and technology education taught by the Teacher Education Department at the University of Jyväskylä to determine its alignment with the NCCBE 2014.

Keywords: learning by doing; curriculum; technology education; craft
Introduction

Almost 30 years ago Brown, Collins and Duguid (1989, p. 32) raised a concern that activities at schools too often create a separation between knowing and doing. They claim that knowledge is treated as ‘an integral, self-sufficient substance, theoretically independent of the situations in which it is learned and used’ (Brown, Collins, & Duguid, p. 32). This might still be the case as PISA (Programme for International Student Assessment) studies show that students may have good knowledge of school subjects and disciplines, but seem to have problems in applying their knowledge in practice. This disconnect indicates the need for a greater emphasis on soft skills, i.e., problem solving, creativity, collaboration and critical thinking, which have become more relevant in today’s society.

Technology education has been developed to help people deal with technology. It can provide pupils active engagement and participation, meaningful experiences and possibilities for hands-on working (Järvinen & Rasinen, 2015; Martin, 2012). It has been suggested that problem-based technological activities can help people engage with both tool-related hands-on and discursive practices of technology (Wilkinson & Bencze, 2011). Williams (2009, p. 248) points out that based on recent recognition, a variety of cognitive skills can be developed and nurtured through application to a practical context.

In order to understand technology education in Finnish basic education, it is necessary to consider it within the subject of craft, especially technical craft. In Finland, technology education is not an independent subject in basic education; rather, the education is decentralized and taught through various subjects (NCCBE, 2014). However, craft education, especially technical craft, supports technology education. Craft is a practical subject that involves hands-on activities, where students actively practise experimentation, investigation, invention, problem solving and designing skills. In technical and textile craft education workshops, pupils work with various materials and techniques when creating their projects. Finland’s former National Core Curriculum for Basic Education 2004 introduced seven cross-curricular themes in Finnish education, one of which was ‘Human beings and technology’, which addresses technology education. Much of the technological content of the theme was studied during technical craft lessons and they shared some same specific aims (Järvinen & Rasinen, 2015). In a study of technology education implementation in Finnish basic education, 90 percent of pupils in ninth grade (n=1181) regarded manual skills and technology as interrelated (Järvinen & Rasinen, 2015). Finland’s new National Core Curriculum for Basic Education 2014 (hereinafter NCCBE 2014) describes seven transversal competence areas, one of which is ‘Taking care of oneself and managing daily life’. This competence area addresses students’ need to receive basic information about technology, its advancement and its impacts on various areas of life and the students’ environment. In instruction, the versatility of technology is examined, and pupils are guided to understand its operating principles. Pupils are also guided in the responsible use of technology, and are invited to consider ethical questions related to it.

Learning by doing in technology education

The nature of technology education provides students with a systematic approach to solving problems and a context in which students can test their own knowledge and apply it to practical problems. Commonly, technology education, engineering design or design and technology education emphasize learning by doing or learning while designing. During activities, designers are involved with continual reflection, brainstorming and prototyping, learning by iteration and from feedback and failure, by noticing and troubleshooting, in a dialogue with ideas, material and people (Adams, Turns, & Atman, 2003; Crismond & Adams, 2012). It can be concluded that learning by doing enhances students’ understanding and engagement (Kelley & Knowles, 2016). Next, learning by doing and pragmatism in relation to technology education is discussed.
John Dewey (1859-1952) was unquestionably the most significant figure in the field of experiential education. He was also a leading proponent of pragmatism one example of which is learning by doing. When considering pragmatism as a concept, it can be divided into four philosophical stances that are understood to loosely define it (Roberts, 2012, p. 49). The first characteristic is about examining things based on practical consequences. In other words, one chooses the right course of action on the basis of the likelihood of success, or with an awareness of the consequences of one’s actions (Roberts, 2012, p. 50). As it relates to technology education, learning by doing is accentuated by activities involving design and scientific inquiry. The design process in technology education, or in engineering, may be characterized as a goal-directed and iterative activity whereby the designer learns about the problem through proposing solutions and synthesizing ideas (see Purzer, Goldstein, Adams, Xie, & Nourian, 2015). The second characteristic of pragmatism is that pragmatists understand that thinking cannot be removed from the world, since knowledge acquisition is inherently interactive (Roberts, 2012, p. 51). This means that the interaction of thinking and action and the ways in which the two revise each other, are key factors in bringing about new awareness and learning (Roberts, 2012, p. 51).

The third tenet of pragmatist ethos is the importance of context (Roberts, 2012, p. 52). This means that in order to consider practical consequences interactively, one must be situated somewhere. In terms of technology education, problem solving, project-based learning and creating with the use of one’s hands are evidently suitable methods for learning, and each of these pedagogical approaches is inherently contextual. A study by Fain, Wagner and Vukasinovic (2016) indicates that problem-based learning can facilitate knowledge transfer, encourage and support collaborative work and improve students’ thinking and designing skills. Often when learning is grounded within a specific context, learning is authentic and relevant, and therefore representative of an experience that may be found in practice (Kelley & Knowles, 2016).

An important characteristic of technology education is a high proportion of tacit knowledge required. Tacit knowledge and skills, i.e., understanding how various materials behave and knowing how to manipulate them, can be gained only through concrete experiences. The fourth characteristic of the pragmatist ethos is fallibilism (Roberts, 2012, p. 52). Fallibilism, meaning that errors are seen part of the learning process, is also an inherent part of technology education.

**Methods**

In embarking on this research, the general aim has been to provide information about the approach of learning by doing, and of making things with one’s hands within the context of craft and technology education. The research questions were: 1) How the ‘learning by doing’ method is visible in NCCBE 2014 and 2) How learning by doing is implemented in craft and technology education?

A multi-method approach was utilized through the use of qualitative, theory-driven approach in the analyses. First, learning by doing was explored in craft and technology education in Finland’s new National Core Curriculum for Basic Education 2014, which came into effect in August 2016. The data were analyzed using qualitative theory-oriented content analysis. In this analysis, Roberts’s (2012) descriptions of four philosophical tenets for pragmatism provided guidelines for the analysis. Meaningful sentences or themes and manifest content were chosen as the analysis units.

In order to answer to the second research question and to gather more information about the role of learning by doing in craft and technology education, the focus of this study was broadened to include craft and technology education curriculum and how it is implemented in teacher education at the University of Jyväskylä. During the academic year 2016-17 a pilot curriculum of an integrated craft education (technical and textile crafts) was put into operation for the first time with one group of teacher education students, who specialized in crafts. The aim of the analysis was to
explore those practical elements that refer to the concept of learning by doing. The case study method was chosen as it provides a way to explore a phenomenon in-depth and is an appropriate tool for describing and explaining processes associated with the it (Gagnon, 2010). The analysis consisted of the two craft and technology education teachers’ reflections about the practical methods in implementing the curriculum during an academic year 2016-2017. This process gave a starting point for the revision of our craft and technology education curriculum that will be implemented in the Department of Teacher Education at the University of Jyväskylä between 2017 and 2020.

Findings of the NCCBE 2014 analysis
Based on the theory-oriented content analysis of NNCBE 2014, it can be concluded that learning by doing was an inherent component of craft education in various aspects. In the analysis of the objectives and key content areas of crafts in grades 1–6 (ages 7-12) findings were divided into four sub-categories based on how learning by doing was related to them:

1) **Ability to manage a complete crafts process:** pupils are guided to design and produce their own craft product independently, using a diverse range of techniques, tools, machines and equipment.

2) **Use of multiple materials:** pupils are guided to invent and experiment with crafts and to work with various materials in a suitable way; promoting pupils’ manual and motor skills.

3) **Development of skills:** pupils are guided to design and produce, practice their spatial awareness, sense of touch, creativity, experimentation, persistence and responsible work.

4) **Learning by doing supported by working methods and environments:** pupils are guided towards learning by doing, experiential learning, use of drama and stories, as well as the multidisciplinary nature of environmental studies.

Based on the learning by doing theory by Roberts’s (2012), the category of examining things based on practical consequences was also observed in the NCCBE 2014. Textual descriptions such as:

- making crafts is an exploratory, inventive, and experimental activity
- guiding pupils in choosing between different techniques, tools, machines, and equipment and in using them in their work
- observing and analyzing objects as well as built and natural environments to produce new ideas
- examining the structures and the use of energy in materials
- studying the properties of materials and the operating principles of the most common machines and tools needed in craft
- on the basis of the experimentation, developing the product or piece further
- selecting and using tools and equipment that are suitable for the work
- selecting and combining crafts materials and techniques and working with them

In NCCBE 2014, there were also some descriptions about the knowledge acquisition is inherently interactive component of Roberts's (2012) learning by doing theory. Textual descriptions such as:

- designing and producing a crafts product or piece independently or together with others
- shared activities are emphasized in the teaching and learning of crafts
- pupils' surroundings, the local cultural heritage, and the cultural diversity of the community
- guiding the pupil to assess, appreciate and examine interactively his or her own crafts process and the processes of others as a whole
• pupils’ own solutions as well as constructing and applying knowledge creatively both independently and together with others is supported

Findings of the case study at the University of Jyväskylä
When considering the pragmatist ethos of the importance of context (Roberts 2012, p. 52), it was obvious that craft and technology education depends heavily upon context, since most activities take place in a specific workshop. Thus, one of the main requirements in most craft and technology education courses is that students use various tools, machines and materials based on their needs when they create something themselves. A previous analysis of NCCBE 2014 showed that craft education has a strong emphasis on enabling a ‘complete crafts process’, which means that the learner will go through every phase of a design process. As it relates to the theory of learning by doing, this process involves examining things based on practical consequences (Roberts, 2012, p. 50) at every stage. During their studies in craft and technology education, students were first encouraged to investigate their surroundings and to identify ‘problems’ that they could solve by creating something by themselves. They then started to investigate existing solutions to similar problems and to develop their own ideas based on their observations. The next step was to decide on a solution and build a prototype for it. In this stage, students were encouraged to test the properties of different kinds of materials. Then students built the artefact, using all of the applicable tools, techniques and materials. This phase included many kinds of experiments, and many errors were made. This demonstrates another characteristic of the pragmatist ethos, fallibilism (Roberts, 2012, p. 52); this was an inherent part of the learning process. The final step was to reflect on the whole process by completing a self-evaluation.

The pragmatist element of knowledge acquisition is inherently interactive (Roberts, 2012, p. 51) can be found in almost all stages of the process within craft and technology education activities at the university. In the first stages, students work in small groups, presenting their ideas and discussing possible improvements. Based on these discussions, students rectified their models and then used suitable materials to build prototypes. The cooperative learning method was used also when students studied how to work with various wood and metal working machines. Also, during the process of working on their projects, students regularly got together to evaluate each other’s work. Finally, at the last phase of the process the element of interaction was a component in peer-evaluation.

Conclusion
Today’s society places a high demand on individuals to understand technology, as the technologies that govern our lives are very complex (Dakers, 2011). There is no doubt that skills such as problem solving, creativity, collaboration and critical thinking are crucial for children’s’ future, including the demands of a working life. As evidenced in the NCCBE 2014 analysis, there are explicit connections between the NCCBE 2014 and Roberts’s (2012) theory of learning by doing. The existence of these connections was further supported by the findings of the case study at the University of Jyväskylä. It is obvious that craft and technology education emphasize learning by doing and learning while designing. Thus, it can be concluded that it has the potential to develop students’ skills in many ways by providing pupils opportunities to work in a practical way, accessing the domain of technological knowledge and working technologically.

Studies have revealed that interest and self-efficacy with respect to technology arise early in childhood (Endepohls-Ulpe et al., 2012). Craft and technology education has the potential to foster students’ self-efficacy by providing them with necessary skills and technological literacy. These are skills they will need to understand and utilize in order to become empowered citizens of tomorrow (Compton, 2011). If we recognize that learning by doing is a fundamental part of developing understanding and tacit knowledge that can support future ventures, it is important to gain more information on the ways it may manifest in primary education.
References


Learn Better by Doing Study Results

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Abstract

The financial cost of an education in the United States today is among the highest in the world. However, student achievement, when compared to other industrialized nations, is not commensurate with that cost. Could it be that students are not doing enough standards-based hands-on activities in their classrooms? The purpose of the Learn Better by Doing Study is to determine to what extent U.S. public school students are doing hands-on activities in science, technology and engineering, and mathematics (STEM) classrooms. To make this determination the researchers created three instruments that asked elementary, middle, and high school STEM teachers to respond “Yes” or “No” to thirteen statements. Two statements were general in nature and asked of all teachers. The remaining statements were based on Standards for Technological Literacy, Next Generation Science Standards, and Common Core State Standards for Mathematics. Those statements asked teachers if their students were performing specific standards-based, hands-on activities. The first three years of this four-year study saw responses from over 4,000 teachers. The researchers compiled the results to determine to what extent students are doing activities in their classrooms. The study found that over 99% of elementary and secondary (middle and high school) STEM teachers felt that their students benefit by doing activities in their classrooms. Ninety-five percent indicate that they would have their students do more activities if they had the time and resources. The study also found that technology and engineering students are doing more activities in their classrooms than are science and mathematics students in those classrooms. The Learn Better by Doing Study results present many thought-provoking findings that focus on the status of doing in STEM classrooms, providing evidence of how technology and engineering programs may be more beneficial to students’ STEM literacy than educational leaders may realize.

Keywords: Doing, elementary education, science education, technology and engineering education, mathematics education, STEM education
Introduction

Students learn better by doing, according to teachers of elementary and secondary science, technology and engineering, and mathematics (STEM) (Moye, Dugger, & Starkweather, 2016). If their feelings are correct, it would be beneficial to determine to what extent United States elementary and secondary STEM students are actually doing in their classrooms. That is what the Learn Better by Doing Study set out to answer. The National Research Council reported that one of the most pressing issues facing education today is that more researchers need to collect data concerning “classroom coverage for content and practice [doing] in the Common Core State Standards for mathematics and a Framework for K-12 Science Education” (NRC, 2013, p. 36).

The United States has used the Programme for International Student Assessment (PISA) to measure students’ mathematics and science literacy since 2000 (NCES, n.d.). PISA provide assessment data of science and mathematics students’ content knowledge in 70 countries. The 2015 results show that U.S. 15 year olds ranked 25 of 70 in science and 40 of 70 in mathematics. (Kastberg, Chan, & Murray, 2016). Assessment of students’ ability to apply (practice) has not been so prevalent. To date, the United States has only once measured students’ technology and engineering literacy. The National Assessment of Educational Progress - Technology and Engineering Literacy (NAEP-TEL) Assessment assessed U.S. students’ “ability to ‘do’ engineering or produce technology...to gauge how well students can apply their understanding of technology principles to real-life situations” (NAGB, 2013, p. 2). In 2014, 21,500 eighth-graders completed the NAEP-TEL Assessment. Compiling and analyzing the results, the May 2016 Change the Equation Vital Signs document reported that technology and engineering literacy is “left to chance” and that “U.S. middle schoolers lack in-depth experience with technology and engineering” (Change the Equation, 2016, p. 1).

The approach to U.S. education has been to prepare students for standardized (high-stakes) tests rather than teach them how to actually apply that knowledge. (Archbald & Newmann, 1988; Martinez & Stager, 2013). Teaching students to become successful test takers is not working (Popham, 1999). Solely preparing (or attempting to prepare) students for these tests creates problems. For example, just because a person can correctly answer a test question is not an indication that he or she is able to apply that knowledge in a real-world situation. Possessing knowledge is not beneficial if it cannot be used. Unfortunately, with the current educational approach, U.S. students are not performing well on standardized tests, and are not able to apply what they should have learned. Further illustrating this point, Yale Global Online reports that “U.S. workers rank dead last among 18 industrial countries when it comes to “problem solving in technology-rich environments” (Yale Global Online. (n.d., para. 1).

The United States was once a leader in education and a nation of doers and innovators. U.S. schools produced citizens who kept the country’s economy strong and secure. However, the ability of U.S. schools to produce innovative citizens is not as evident as it once was. The concern is that the U.S. is not producing students that will change this trend (Change the Equation, 2016).
In 2012, the United States “spent $11,700 per full-time-equivalent (FTE) student on elementary/secondary education, 31 percent higher than the OECD [Organization for Economic Cooperation and Development] average of $9,000” (NCES, 2016, para. 1). Even with the high price tag of education, U.S. students “continue to rank around the middle of the pack, and behind many other advanced industrial nations” (PRC, 2017, para. 1). The United States spends more on education than other industrialized nations but students’ science and mathematics literacy is around the “middle of the pack.” The U.S. Department of Education may be failing to meet its mission “to promote student achievement and preparation for global competitiveness by fostering educational excellence and ensuring equal access” (UDOE, n.d., para. 1).

Drawing upon and applying knowledge is necessary to adequately function in life and the reason why learning is so important. In a study identifying a means to improve students’ statistical thinking, Sedlmeier (2000) found that, “learning by doing has a large and lasting effect on how well people can solve conjunctive probability tasks” (p. 227). Supporting an activity based learning approach, Robert Yager (Professor of Science, University of Iowa) posed the question: “Why is there not more attention to all students (and teachers) actually ‘doing’ science in every K-16 science classroom?” (2011, p. 62). In March of 2017, the National Academies Press published the Seeing Students Learn Science document. That document details how “Some students who successfully complete their K-12 science classes have not really had the chance to ‘do’ science for themselves in ways that harness their natural curiosity and understanding of the world around them” (NAP, 2017, p. vii).

**Study purpose and methodology**

The purpose of the Learn Better by Doing Study is to determine, according to STEM teachers, the extent to which U.S. public school STEM students are doing hands-on activities in their classrooms. To make this determination the researchers developed three instruments, elementary (Grades 1-5), middle (Grades 6-8), and high school (Grades 9-12).

The three instruments asked teachers to respond “Yes” or “No” to 13 statements. The first two statements were presented in all three instruments. The remaining 11 grade-level statements reflect what students should know and be able to do, as recommended by Standards for Technological Literacy (STL) (ITEA/ITEEA, 2007), Next Generation Science Standards (NGSS) (Achieve, 2013), and Common Core State Standards for Mathematics (CCSSO, 2010). Surveys were emailed to more than 6,000 teachers in 2014. After collecting additional email addresses, approximately 30,000 teachers received an invitation to participate in the 2015, 2016, and 2017 rounds. As of the writing of this article, teachers were completing the 2017 (and final) round of surveys.

A cover letter introduced the study and requested teacher participation. The letter explained the purpose of the study and how to use Uniform Resource Locator (URL) links to access the list of definitions and survey instruments using SurveyMonkey®. Over the three-year period, 4,432 elementary, middle, and high school STEM teachers responded to the study.

Elementary, middle, and high school STEM teachers were asked to respond “Yes” or “No” to
eleven grade-level standards-based statements. The statements reflect hands-on activities that students could have done in class. An example of an elementary statement is, “My students have constructed an object using the design process." A middle school example is, “My students have created a model by applying criteria and constraints." “My students have built a prototype and checked it for quality and efficiency” is an example of a high school statement (Moye, Dugger, & Starkweather, 2016, pp. 17-19). The number of “Yes” responses to each of the 11 statements, in each content area, was tallied and divided by the total number of responses for the statement, thus deriving the percentage of students doing each specific hands-on activity. Elementary, middle, and high school percentages were determined. In addition to specific middle and high school data, that data were combined to determine secondary level percentages. To determine the level of doing at the secondary level, the middle and high school percentages were combined to determine the percentage of doing occurring in each of the three STEM content areas.

**Findings/Discussion**

**Technology and engineering students are doing more hands-on activities in their classrooms.** With the first three of four rounds of the Learn Better by Doing study complete, the data show that technology and engineering students are doing more hands-on activities than students in science and mathematics classrooms. The secondary education results show that technology and engineering students are performing the standards-based, hands-on activities 22.9% more frequently than science students and 43.6% more than mathematics students. Table 1 provides the specific percentage of “doing” in each of the three secondary level content areas for 2014, 2015, and 2016. The overall percentage of elementary doing is also presented. Figure 1 provides a graphic illustration of elementary and secondary content area percentages.

**Table 1. Content Area, Total Number of “Yes” Responses/Total Responses, Percentages, and Averages.**

<table>
<thead>
<tr>
<th>Content Area</th>
<th>2014 Number “Yes”/Total Responses/Percentages</th>
<th>2015 Number “Yes”/Total Responses/Percentages</th>
<th>2016 Number “Yes”/Total Responses/Percentages</th>
<th>&quot;Yes”/Total Responses and Average Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary Science</td>
<td>1895/3883 48.8%</td>
<td>1407/2475 56.8%</td>
<td>1257/2453 51.2%</td>
<td>4559/8811 51.7%</td>
</tr>
<tr>
<td>Secondary Technology and Engineering</td>
<td>4069/5522 73.7%</td>
<td>4438/5973 74.3%</td>
<td>2164/2805 77.1%</td>
<td>10671/14300 74.6%</td>
</tr>
<tr>
<td>Secondary Mathematics</td>
<td>892/2805 31.8%</td>
<td>549/1859 29.5%</td>
<td>720/2310 31.2%</td>
<td>2161/6974 31%</td>
</tr>
<tr>
<td>Elementary</td>
<td>1927/4015 48%</td>
<td>1339/2673 50.1%</td>
<td>932/1705 54.7%</td>
<td>4198/8393 50%</td>
</tr>
</tbody>
</table>
Additional Findings
Teachers were also asked to respond “Yes” or “No” to two general statements. The first, statement was, “I believe that students benefit from doing activities to support learning.” Of the 4,070 responding teachers, 4,042 (99.3%) said “Yes.” For statement two, 3,074 of the 4,058 (95.5%) responding teachers said that if given the time and resources they would assign their students more projects to do in class.

The results of these two statements imply that the vast majority of responding teachers feel that students learn better by doing hands-on activities in classrooms and laboratories. If these sentiments are correct, and doing is occurring more frequently in technology and engineering classrooms, education leaders should realize that such programs are valuable assets that support student success.

Teacher responses indicate that students are doing the same type of standards-based activities in the three content areas. This is an important point identifying a rich collaborative opportunity between STEM as well as other teachers. Potentially, education leaders could, for example, lead teachers in an effort where students learn the laws and principles of science and mathematics in science and mathematics classrooms and then practice those laws and principles by doing hands-on activities in their technology and engineering classrooms and laboratories.

High school students are doing less hands-on activities than are middle school students. When the total percentage of doing in middle school and high schools are compared, the data show a decrease of doing hands-on activities in all content areas each year. When the percentage of doing in technology and engineering courses is compared to doing in science and
mathematics courses, the results show that the amount of decrease is not as substantial in technology and engineering classrooms. Figure 2 compares the percentage of doing between middle and high school science, technology and engineering, and mathematics classrooms. The Figure also illustrates that doing in technology and engineering programs remains higher than in science and mathematics classrooms. (Moye, Dugger, & Starkweather, 2016, p. 22).

![Percentage Doing Decreased Between Middle and High School: 2014, 2015, and 2016](image)

**Figure 2. Level of Doing Decrease Between Middle and High Schools in each Content Area.**

Research shows that many students become less interested in their studies while in high school (NRC-IM, 2004). Could there be a correlation between the decrease of doing hands-on activities and students’ losing interest in school? If hands-on activities help students stay interested in school, it could be possible that technology and engineering programs help maintain their interest in secondary education as well as into post-secondary education and occupations.

**Technology and engineering provide more activities that interest female students.** The Learn Better by Doing Study contains middle and high school statements that focus on individual and/or a societal need or want. Overall, teachers reported that technology and engineering students performed these activities more frequently than science or mathematics students.

Presenting exciting and relevant activities is important to maintain students’ interest and participation in school. Research shows that female students prefer studies and occupations that directly benefit society and/or individual needs and wants (Change the Equation, 2016; Eccles, 1994; NAE, 2008). The Change the Equation Vital Signs document tells us, “Educators who harness TEL’s [technology and engineering literacy] vision of literacy in technology and engineering may well attract many more girls to those fields” (Change the Equation, 2016, p. 9). Leaders in education are interested in increasing all student participation in STEM-related activities, continued education, and ultimately professions. Based on study results, technology and engineering programs present students (male and female) with interesting and challenging real-world scenarios, many of which focus on individual and societal needs and wants.
**Teacher Comments.** In addition to responding “Yes” or “No” to statements, teachers were given the opportunity to comment on each statement. Teachers provided hundreds of comments. While all comments are important, some stressed the importance of learning by doing. For example, one middle school mathematics teacher stated, “I attribute most of my students’ success with algebraic concepts to the kinesthetic learning processes we used.” Another middle school mathematics teacher commented, “Statistically, my students score higher on assessments after they have completed a project that supports their learning.” Finally, one elementary teacher wrote, “Students, just like most adults, learn better by doing.”

**Conclusions.** STEM teachers feel students learn better by doing and report that their students are doing hands-on activities reflecting *Standards for Technological Literacy, Next Generation Science Standards, and Common Core State Standards for Mathematics*. The *Learn Better by Doing Study* findings suggest that technology and engineering students are doing more hands-on activities in their classrooms and laboratories than are science and mathematics students in their classrooms. Technology and engineering programs are an important asset and should be used to improve students’ academic knowledge and practical application of science, technology and engineering, and mathematics.

This article reports only a few of the results gleaned from the *Learn Better by Doing Study*. For more results, the reader is invited to review Moye, Dugger, and Starkweather 2014a, 2014b, 2015, and 2016. The 2017 results are scheduled to be published in a future edition of the *Technology and Engineering Teacher* journal. *Learn Better by Doing Study* articles and presentations can be found by accessing this International Technology and Engineering Educators Association (ITEEA) web page: https://www.iteea.org/Activities/2142/ Learning_Better_by_Doing_Project/50026.aspx#tabs.

**Recommendations.** Researchers should conduct studies to assess the link between students performing hands-on activities and academic success.

Science, technology and engineering, mathematics and other teachers should collaborate and teach thematic lessons and administer hands-on assessments.

STEM teachers should work together to develop standards based instruction and activities that could be used in any STEM classroom or laboratory. When time and resources are not available for science and mathematics students to complete activities in their classrooms, they could complete those activities in technology and engineering classrooms. This approach to education would better utilize time and resources, and, if the teachers who responded to this study are correct, students will *Learn Better by Doing*.

**References**


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Tools and Materials in Primary Education: Examining Differences Among Male and Female Teachers’ Safety Self-Efficacy

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Abstract
The Standards for Technological Literacy call for primary education students to learn about the safer use of tools and materials to design and create solutions. Moreover, numerous sources have indicated specific tools and materials at this level are appropriate and can help enhance students’ knowledge of science, technology, engineering, and mathematics (STEM) practices. However, the use of tools and materials in primary education is sometimes limited due to teachers’ lack of safety training. This study utilized a concurrent quasi-mixed design to investigate 131 U.S. primary teachers’ self-efficacy regarding safer use of tools and materials before and after a four week STEM professional development (PD) experience. Quantitative pre and postsurvey self-efficacy ratings derived from the Science Teaching Efficacy Belief Instrument (STEBI) were mixed with qualitative findings from open-ended survey questions. The overarching goal of this study was to examine if there was a significant difference among gains in male and female participants’ self-efficacy after participating in a four week STEM professional development experience. The findings revealed that female primary educators reported significantly greater safety self-efficacy gains than male participants. This study provided recommendations to enhance primary teachers’ self-efficacy toward safer use of tools and materials in their classroom.

Keywords: Safety, STEM education, self-efficacy, gender differences

Introduction and Background
Safer use of engineering tools (hand and power tools such as hammers, screw drivers, coping saws, hand crank drills, clamps, files, etc.) and materials (wood, metal, plastic, etc.) is a key part of hands-on, design based science, technology, engineering, and mathematics (STEM) teaching and learning (Love, 2014; NSTA 2016; Roy, 2013). This has been a core component of technology and engineering (T&E) education instructional standards (ITEA/ITEEA, 2000/2002/2007; Gunter, 2007; Love, 2014) and program standards (ITEA/ITEEA, 2003) for over a decade. Specifically, the Standards for Technological Literacy state that when learning about the core concepts of technology, primary grade students “need to recognize the importance of tools in getting things done” and “the safety needs” of designing a solution (ITEA/ITEEA, 2000/2002/2007, pp. 35). In the United States (U.S.) the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) have also called for students, including those in the primary grades, to construct models and engage in engineering design that involves the use of hand and power tools (NSTA, 2016; Roy, 2013). Some have advocated that the use of engineering tools is not only appropriate for primary grade students, but necessary for solving engineering design problems (Roy, 2013; Weaver, 2017).
One concern with using engineering tools and materials at the primary grade level is the limited experience and preparation of primary teachers to safely use these items in their classroom (Love, in press; Roy, 2013). Few studies have examined STEM education safety issues, especially the influence of preparation experiences on safer teaching and learning. Plohocki (1998) discovered that a number of training experiences did not significantly increase science teachers’ safety knowledge. One of the most renowned safety studies found that accidents and mishaps increased at a statistically significant rate as the number of students in a classroom increased (Stephenson, West, Westerlund, & Nelson, 2003). A more recent study discovered that primary level teachers had reservations about using engineering tools and materials in their classroom and also had difficulty imagining ways in which they could be safely incorporated to solve engineering design problems (Grubbs et al., 2016). Outside of the U.S. there have been studies conducted on methods for teaching safety concepts (Mayo, Quintana, & Rogado, 2015), and assessing students’ use of laboratory manuals to improve safety practices and encourage active participation in the learning process (Rogado, Quintana, & Mayo, 2017). The latest STEM education safety study found that primary level U.S. teachers who participated in professional development (PD) taught by T&E educators reported significantly greater gains in their safety self-efficacy than those who participated in the same PD experience delivered by science educators. This study also indicated that there may be differences among male and female teachers’ perceptions regarding safer use of engineering tools and materials but recommended further research to examine this issue (Love, in press).

A number of studies have investigated differences among male and female perceptions’ of engineering tools and materials, however there is limited research on the differences among male and female educators’ perceptions about teaching the safer use of these items. Perceptions such as self-efficacy have been found to influence teaching practices (Love, in press; Luft et al., 2011). Lippa (1998) found a significant difference among the number of men who preferred careers doing things or impersonal tasks (e.g., working with machines, materials, and tools) versus women who wanted a career performing interpersonal tasks (e.g., caring for, teaching, or helping others). Moreover, Agapiou (2002) discovered that Scottish construction supervisors and employers viewed females as capable of learning to use tools and doing all aspects of the construction work, however they believed females “did not have the innate ability to use tools” and were “not equally suitable for the work” (p. 701). Within education, a study examining middle school Taiwanese students found that both males and females had difficulty operating hand tools, and females were more likely to rely on teachers’ extra guidance but eventually overcame their fear associated with operating power tools (Hong, Hwan, Wong, Lin, & Yau, 2012). Gender perceptions associated with the use of engineering tools and materials must be addressed within STEM education to encourage more female students to pursue careers in male dominant STEM fields that require tool and materials knowledge (Knopke, 2014; Weber & Custer, 2005).

Considering the importance of tools and materials to solve engineering design problems in STEM education, and the limited amount of research examining differences between male and female teachers’ perceptions’ related to teaching the safer use of these items, the following research questions were developed.

**Research Questions**

RQ1: To what extent do select prior experiences using engineering tools and materials differ among male and female primary level educators?

RQ2: To what extent do primary level educators’ self-efficacy gains regarding the safer use of engineering tools and materials in their classroom differ among male and female participants after participating in a PD experience?
RQ3: Was there an identifiable difference among male and female primary level educators’ perceptions regarding the safer use of engineering tools and materials in their classroom after participating in a PD experience?

Participants
The participants of this study were the same as those identified by Love (in press). This research was part of a grant-funded project focused on enhancing primary level educators' teaching of engineering within elementary science lessons. Participants were grades 1-6 teachers from across a southern state within the U.S. and possessed a broad range of background experiences. The mean age of the 131 participants was 39 years old and the average years of teaching experience was 10.5. Most participants were white (80%) females (92%) who taught fourth (31%) or fifth (50%) grade in rural school districts (45%). Many were certified to teach grades K-6 (71%) or PreK-8 (23%).

Methodology
The methodology closely followed that used in a similar study by Love (in press). This study used a concurrent quasi-mixed design (Teddlie & Tashakkori, 2006) with mixing of quantitative and qualitative data occurring at the analytical and inferential stages. The four-week PD was delivered by science and T&E education experts at four sites across the state. Each site engaged participants in the same engineering design challenge that required instruction on safer use of engineering tools and materials. Participants completed the presurvey prior to the engineering challenge instruction during week one, and the postsurvey during the fourth and final week of the PD. Quantitative responses were entered into SPSS for statistical analyses.

Instrumentation
The Science Teaching Efficacy Belief Instrument (STEBI) (Enochs & Riggs, 1990) modified by Love (in press) was used to measure participants’ self-efficacy toward teaching the safer use of engineering tools and materials in their classroom. The original STEBI instrument was found to be reliable and valid (Bleicher, 2004; Enochs & Riggs, 1990), and using Cronbach’s alpha Love (in press) determined the instrument used in this study had a high reliability for both presurvey (.807) and postsurvey (.888) questions. This instrument used a five point Likert scale ranging from strongly disagree (1) to strongly agree (5). The 13 items which were used to measure participants’ self-efficacy are included in Appendix A. Face validity of the instrument items was established among a panel of U.S. science and T&E education safety experts (Love, in press).

Findings

Prior Experiences with Engineering Tools and Materials (RQ1)
Research question one examined to what extent participants’ prior experiences using engineering tools and materials differed according to gender. Descriptive statistics from the supplemental presurvey questions were analyzed. Responses to the supplemental presurvey question asking participants to describe their prior formal and informal experiences with engineering tools and materials were qualitatively coded into three categories and assigned a quantitative rating (Love, in press). Sixty-four percent of the male participants had completed at least one T&E education course in secondary school, 72% reported having mediocre to extensive prior experience using engineering tools and materials; whereas 32% of female participants had taken at least one T&E education course, and 31% reported having mediocre to extensive prior experience using engineering tools and materials. A low percentage of male (27%) and female (35%) teachers reported using tools in prior courses they taught, and most male (82%) and female (85%) teachers had not participated in any prior PD about safer engineering tool and materials usage.
Table 1
Summary of Participants’ Prior Experiences with Engineering Tools and Materials

<table>
<thead>
<tr>
<th>Experience</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of T&amp;E Secondary Courses Completed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4 (36)</td>
<td>81 (68)</td>
</tr>
<tr>
<td>1-2</td>
<td>5 (46)</td>
<td>35 (29)</td>
</tr>
<tr>
<td>3-4</td>
<td>1 (9)</td>
<td>4 (3)</td>
</tr>
<tr>
<td>5+</td>
<td>1 (9)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Prior Level of Tool and Materials Experience</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>2 (18)</td>
<td>36 (30)</td>
</tr>
<tr>
<td>Limited</td>
<td>1 (9)</td>
<td>47 (39)</td>
</tr>
<tr>
<td>Mediocre</td>
<td>4 (36)</td>
<td>19 (16)</td>
</tr>
<tr>
<td>Extensive</td>
<td>4 (36)</td>
<td>18 (15)</td>
</tr>
<tr>
<td>Used Tools and Materials in Prior Courses Taught</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>3 (27)</td>
<td>42 (35)</td>
</tr>
<tr>
<td>No</td>
<td>8 (73)</td>
<td>78 (65)</td>
</tr>
</tbody>
</table>

(continued)

Table 1 Continued

<table>
<thead>
<tr>
<th>Experience</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior PD on Tool and Materials Usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>2 (18)</td>
<td>18 (15)</td>
</tr>
<tr>
<td>No</td>
<td>9 (82)</td>
<td>102 (85)</td>
</tr>
</tbody>
</table>

Note. PD = Professional Development.

Mann-Whitney U tests were conducted to further examine the extent of the differences among male and female participants’ prior experiences with engineering tools and materials. The Mann-Whitney U analysis was selected due to the ordinal characteristics of the two independent samples from a non-parametric population (Sheskin, 2011). The first test examined the number of T&E education courses that male and female teachers reported completing during their experience as a secondary education student. The p-value among males and females (0.016) was less than the alpha value of 0.05, indicating that there was a statistically significant difference between the number of secondary T&E courses that male and female participants completed (Table 1). The second test examined participants’ prior experience level with engineering tools and materials. The p-value among males and females (0.031) was less than the alpha value of 0.05, indicating that there was a statistically significant difference between
male and female participants’ level of engineering tools and materials experience prior to participating in the PD (Table 2).

Table 2

<table>
<thead>
<tr>
<th>Differences in Number of T&amp;E Secondary Courses Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
</tbody>
</table>

Note. * = statistical significance at the 0.05 level.

Table 3

<table>
<thead>
<tr>
<th>Differences in Prior Level of Engineering Tools and Materials Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
</tbody>
</table>

Note. * = statistical significance at the 0.05 level.

Self-Efficacy toward Engineering Tools and Materials (RQ2)

Research question two examined to what extent participants’ self-efficacy gains regarding the safer use of engineering tools and materials in their classroom differed according to gender. Multiple data sources were used to analyze this research question. When asked in the supplemental postsurvey questions if they believed their awareness of engineering tools and materials safety had increased after participating in the PD, nine (82%) male participants reported some increase while two (18%) reported no increase. Among the female participants, 29 (24%) reported some increase, 41 (34%) reported no increase, and 50 (42%) reported a considerable increase. Additionally, differences between the mean scores on the pre and post self-efficacy survey questions were examined. Female participants reported greater mean self-efficacy gains than male participants on nine of the 12 (75%) items. Females also reported a total mean self-efficacy difference that was 59% higher than male participants (Appendix A). To examine the extent of the differences between male and female participants’ overall self-efficacy gains, the researcher once again conducted a Mann-Whitney U test. The p-value among males and females (0.035) was less than the alpha value of 0.05, indicating that there was a statistically significant difference between male and female participants’ self-efficacy regarding safer use of engineering tools and materials (Table 3).

Table 4

<table>
<thead>
<tr>
<th>Differences in Total Self-Efficacy Gains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
</tbody>
</table>

Note. * = statistical significance at the 0.05 level.

Perceptions of Using Tools and Materials in the Classroom (RQ3)

To examine the third research question and elicit more detail regarding differences in teachers’ perceptions about using engineering tools and materials, open-ended postsurvey questions were qualitatively analyzed for any gender related comments. A few female participants believed that they would not need to use engineering tools and materials in their classroom. As
one teacher expressed, “I would never use these engineering tools in my classroom. These are things my husband would do for me in prep for a lab.”

Another finding that emerged was some female participants were not as comfortable with using engineering tools and materials as males because they were not taught how to use them during their educational and teacher preparation experiences. As one participant noted, when she went to school the industrial arts classes (now T&E education) were reserved for males while the females were placed in home economics (now family and consumer science) courses. She referred to these courses as “gender segregated” and believed the industrial arts classes would have benefited her ability to incorporate safer use of engineering tools and materials into her teaching.

Discussion
A number of conclusions were drawn from mixing the quantitative and qualitative findings. The data revealed that female participants reported a significantly lower level of prior experiences using engineering tools and materials than male participants. They also completed significantly less T&E education courses than male participants during their secondary education experience. As suggested by the literature and the qualitative findings, these are generally the courses where students learn about the safer use of engineering tools and materials from teachers with expertise in this area (Love, in press; NSTA, 2016; Roy, 2013). These experiences could be beneficial for future primary level teachers and the safer use of these items in their classroom. Additionally, if gender perceptions or barriers are discouraging female students from enrolling in T&E courses, they may be less likely to pursue STEM careers involving tools and materials (Knopke, 2014; Weber & Custer, 2005).

The findings from this study do not suggest that female participants were not as prepared or not as capable as male teachers to safely use engineering tools and materials in their teaching. This study simply suggests that participating female teachers reported significantly greater self-efficacy gains than males regarding the safer use of engineering tools and materials in primary education. A greater percentage of female participants also reported considerable increases in their safety awareness. While the correlations between these gains and select preparation experiences were not examined, this study does provide a promising outlook about the potential benefits of PD addressing the safer use of engineering tools and materials.

There are certain limitations of this study that should be acknowledged. Findings from this study cannot be generalized beyond those participating teachers. Although self-efficacy has been found to influence teaching practice and quality (Love, in press), the findings reflect participants’ self-reported perceptions, not observed safety practices. The PD at three of the sites was delivered by both male and female instructors while one of the sites consisted of only female instructors. To what extent the gender of the instructors influenced participants’ safety self-efficacy and perceptions was not investigated as part of this study. Lastly, the findings from this study merely examined differences between male and female participants, no correlations can be drawn between their preparation experiences and the significant differences without further analysis.

Recommendations

For Practitioners
STEM PD for primary level educators should emphasize the safer use of engineering tools and materials to increase teachers’ self-efficacy and perceptions about using these items to develop engineering design solutions. Similar experiences should be included in primary teachers’ pre-
service preparation coursework. Additionally, strategies to modify engineering tool and material activities so they are more appealing to both genders should be a component of pre and in-service teacher preparation experiences.

For Researchers
Further research is needed to examine the strength of the relationships between teachers’ prior experiences using engineering tools and materials, and their self-efficacy gains regarding safer use of these items. Additional safety preparation experiences (e.g., informal experiences, gender of those delivering the PD or coursework) and the extent to which these experiences influence males’ and females’ safety self-efficacy should also be examined. Consistent with Love’s (in press) previous recommendation, future studies should investigate teachers’ demonstrated safety practices through observations.

References


Appendix A

*Differences in Pre/Post Self-Efficacy Survey Item Mean Gains*

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>μ Presurvey</th>
<th>μ Postsurvey</th>
<th>μ Gains</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. I will continually find better ways to teach about the safer use of</td>
<td>4.18 M</td>
<td>4.36 M</td>
<td>0.18 M</td>
</tr>
<tr>
<td>engineering tools and materials.</td>
<td>4.01 F</td>
<td>4.29 F</td>
<td>0.28 F</td>
</tr>
<tr>
<td>3. Even if I try very hard, I will not teach about the safer use of</td>
<td>4.55 M</td>
<td>3.73 M</td>
<td>-0.82 M</td>
</tr>
<tr>
<td>engineering tools and materials as well I will most subjects.</td>
<td>4.12 F</td>
<td>4.26 F</td>
<td>0.14 F</td>
</tr>
<tr>
<td>5. I know the necessary steps for teaching about safer use of</td>
<td>3.18 M</td>
<td>3.73 M</td>
<td>0.55 M</td>
</tr>
<tr>
<td>engineering tools and materials.</td>
<td>2.84 F</td>
<td>4.05 F</td>
<td>1.21 F</td>
</tr>
<tr>
<td>6. I will not be very effective in monitoring the safe use of engineering</td>
<td>3.91 M</td>
<td>4.27 M</td>
<td>0.36 M</td>
</tr>
<tr>
<td>tools and materials.</td>
<td>4.20 F</td>
<td>4.32 F</td>
<td>0.12 F</td>
</tr>
<tr>
<td>8. I will generally teach engineering tool and material safety concepts</td>
<td>3.73 M</td>
<td>3.91 M</td>
<td>0.18 M</td>
</tr>
<tr>
<td>ineffectively.</td>
<td>3.92 F</td>
<td>4.16 F</td>
<td>0.24 F</td>
</tr>
<tr>
<td>12. I understand engineering tool and materials well enough to be</td>
<td>3.09 M</td>
<td>3.64 M</td>
<td>0.55 M</td>
</tr>
<tr>
<td>effective in teaching how to safely use them.</td>
<td>2.97 F</td>
<td>4.00 F</td>
<td>1.03 F</td>
</tr>
<tr>
<td>17. I will find it difficult to explain to students how to safely use</td>
<td>4.00 M</td>
<td>4.00 M</td>
<td>0.00 M</td>
</tr>
<tr>
<td>engineering tools and materials.</td>
<td>3.77 F</td>
<td>4.19 F</td>
<td>0.42 F</td>
</tr>
<tr>
<td>18. I will typically be able to answer students' questions about the safety</td>
<td>4.00 M</td>
<td>3.91 M</td>
<td>-0.09 M</td>
</tr>
<tr>
<td>of engineering tools and materials.</td>
<td>3.53 F</td>
<td>4.17 F</td>
<td>0.64 F</td>
</tr>
<tr>
<td>19. I wonder if I will have the necessary skills to teach how to safely use</td>
<td>3.27 M</td>
<td>3.82 M</td>
<td>0.55 M</td>
</tr>
<tr>
<td>engineering tools and materials in science.</td>
<td>2.96 F</td>
<td>3.72 F</td>
<td>0.76 F</td>
</tr>
<tr>
<td>20. Given a choice, I will not invite the principal to evaluate my teaching</td>
<td>3.64 M</td>
<td>4.00 M</td>
<td>0.36 M</td>
</tr>
<tr>
<td>regarding the safe use of engineering tools and materials in science.</td>
<td>3.72 F</td>
<td>4.05 F</td>
<td>0.33 F</td>
</tr>
<tr>
<td>22. When teaching science, I will usually welcome student questions about</td>
<td>4.27 M</td>
<td>4.18 M</td>
<td>-0.09 M</td>
</tr>
<tr>
<td>the safer use of engineering tools and materials.</td>
<td>4.14 F</td>
<td>4.32 F</td>
<td>0.18 F</td>
</tr>
<tr>
<td>23. I do not know what to do to motivate students to learn about safer use</td>
<td>3.45 M</td>
<td>4.09 M</td>
<td>0.64 M</td>
</tr>
<tr>
<td>of engineering tools and materials.</td>
<td>3.50 F</td>
<td>3.98 F</td>
<td>0.48 F</td>
</tr>
<tr>
<td>Sum of μ scores</td>
<td>45.27 M</td>
<td>47.64 M</td>
<td>2.37 M</td>
</tr>
<tr>
<td></td>
<td>43.68 F</td>
<td>49.51 F</td>
<td>5.83 F</td>
</tr>
</tbody>
</table>

*Note.* M = males; F = females.
Design Heuristic Use to Overcome Similarity or Fixation of Design Ideas

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Abstract
A key issue highlighted by the Irish State Examinations Commission Chief Examiner was similarity of students’ practical coursework for State Examinations. Similarity of practical coursework may arise due to fixation on existing products and/or initial ideas, thus limiting creative design ideas. While successful idea generation is essential for creative solutions, second level students often receive limited instruction about how to accomplish it. This issue evidenced the need for design methods to support idea generation in the initial stages of a design process. This research study investigated the application of an idea generation method, Design Heuristics, to support the initial stages in a design process in a second level education context. The study occurred in a second level school in the south of Ireland with thirty-two second year students. The students had little to no experience of a design process. After posing a problem statement, idea generation was facilitated over two sessions. Using the same problem statement, session one facilitated student’s natural idea generation, or initial naïve ideas, and session two facilitated students’ application of the idea generation method, Design Heuristics. In this study, through comparison of session one and session two, we investigated how Design Heuristics promote fluency and flexibility for creative idea generation with second level education students. The findings demonstrated the positive influence (large effect size; 0.946) of Design Heuristics in the context of increasing fluency and flexibility of creative design ideas. The findings also evidence a reduction in fixation and similarity of design ideas. It is necessary that idea generation is supported and promoted in second level education to ensure students experience and develop their creative capacities.

Keywords: Idea Generation, Similarity, Fixation, Design Heuristics

Introduction
Teaching students to think innovatively and creatively is an area of difficulty for many second level education educators. Educators lack techniques to support instruction on idea generation (Grasso, et al, 2008; Klukken, et al, 1997; Pappas & Pappas, 2003; Richards, 1998), and pedagogical strategies for creative idea generation can raise challenges for educators. During the early concept generation phase, students often become fixated on their initial concepts (Cross, 2010; Jansson et al, 1991; Purcell et al, 1996). This results in a need for pedagogical tools and strategies to aid students in enriching their early design phase.
In this study we investigated how an empirically-validated idea generation tool, Design Heuristics, was integrated into the initial conceptual stages of a design process by 14 year old students. The goal of this research was to overcome the similarity of coursework challenge through the incorporation of the idea generation tool, Design Heuristics. This paper presents results in the context of overcoming fixation and improving second level student idea generation outcomes with the integration of Design Heuristics.

**Design best practice and misconceptions**

Effective implementation of design practice through a design process initially stems from previous personal experience. Bantock expresses this view as he observes children designing Christmas party hats. This design task was an unstructured design activity whereby children were allowed freedom of action, or without a prescribed process. Bantock states that “one child finally evolved a very inadequate copy of a crown he had previously seen. The rest merely copied” (Bantock, cited in Kimbell, 1982 p.13). Kimbell further elaborates on Bantock’s view stating that “unless and until the child has been given some options from which to choose, he has no real choice at all”. Therefore, design practice through problem solving is best implemented through an initial framework of guidance. Thus the quality of any evocation of previous experiences and examples the beginner designers have will be “directly related to the skill with which the teacher constructs the framework of learning” (Kimbell, 1982). In the Irish context a design process is outlined as a guideline for the problem solving task (Figure 1). This systematic approach provides both the teacher and students with a framework. However a design process model in second level education often represents a linear approach, due to many issues such as assessment-driven practices. In addition, in the context of each stage of a design process students may not have support or guidance on best practice methods or tools. This is especially evident in the context of generation and development of design ideas. This is highlighted by Atkinson, (2000) who refers to the design process by expressing that it is possibly preventing flexibility which in turn is affecting pupils’ creativity. This example represents the practice occurring with second level students’ similarity of coursework. These issues highlight the need for greater commitment in supporting students with tools to foster best practice design skills for idea generation.

![Figure 1. State Examination Commission design process model (SEC, 2017)](image-url)
Crismond’s research on engineering design and science inquiry outlines common misconceptions in design approach and practice for novice designers (Crismond & Adams, 2012). The first misconception outlined details a novice designer’s initial approach in defining a problem. Novice designers often embark on challenges as “well-defined problems that they immediately solve with a single correct answer” (ibid). This approach could lead to an inability to identify, understand and frame the problem. In addition, Crismond’s research draws a parallel with the Chief Examiners suggestion that students’ intention of finding an immediate solution limits design exploration thus results in fixation on one solution, the initial idea. Crismond further states that beginner designers can be “reluctant to generate more than one solution to a design challenge” (Crismond, 2013). This is known as idea fixation whereby the designer is unable to see new applications for objects they are exposed to, which results in early commitment to a design solution (Gero, 2011).

Fixation
Jansson & Smith (1991) describe the influence a design process has on the outcome of conceptual design. Each step of the design process is different, yet highly important. A designer’s prior experience and knowledge also has an impact on a final solution based on how a design process is approached. Depending on the level of prior knowledge and experience held by the designer, a different approach within a design process may be needed to ensure fixation is overcome.

Examples of existing solutions generally provide inspiration to designers. Studies show that designers fixate to examples given to them whether the examples are in the form of sketches, line drawings, photographs, or physical models (Atilola, et al., 2015). These examples act as external stimuli and tend to make designers sensitive to the features of that particular example. Despite looking for inspiration on the design, on the down side, this hinders their creativity. Toh, et al., (2014) discuss design fixation as a considerable limitation on the idea generation stage of the design process. During the idea generation stage of a project, creativity and exploration are key aspects in generating original solutions. Condoor & LaVoie, (2007) discuss the effect that fixation has on idea generation in that it focuses the designer into “locking” into existing ideas, hence disregarding creativity, and exploration during the early stages of idea generation (Condoor & LaVoie, 2007). To prevent the issue of similarity that is outlined in the Chief Examiners Report, overcoming fixation going to play a crucial role in reducing this similarity. This way, more unique ideas could be produced.

Idea generation methods
There are a variety of idea generation tools available for concept generation (Daly, et al, 2012; Daly, et al, 2014), including analogical thinking (Perkins, 1997), brainstorming (Osborn, 1957), conceptual combination (Finke, et al, 1992), Design Heuristics (Daly, et al, 2012; Daly, et al, 2014; Design Heuristics, 2012;; Yilmaz, et al, 2010a; Yilmaz, et al, 2010b), lateral thinking (de Bono, 1999), morphological analysis (Allen, 1962; Zwicky, 1969), SCAMPER (Eberle, 1995), Synectics (Gordon, 1961), and TRIZ (Altshuller, 1984; Altshuller, 1997). These tools vary in focus and specificity. For example, brainstorming recommends general guidelines, including ‘suggest many ideas’, and ‘do not evaluate ideas’, but provides little direction about how to actually generate ideas. Other methods, such as SCAMPER, provide more specific prompts on how ideas can be formed by “combining” or “modifying” existing ideas. Some tools, such as Synectics and TRIZ, require extensive training and practice to become skilled in their use (Ilevbare, et al, 2013). In addition, only a few of these idea generation tools have been

Brainstorming, like the other methods mentioned above, can be successful idea generation tools for designers overcoming fixation. An informed and experienced designer can generate many ideas through brainstorming with the intention of selecting the optimal idea for further development. In an educational setting with novice designers, a systematic iterative design process requires the support and direction of methods, activities, and instructional strategies for the promotion of creative idea generation.

To ensure a design method or activity is used effectively it is important that an informed approach is implemented. In the context of this study, fixation represents the over-reliance on features of existing designs or initial design ideas (Crilly, 2015). As outlined earlier, in a second level Technology Education setting a design process is often practiced in a systematic assessment driven manner, which results in an Einstellung effect, where students and teachers are mentally set in their approach to problem solving (Crilly, 2015). Aligning with de Bono’s assumption that education is based “on collecting more and more information for it to sort itself out into useful ideas” (de Bono, 1970, p. 9). He further extrapolates on this assumption that education “is not only concerned with collecting information but also with the best ways of using the information collected” (ibid, p. 10). He draws upon how the mind works whereby the mind holds “the ability to create its own patterns” (ibid, p.28) and therefore acts as a type of information handling system. He interprets this system as “an arrangement of circumstances that make things happen in a certain way” (de Bono, 1969, p. 17). He highlights disadvantages of this system, two being; “It is extremely difficult to change patterns once they have become established” (de Bono, 1970, p. 36) and “Information that is arranged as part of one pattern cannot easily be used as part of a completely different pattern” (ibid, p. 37). Such disadvantages suggest the limitations the system has surrounding the modification of an idea or the creation of a completely new idea. This highlights the limitations on promoting fluency and flexibility in idea generation. It is evident that a method is required to support lateral thinking, thus overcome similarity of coursework, or fixation on existing, or initial ideas. This study investigated the use of the Design Heuristics tool to overcome this issue, thus foster the creativity of students design ideas.

**Design Heuristics**
Design Heuristics serve as “cognitive shortcuts” for exploring the space of possible design solutions. They are intended to guide designers towards non-obvious ideas, and helping them generate multiple concepts to consider. They are also intended to assist designers when they become fixated by helping to generate more (fluency), and more different (flexibility), ideas (Daly, et al, 2012; Daly, et al, 2014; Yilmaz, et al, 2010c).

The Design Heuristics tool is comprised of 77 cards used to enhance idea generation. Each card includes a specific design prompt, along with a graphical representation and descriptive text. On the reverse of each card, two existing product examples are provided where the specific heuristic is evident. An example of a Design Heuristic is, **Add to existing product** (Figure
2). This prompts the designer to use an existing item as part of the products function. For example, an engineer could take an existing product like a bicycle and apply the foot-operated lever as a power source for a new idea. This one Design Heuristic can be applied repeatedly in alternate ways to generate other unique ideas (e.g., using stilts to add height to a standard chair). Other Design Heuristics can be added and combined to produce a variety of novel ideas. The many prompts available in the 77 Design Heuristics ensure a large supply of possible directions to pursue.

![Design Heuristic Card Example](image)

*Figure 2. Example of a Design Heuristic card (front and back)*

The set of Design Heuristics were identified in empirical studies including 1) behavioral studies of student and expert conceptual designs; 2) a case study of a long-term project by a professional designer; and 3) analyses of award-winning products. Design Heuristics were identified through analysis of sketches showing transitions from one concept to another over time (Yilmaz & Seifert, 2011). Each heuristic was observed multiple design concepts, by multiple engineers and designers, and in solutions for multiple design problems. Accumulating evidence across studies resulted in 77 unique Design Heuristics applicable to a wide variety of products. Past research has demonstrated the effectiveness of the Design Heuristics tool in facilitating idea generation for third level engineering students (Daly, et al, 2012; Daly, et al, 2014; Yilmaz, et al, 2014; Kramer, et al, 2015; Yilmaz, et al, 2010c; Christian, et al, 2012) and professionals (Yilmaz & Seifert, 2011; Daly, et al, 2011).

This study focuses on the impact of the Design Heuristic cards on students’ idea generation during the early stages of the design process in second level education. Teaching students to think innovatively is difficult for many educators, mainly because of a lack of effective instructional methods. The investigation on Design Heuristics in a second level education context will potentially support students in the initial stages of a design process to promote the experience of multiple varied solutions, thus reduce the issue of similarity and fixation.

**Methodology**

**Introduction**

This study set out to investigate overcoming similarity of coursework, in the context of fixation on a first idea, and/or an existing solution, through the use of the Design Heuristics tool. For the purpose of this study session one (control) and session two (experimental) design ideas were assessed using two attributes relevant to creativity; fluency, and flexibility.
Participants
Session one and session two involved thirty-two second level education Technology Education students from the south of Ireland. The gender ratio is 1:4 female to male. The mean age of participants was 13.9 (StDev 0.465). The participants had no prior experience of a design process or the idea generation tool, Design Heuristics. The participant’s prerequisite knowledge includes wood science, best practice principles for wood processing, and creative craft practices.

Study protocol
The study was piloted with a similar cohort to ensure the study was valid, and refinements were identified and implemented prior to the study reported in this paper. The study focused on two 30-minutes idea generation sessions carried out at the beginning and end of an eight week period; session one took place in week one, and session two took place in week eight (Figure 3). Between weeks two and eight, participants were not exposed to any design-based activities which could impact on their experience or approach in session two. However it is acknowledged that session one could influence session two. The two sessions were structured cognizant of the State Examinations Commission design process, which recommends students follow the sequence of such a design process (Figure 1). For the purpose of this study, the initial conceptual stage ‘Analysis of brief’ and ‘Development of design ideas’ were supported via worksheets. The worksheet (A3 size page) required students to sketch up to four ideas. The worksheet was divided in four quadrants comprising of a blank square, text box for a description of the idea, and another text box to outline the origin of the idea. The session two worksheet had one additional text box to detail the Design Heuristic card number they used in developing their design ideas. For this paper ‘Development of design ideas’ are the focus in addressing the research question. The other design process stages were not of focus for this study. With the isolation or removal of ‘Investigation / Research’ from the initial conceptual design process stages, it is acknowledged that the design ideas could be naïve, as students primarily used their intuitive knowledge to generate initial ideas.

![Figure 3. Session one and session two protocol structure](image)

The problem statement used in this study was derived from the State Examinations Junior Cycle Practical Project work briefs. Participants addressed the following problem statement in the study: “Bathrooms are one of the main rooms in every domestic home and can very easily get unorganized and cluttered. Design and make an artefact which will provide the user with a ‘go-to’ point for typical bathroom utensils in your home. The artefact is to be elegant in setting and must be easily accessible to all items as bathroom items are used at often stages of the day”.

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6 | P a g e
For both session one and session two, participants were allocated 10 minutes to generate a maximum of or up-to four design ideas. The maximum of four ideas was based on the State Examinations assessment guidelines, whereby students are required to generate and develop up to four ideas. In this context both sessions reinforced the following idea generation guidelines:

- It does not matter if you cannot make it
- Quality of sketches do not matter
- If you cannot draw it very well, use words to explain it.
- Quantity counts - not quality
- Spellings do not matter

In session one, students were informed to generate ideas using Brainstorming as the method for idea generation. In this context they were informed of the following guidelines for Brainstorming; 1) Postpone and withhold your judgment of ideas; 2) Encourage wild and exaggerated ideas; 3) Quantity counts at this stage- not quality; 4) Build consecutively on your ideas; 5) Every idea has equal worth. In session two, with the use of five Design Heuristics cards, students were informed of the following Design Heuristic tool guidelines; 1) Use a new card every time you want to generate a new idea; 2) Combine multiple cards to generate a single idea; 3) Use a single card to generate multiple ideas; 4) Generate new ideas by applying a card to a previous idea; 5) Use the abstract image or the examples to inspire ideas.

Data analysis
This study sought to investigate the impact of the Design Heuristic tool in over-coming similarity of coursework and fixation, through comparison of design ideas from session one and session two. Thus the design ideas were evaluated in the context of creativity attributes; fluency, and flexibility (Haensly & Torrance,1990; Runco, 2001). When judging creativity, reliability issues are inherently major concerns. Numerous validity issues need to be addressed in creativity assessment. Thus fluency and flexibility were the two main criteria to evaluate participants ideas in session one and session two. In the context of fluency, all ideas were analyzed in the context of relevant responses, after which a count of the number idea these ideas was recorded. The relevant responses were then thematically analyzed, which allowed for categorization of ideas. Thus the number of different categories of unique ideas (flexibility) for each session was recorded. Using fluency and flexibility analysis an overall comparison between session one and session two generated ideas occurred.

Results
This study set out to overcome the issue of similarity of coursework through investigating the impact of applying an idea generation tool in a second level education setting. This research aim was explored through a comparison of two sessions’ design ideas. In the context of creativity, session one and session two design ideas were comparatively analyzed with respect to fluency and flexibility.

Fluency
The number of relevant ideas generated by the 32 participants in session one and session two was 65 (42%) and 88 (58%), respectively (Table 1). From analysing the 153 ideas in the context of fluency comparison between session one and session two, there was a 74% increase in idea generation. The implementation of the Design Heuristic tool in session two could be identified as the main rationale for participants’ increase in number of relevant responses as the tool provided students with a mechanism to modify and develop their ideas further.
Table 1

Fluency of idea generation

<table>
<thead>
<tr>
<th></th>
<th>Session 1</th>
<th>Session 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of relevant ideas:</td>
<td>65</td>
<td>88</td>
<td>153</td>
</tr>
<tr>
<td>Percentage of ideas:</td>
<td>42%</td>
<td>58%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Five participants generated the maximum of four ideas in both session one and session two (Table 2). Of the ideas generated in session one (42%), 12 participants generated ‘one idea’, representing eight-percent of the total number of ideas generated. This percentage for ‘one idea generation’ could indicate fixation on initial idea in session one. In session two, 5 participants demonstrated fixation on initial idea, representing three-percent of the ideas generated. In terms of generating three or four ideas; for session one 13% of the ideas generated represent the ‘fourth idea’ by five participants, which increased to 21% in session two by eight participants. The main rationale for this 62.5% increase in the number of ideas generated is the application of the Design Heuristic tool. A selection of participants’ feedback also supports this finding;

“The cards helped me come up with more ideas” (Participant 5)
“The card activity made it a lot easier to think of ideas” (Participant 6)
“It made me think of more ideas to try solve the problem” (Participant 9)
“I will think of more ideas in future before I make it” (Participant 10)
“I used my imagination more when designing” (Participant 12)
“The cards pushed by creativity by adding more” (Participant 23)

Table 2

Distribution of ideas generated with respect to requested maximum (4 per session)

<table>
<thead>
<tr>
<th>Requested number of ideas:</th>
<th>Four</th>
<th>Three</th>
<th>Two</th>
<th>One</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Ideas distribution in Session 1</td>
<td>13%</td>
<td>6%</td>
<td>16%</td>
<td>8%</td>
</tr>
<tr>
<td>No. of participants:</td>
<td>5</td>
<td>3</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>% Ideas distribution in Session 2</td>
<td>21%</td>
<td>25%</td>
<td>8%</td>
<td>3%</td>
</tr>
<tr>
<td>No. of participants:</td>
<td>8</td>
<td>13</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

The following section further analyses the participant’s idea generation with respect to flexibility. This further explored evidence for similarity of design ideas in the context of fixation on existing examples, and initial ideas.

**Flexibility**

The study problem statement did not prescribe the artefact domain; ‘for the user with a ‘go-to’ point for typical bathroom utensils in your home’. Thus the flexibility, or diversity of categories identified, was broad from the 153 relevant ideas generated. Overall from session one and session two, in the context of flexibility of 153 design ideas, there were 33 categories identified (Table 3). From analysing the 153 relevant ideas in the context of the 33 categories, there were 325 instances identified overall. Thus many ideas represented numerous categories. From Table 2 it is evident that two main categories dominated; ‘storage unit’ (22%) and ‘shaped
mirror’ (18%). The ‘backboard’ and ‘shelving unit’ ideas were the categories evident in 7% of ideas generated. The remainder of idea categories evident represented 4%, 3%, 2%, and 1%.

Table 3  
*Session one and Session two fluency and flexibility of categories*

<table>
<thead>
<tr>
<th>Category</th>
<th>Session one</th>
<th>Session one %</th>
<th>Session two</th>
<th>Session two %</th>
<th>Overall</th>
<th>Overall %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage unit</td>
<td>35</td>
<td>47%</td>
<td>39</td>
<td>53%</td>
<td>74</td>
<td>22%</td>
</tr>
<tr>
<td>Shaped Mirror</td>
<td>29</td>
<td>48%</td>
<td>31</td>
<td>52%</td>
<td>60</td>
<td>18%</td>
</tr>
<tr>
<td>Backboard</td>
<td>12</td>
<td>48%</td>
<td>13</td>
<td>52%</td>
<td>25</td>
<td>7%</td>
</tr>
<tr>
<td>Shelving unit</td>
<td>15</td>
<td>63%</td>
<td>9</td>
<td>38%</td>
<td>24</td>
<td>7%</td>
</tr>
<tr>
<td>Support unit</td>
<td>6</td>
<td>43%</td>
<td>8</td>
<td>57%</td>
<td>14</td>
<td>4%</td>
</tr>
<tr>
<td>More storage</td>
<td>8</td>
<td>57%</td>
<td>6</td>
<td>43%</td>
<td>14</td>
<td>4%</td>
</tr>
<tr>
<td>Holder(s)</td>
<td>8</td>
<td>67%</td>
<td>4</td>
<td>33%</td>
<td>12</td>
<td>4%</td>
</tr>
<tr>
<td>Shelves</td>
<td>4</td>
<td>29%</td>
<td>10</td>
<td>71%</td>
<td>14</td>
<td>4%</td>
</tr>
<tr>
<td>Additional storage</td>
<td>1</td>
<td>11%</td>
<td>8</td>
<td>89%</td>
<td>9</td>
<td>3%</td>
</tr>
<tr>
<td>Drawers</td>
<td>3</td>
<td>50%</td>
<td>3</td>
<td>50%</td>
<td>6</td>
<td>2%</td>
</tr>
<tr>
<td>Decorative finish</td>
<td>0</td>
<td>0%</td>
<td>8</td>
<td>100%</td>
<td>8</td>
<td>2%</td>
</tr>
<tr>
<td>Hook(s)</td>
<td>2</td>
<td>33%</td>
<td>4</td>
<td>67%</td>
<td>6</td>
<td>2%</td>
</tr>
<tr>
<td>Chair</td>
<td>0</td>
<td>0%</td>
<td>8</td>
<td>100%</td>
<td>8</td>
<td>2%</td>
</tr>
<tr>
<td>Hanger</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>100%</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Mirror</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>100%</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Sink</td>
<td>1</td>
<td>50%</td>
<td>1</td>
<td>50%</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Dismantable unit</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>100%</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Ladder</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>100%</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Shower</td>
<td>0</td>
<td>0%</td>
<td>4</td>
<td>100%</td>
<td>4</td>
<td>1%</td>
</tr>
<tr>
<td>More support</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>100%</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Circular features</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>100%</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Door</td>
<td>2</td>
<td>50%</td>
<td>2</td>
<td>50%</td>
<td>4</td>
<td>1%</td>
</tr>
<tr>
<td>Additional support unit</td>
<td>3</td>
<td>60%</td>
<td>2</td>
<td>40%</td>
<td>5</td>
<td>1%</td>
</tr>
<tr>
<td>Additional backboard</td>
<td>2</td>
<td>100%</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Handle(s)</td>
<td>0</td>
<td>0%</td>
<td>4</td>
<td>100%</td>
<td>4</td>
<td>1%</td>
</tr>
<tr>
<td>Pillars</td>
<td>0</td>
<td>0%</td>
<td>3</td>
<td>100%</td>
<td>3</td>
<td>1%</td>
</tr>
<tr>
<td>Additional shelves</td>
<td>5</td>
<td>100%</td>
<td>0</td>
<td>0%</td>
<td>5</td>
<td>1%</td>
</tr>
<tr>
<td>Additional levels</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>100%</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Additional decorative finish</td>
<td>0</td>
<td>0%</td>
<td>4</td>
<td>100%</td>
<td>4</td>
<td>1%</td>
</tr>
<tr>
<td>Folding Mirror</td>
<td>0</td>
<td>0%</td>
<td>1</td>
<td>100%</td>
<td>1</td>
<td>0%</td>
</tr>
<tr>
<td>Folding doors</td>
<td>1</td>
<td>100%</td>
<td>0</td>
<td>0%</td>
<td>1</td>
<td>0%</td>
</tr>
<tr>
<td>Headboard</td>
<td>1</td>
<td>100%</td>
<td>0</td>
<td>0%</td>
<td>1</td>
<td>0%</td>
</tr>
<tr>
<td>Wheels</td>
<td>0</td>
<td>0%</td>
<td>1</td>
<td>100%</td>
<td>1</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total number of ideas:</strong></td>
<td><strong>65</strong></td>
<td><strong>42%</strong></td>
<td><strong>88</strong></td>
<td><strong>58%</strong></td>
<td><strong>153</strong></td>
<td><strong>100%</strong></td>
</tr>
<tr>
<td><strong>Unique categories count:</strong></td>
<td><strong>4</strong></td>
<td><strong>21%</strong></td>
<td><strong>15</strong></td>
<td><strong>79%</strong></td>
<td><strong>19</strong></td>
<td><strong>100%</strong></td>
</tr>
<tr>
<td><strong>Total number categories:</strong></td>
<td><strong>18</strong></td>
<td><strong>55%</strong></td>
<td><strong>29</strong></td>
<td><strong>88%</strong></td>
<td><strong>33</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
In comparing session one and session two, it is evident that the Design Heuristic tool supported more diverse ideas generated. This is evident from the percentage difference of category instances in session two ideas generated (58%). From determining the effect size between session one and session two categories percentage weighting, there was a very large difference (effect size: 0.946) between session one and session two. In the context of the 33 categories, four categories were unique to session one ideas generated, and 15 categories were unique to session two ideas generated (end of Table 3). Examples of unique categories for session one included ‘Additional backboard’, and ‘Folding doors’ (Table 4). Examples of unique categories for session two included ‘pillars’, and ‘wheels’ (Table 5). There were three equally shared categories evident between session one and session two ideas generated. These categories included ‘Drawers’, ‘Sink’, and ‘Door’.

Table 4
 Session one unique categories idea generation examples  
<table>
<thead>
<tr>
<th>Unique category</th>
<th>Idea generated</th>
<th>Idea description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional backboard</td>
<td>Participant 6</td>
<td>Shelving unit with main backboard, and slanted backwards internally.</td>
</tr>
<tr>
<td>Folding doors</td>
<td>Participant 32</td>
<td>Rectangular backboard with 3 folding triangular doors</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unique category</th>
<th>Idea generated</th>
<th>Idea description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillars</td>
<td>Participant 2</td>
<td>2 x 1/4 circle presses, 2 x rectangular presses, circular mirror &amp; 2 pillars. Design heuristic: Stack. DH #62</td>
</tr>
<tr>
<td>Wheels</td>
<td>Participant 1</td>
<td>Sliding shelves with semi-</td>
</tr>
</tbody>
</table>

10 | Page
Further analysis occurred in the context of the dominance of idea flexibility among the grouped categories (Table 6). These grouped categories were collated from Table 3 ‘Overall %’ column. Table 6 details the dominance or balance (equal) of idea flexibility between session one and session two. The >15% grouped category represents the most instances from the 153 relevant ideas. It is also evident that session two represents a greater proportion (21%) of relevant ideas in comparison to session one (19%). This >15% category could indicate similar ideas. However, the other categories (7%, 4%, 3%, 2%, 1%) are dominated by session two, which represents unique ideas by fewer instances. In the 1% category, session two dominates with 11% of design ideas. These 1% categories are more representative of unique designs, thus further providing the advantage of the Design Heuristic tool to push ideas further into unique categories. This 1% category suggests with increased use of the Design Heuristic tool there was less instances in categories, indicating the generation of more unique ideas.

Table 6
Summary of dominance of idea flexibility in categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Session one</th>
<th>Session two</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;15% category</td>
<td>19%</td>
<td>21%</td>
</tr>
<tr>
<td>7% category</td>
<td>8%</td>
<td>7%</td>
</tr>
<tr>
<td>4% category</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>3% category</td>
<td>1%</td>
<td>5%</td>
</tr>
<tr>
<td>2% category</td>
<td>1%</td>
<td>7%</td>
</tr>
<tr>
<td>1% category</td>
<td>4%</td>
<td>11%</td>
</tr>
<tr>
<td>Total:</td>
<td>42%</td>
<td>58%</td>
</tr>
</tbody>
</table>

Overall from the results presented it was evident that session one ideas were representative of existing examples, and fixation on initial idea. In session two, idea ideas were modified and altered with the influence of the Design Heuristic cards to produce more unique ideas. Thus the Design Heuristic tool had a positive effect on reducing similarity of design ideas and fixation on initial ideas.

Discussion and future endeavors
From previous studies involving Design Heuristics with first-year engineering students, the result showed that the Design Heuristic inspired ideas were more original than initial ideas. In addition, ideas created without the Design Heuristics were less developed and were often replications of
known ideas, or minor changes to existing products. This study correlates with previous studies' findings. Jansson and Smith (1991) demonstrated that the solution explored first in a design task heavily influences the exploration of new solutions. This fixation effect phenomenon was evident in approximately 20% of participants' ideas. From a first time implementation of the Design Heuristic tool with the second year group, the difference between session one and session two ideas represents a large effect. With Design Heuristic tool increased use there was a decrease of instances in categories, thus ideas were more unique or reduced in similarity. This study demonstrated that we must facilitate idea generation using empirically valid tools to ensure pupils are pushed outside of their initial ideas which will in turn foster their creativity. In fostering creativity and pushing students beyond their initial ideas will reduce the issue of similarity of coursework and fixation.

Creativity is a skill that students find difficult and complex to develop and foster, but this is where a suitable design tool assisted with the complexity and unknown practice of designers. The implementation of an idea generation tool developed from professional designers also provides reliability, credibility, and true meaning for design practice. Teachers need to be more creative and innovative in developing pupil’s creativity. This study represented the positive influence of the Design Heuristic tool in supporting second level students and pushing their thought process further to modify and expand their ideas. The increase in flexibility of design ideas in session two indicates an iteration of ideas thus overcoming fixation and reducing similarity of design ideas. A further investigation could occur in the context of the feedforward and iteration of analysis of problem statement and flexibility of ideas generated.

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Fostering Creativity in Youth through an Examination of the Socio-Cultural Approaches to Learning in Technology Education Classes in Australia from a Feminist Perspective

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Keywords: female students; technology; creativity; pedagogical practice.

Abstract:

Resulting from a doctoral study examining factors which encourage females to participate in technology education classes, this paper focuses on post compulsory schooling. Studies undertaken during the last three decades show that too few females have engaged in technology education, despite the efforts of teachers and our national education system to implement programs which appeal to all students. Researchers such as Dakers and Dow (2009), Banks (2009), Murphy (2007), and Weber and Custer (2005) note the importance of gender inclusion and a pedagogy which attracts female learners.

If educators focused on the essence and values inherent in technology education and diversified their practice using a feminist pedagogical paradigm, the outcomes for female students may be increased participation rates, improved motivation and gains in creativity. The National Australian Technology Teachers Association (DATTA) raised concerns about the low numbers of females enrolling in technology subjects, because of the lack of appeal these subjects have for girls.

The 2012 UNESCO (2012) gender debates addressed gender parity in schools. The feminist writings of Spender (1985), Rothschild (1988), Wacjman (1991, 2004), and Talbot (2010) contribute to the context of this paper. If females believe they have a voice in their learning, they will be more creative in their thinking and their outputs.

The qualitative methodology of this study examines ethnographic socio-cultural approaches to learning. A participant observation approach addresses two areas: the social interactions of learning and the positions and voices of participants in their educational setting (Knopke, 2015). Data were collected and triangulated from interviews with students, teachers and administrators. The outcomes of the study suggest that the inclusion of a feminist perspective in technology education would provide the potential for transformation in learning.
Introduction

This paper examines how creativity can be fostered in females, in technology education, through an examination of research conducted in a doctoral study. The research focused on factors which encouraged and facilitated female students to engage in technology education and as a consequence, increase participation rates in the long term. The investigation centered on female technology students in the post-compulsory area of schooling in Queensland high schools.

The research addressed three questions. Firstly, what factors have influenced female student's choices to take technology education classes as part of their senior schooling pathway? This question looked at the social construction of realities (Bijker, Hughes, Pinch & Douglass, 2012) and women's ways of knowing by Belenky, Clinchy, Goldberger and Tarule (1986). The second research question asked – how teaching and learning was conducted and approached in selected technology education classrooms? The third question asked – what values were addressed in the teaching and learning in specific contexts in technology education for classes? Does an active social construction of gender improve the quality of engagement in technology education?

This paper focuses on socio-cultural approaches to learning using the feminist perspective. The following examines the literature then the methodology of the study followed by the conclusions.

Literature

The literature review provides an analysis of research examining the theoretical and practical backgrounds to the socio-cultural approach that was taken. This approach investigated the factors which encouraged female students to participate and engage in technology education. The literature review found there was little in-depth research on gender and the socio-cultural context for technology education in Australian classrooms.

UNESCO (2012) devoted time and resources to encourage females to participate not only in education in general, but specifically in technology education. More recently the focus is on information and connected technologies.

The research of Zuga (1997) and Wajcman (2004) suggest that artefacts have become gender assigned. Products have become stereotypically relegated to females. This was characterized by Wajcman’s (2004) ‘techno-feminist’ which represented a major development in theorizing the gendered character of technology. Cyborg-feminists were coined as a cultural term in social theory by Haraway (in Wajcman, 2004) in a quest to expose the gender blindness of main stream techno-science studies in order to show the possibilities this area offers women and how they could strategically engage with technology.

Belenky, Clinchy, Goldberger and Tarule (1986) questioned the power and authority elements of women in society. The authors argue that in the present system of projects, only certain
students will grow beyond their dependence on the existing social structures and norms that are articulated in a male-dominated society. The five perspectives from which females perceive truth and knowledge (silence, received knowledge, subjective knowledge, procedural knowledge and constructed knowledge) need to be understood in order for females to strive towards self-realization. Belenky et al.’s (1986) research led to the question of what may be the difference in how different genders learn. Dominance theory does not solve the issue of gender difference. Danilova and Pudlowski (2010) argue that one size does not fit all when it comes to technology and engineering studies. The shrinking pipeline could be due to the use of learning styles that attract some participants and not others. Eckert & McConnell (2003) talk of the performance turn of language in constructing gendered identities and norms. In a study of teenage students, Persson (2010) argues that, when appealing to youth, we need to acknowledge that issues of gender, design and culture exist. These issues shape what values are placed on artefacts students wish to work with. Wajcman (2004, p. 106) argues that to move forward we need to bridge the common polarization in social theory...Technology ...is seamless web or network combining artefacts, people, organizations, cultural meanings and knowledge.

Fleer and Jane (2004) argue that socio-economic backgrounds as well as the intended and extra-curricular activities influence what students choose to study in schools. Life experiences and vocational aspirations of students will further contribute to their choice of subjects and potentially their depth of engagement (Pavlova & Turner, 2007). These factors influence the socio-cultural experiences of all students and will impact of subject choices that are made in schools. Weber and Custer (2005) conclude that both genders enter technology education with preconceived notions about the types of activities in which they would engage. It follows that technology curriculum developers have a challenge to make connections between the skills and concepts. Weber and Custer (2005) recommend more research to better understand the dynamics of student preferences for technology related topics, activities and pedagogical approaches.

Dakers and Dow (2009) suggest that it is not vocationalism that should be the motivating factor for students to engage in the subject area rather the academic rigor of the area in its own right. Banks (2009) and Murphy (2007) note the importance of gender inclusion and a pedagogy which attracts and motivates female learners to become creative in this area.

Fuller (2008) argued that we need to be in the business of ‘sparkling minds and igniting passions in young people’. This Australian psychologist says adolescents are ready to solve the big questions of life. Research around mathematics in early adolescents has shown that studying this area can accelerate learning for all adolescents. Not only do the highly capable improve, but so do the less able. Fuller (2008) claims that too many female students are receiving a strong message from schools that mathematically based subjects are not for them.

**Background**

Socio-cultural educational research and practice explores the zone of proximal development (Vygotsky, 1978). The collaboration of thinking that results from a learner’s participation in a community of practice opens up access to direct data on thought processes and uncovers the ability to recognize the interdependence of concepts. The goal of using a socio-cultural
methodological approach is to establish a process and provide ways of documenting change and transformation.

Gender has previously been defined as ‘identity’ however Eckert & McConnell-Ginet, (2003) argue that the interpretation has moved from something one has, to involving what people ‘do’ (p.4). In this case gender is in a constant state of change through being reproduced and acted out. Empowerment is then individuals and communities engaging in learning processes in which they create, appropriate and share knowledge, tools, and techniques in order to change and improve the quality of their own lives and societies. Wajcman (1991) claims that through empowerment, individuals not only manage and adapt to change but also contribute to generate changes in their lives and environments.

Post-modern theory of gender itself is a social construct which clarifies how gender inequality interacts with issues such as racism, homophobia, classism and colonization to produce and establish a matrix of domination. The highly individual oriented post-modern feminist thought relates to specific issues of women in cultural contexts. In recent decades women have broadly agreed that the goal of feminism is gender equality in order to end gender discrimination (Gillian, 1993). The movement has moved past looking for the causes of sexism and the quasi meta-narrative style and looks for pathways to equity (Fleer & Jane, 2011). Techno feminism stemming from Wajcman (1991) followed the Marxian groups represented by Spender (1985 ed.) Those who assert a degree of power are in a position to construct the myth of male superiority...As part of the human condition is to attempt to make existence meaningful... We make sense of a world if we have rules by which to do it.... Spender questions who rules and who constructed the view of the world in which both sexes are accorded equal value. In a patriarchal order Spender (1985, p 2) says it is language that is the schema for creating power relations.

Having looked at the underpinning concepts, the following examines the methodology used to examine how female approaches could be better incorporated into the pedagogy of technology.

Methodology

The research was conducted using an ethnographic case study design. The design enabled the study of behavior, beliefs, language and how shared patterns of interacting in the educational settings developed over time (Knopke, 2015, p 70).

The research study examined three senior secondary schools in south- east Queensland. Three groups were studied; the females in the class, the teacher and the HOD (Head of Department) in the school. The researcher took on the role of participant observer visiting the schools and classes regularly over two terms across fourteen (14) weeks.

Data collected included interviews, conversations, observations, audio recordings and photographs with students, teachers and the HOD in each site. Notes were made, observation sheets compiled and reflections written after the visit. Seven themes: learning ecology, gender and technology education, language use, socio-cultural approaches to learning; motivation; role modelling and peer support and values, became the areas of analysis which enabled the researcher to look for common patterns across the sites and code accordingly.
Findings
The study described analyzed and interpreted patterns within the context of culture-at-work through seven themes which emerged. The implications for this research stem from the theory which underpinned the study. The literature showed the limited nature of research in the area of gender and technology education despite clear efforts from national subject associations such as DATTA (Design and Technology Teachers Australia) to redress this imbalance.

The research contributed to the academic discourse through engaging in active reform processes, encouraging pro-active reflective awareness and theoretical-reflective awareness. The lack of take up of the concept in Australia has not addressed the numbers of female participants in technology education and STEM.

The socio-cultural liberal feminist perspective addresses the second of the research questions. Socio-cultural approaches to learning provide instruction which recognize and empower linguistically and culturally diverse students. The collaboration of thinking that results from these processes opens up access to data on thought processes, creativity, and uncovers characteristics unique to the learner and context (Knopke, 2015, p. 278).

Wright (1992) suggested that technology educators needed to look at other ways to conceptualize their subject matter to reach the diversity of students who are now in schools. Technology educators need to rethink how they legitimize the knowledge of technology education in order to meet the needs and wants of modern-day students, ‘It is through the legitimacy of differences that new and necessary forms of rationality will emerge’ (p 212).

Discussion
If educators use a socio-cultural liberal feminist approach toward the curriculum the approach may help change the masculine dominated approach that has prevailed. Incorporating the voices, values and essence of women’s ways of knowing into the subject area through an understanding of female values heightens the motivation of females to engage (Knopke, 2015, Zuga, 1999). In turn female students are empowered to be more creative in their engagement with and within technology education.

The research showed that understanding, empathizing and being inclusive of female participants in real life situations made a long term difference to other female students wanting to engage in technology curriculums. Gender neutrality is not the answer. Finding projects that enable females to project manage and solve difficult problems through discussion and experimentation addresses the issue. Providing structure and guidance to a cultural group who are unfamiliar with the area will entice other females into technology.

Conclusion
The study found that the perception of curriculum has an impact on what female students choose to study. Life experiences, socio-economic status and vocational aspirations contribute
to female students’ study plans. A knowledge of the benefits of the subject area, the development of thinking, hands-on skills and the advantages that learning affords participants makes a positive difference to females through their values orientations.

A female-oriented pedagogy needs mixed learning styles with structure and scaffolding, providing individuals with the independence to problem solve, discuss issues and to become more creative is part of the solution. The value of the output and its social contribution is part of the criteria that female students use to judge the relevance of technology education activities. While these features relate to both sexes it is the empathy invested in the process and material outcomes that meet the needs of females.

The findings of case study 1 showed that students could overcome historic stereotypes if they were motivated to achieve in the subject area. The female students achieved high level results once they found and established their place in the class. They did this by learning the discourse and skills required to engage and interact in the subject. Learned skills enabled them to plan and create innovative solutions to design problems.

The staff in case study 2 adjusted their language use for the female students early in the course. The female students were quick to learn the technical terms and engage. Gendered power relations were evident between teachers, male and female learners. This was despite the verbalized progressive views of staff. Talbot (2010) argues that ‘until more of the positions of power alter from the traditional gendered practices that are endemic of trade workshops of days gone by then we cannot fully embrace communities of practice that will entice female learners into technology education workshops’ (p121).

Case study 3 promoted the traditional industrial nature of trade learning. The female students saw the worth of their contribution to the community. The sociological aspects of the class (service beyond the school gate) executed through learned skills, were the most important factors developed in the course. Female students believed they could use their skills in the future to create home and social environments but were unable to challenge the ‘vocational norms’.

The more freedom given to female students to exercise their own values sets enabled them to be more motivated and employ more creative thinking around the social and material aspects of technology education. The feminist socio-cultural approach is about changing the nature of the pedagogy in favour of female participation.

References
The Effects of Ideation Assessments on College Student Confidence and Motivation in Creativity

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Abstract

Measuring creativity is of interest to technology and engineering education researchers. It is important that measurements of capability, confidence and motivation in creativity follow valid and reliable procedures. Research designs must be aware of potential confounding variables when attempting to measure several aspects of creativity. Surveys are often used to measure confidence and motivation in creativity. Ideation assessments (Mind-Mapping, 30 Circles Challenge, Empathy Mapping) can be used to determine a student's creative capacity. After completing an ideation assessment, research suggests that students may become self-aware of their own creativity abilities. This self-awareness presents an interesting question for inquiry. Does a series of ideation assessments significantly impact student confidence and motivation in creativity? Pre-service teachers at a public college in New Jersey are required to take the course, Creative Design, to fulfill one of their liberal learning breadth requirements. Creative Design is a course that blends students from several majors across the college campus (e.g., Education, Engineering, Sociology, Business, Art) and asks them to engage in creative problem solving through multiple hands-on projects. At the beginning of Fall 2016, students (n=39) in two sections of the Creative Design course completed the survey, Creative Self-Efficacy and Creative Role-Identity Scale. Immediately following the survey, students were given a pair of ideation activities to measure creative capacity (Mind-Mapping, 30 Circles Challenge, Empathy Mapping). Upon completion, students were asked to retake the original survey for a second time. Data analysis consisted of a paired sample t-test. Results reported that there was no significance difference between student survey results. The data and findings indicated that ideation assessments have no significant impact on student confidence and motivations as measured by the survey in this study. The findings suggest that future research may utilize ideation assessments in parallel with confidence and motivation scale.

Keywords: Measurement, Creativity
Introduction

The education of creative individuals is a priority of the international community. The global economy no longer favors those based only on what they do and do not know but also about the ways in which they think (Schleiner, 2016). The Grand Challenges of Engineering, presented by the National Academy of Engineering (NAE, 2016), will require the “spark of creative imagination” to solve. Today’s students need to develop these creative ways of thinking so that they may become the innovative engineers, technologists and scientists of tomorrow. The teaching of creativity has been a theme of technology education for over a century (Warner & Gemmill, 2011). Technology education classroom experiences often involve design-centric activities with a focus on students developing solutions to ill-defined, authentic real-world problems. These types of activities provide a rich platform for the teaching of creative processes such as curiosity, divergent and convergent thinking, and empathy as well as encouraging students to believe in their own creative identities (O’Brien, 2012). To advance the teaching creativity in schools, it is necessary to develop appropriate assessment techniques to measure the effectiveness of our instruction.

Researchers have used various methods to measure creativity (Tierney & Farmer, 2002; Runco, Illies & Eisenman, 2005; Denson, Buelin, Lammi & D’Amico, 2015). One’s creative capacity is often described as multidimensional. Cropley (2000) described assessments of creativity as:

> Creativity tests measure specific cognitive processes such as thinking divergently, making associations, constructing and combining broad categories, or working on many ideas simultaneously. They also measure noncognitive aspects of creativity such as motivation (e.g., impulse expression, desire for novelty, risk-taking), and facilitatory personal properties like flexibility, tolerance for independence, or positive attitudes to differentness. (pp.1)

Spencer, Lucas and Claxton at The Center for Real-World Learning at the University of Winchester (2012) indicated that the primary use of any assessment framework should be formative to support and guide students as they aim to develop their creative abilities. Formative assessment frameworks often rely on the use of multiple measurement instruments to provide feedback on one or more component of creativity. A potential issue with using more than one assessment tool to conduct research is the presence of cofounding variables. Two components of creativity of interest for this paper are student self-efficacy and ideation ability.

Creative self-efficacy is one’s belief that they can design creative products (Tierney & Farmer, 2002). Research completed by Tierney and Farmer reported that creative self-efficacy is a predictor of creative design performance. The Creative Self-Efficacy and Creative Role-Identity Scale is an appropriate instrument to measure student growth through a pretest/posttest research design and has been used or modified by international researchers over the last three years (Al-Zoubi, 2014; Sangsuka & Siriparpb, 2015; Huffman & Figueroa, 2017).
Ideation is defined as the formation of ideas or concepts. Runco, Illies, Eisenman argued that high quality creative ideas should be both original and appropriate. A series of three ideation activities suggested by Kelley and Kelley (2013) can be used to generate evidence of student ideation ability; 30 Circles, Mind Mapping, Empath Mapping. The 30 Circle Challenge can be useful to measure originality in which students are asked to turn as many circles as possible into real objects. The mind mapping and empathy mapping tools can measure appropriateness by creating word associations on a focused topic. The 30 Circle Challenge, mind mapping and empathy mapping activities provide design artifacts that can be used to evaluate creative ideation through coding techniques such as the Jackson and Messik (1964) method, the simple counting of original ideas (Basadur, Graen & Green, 1982) or a combination of factors like the Torrance Test of Creative Thinking (1966).

After completing an ideation activity, research suggests that students may become self-aware of their own creativity abilities (de Beer, 2016). One could propose that there is a connection between one’s perceived ability and confidence in creative endeavors and the practice of what one considers to be creative practice. For example, a person may have a relatively high confidence in their creative ability if the perceive creativity practice is simply making and creating things (e.g. arts, crafts, tinkering). When the same person’s perceptions of creative practice changes, due to the introduction of a creative assessment tool that measures a piece a creative capacity such as ideation, it is possible that their confidence in what they now perceive as creative practice could change dramatically. This self-awareness presents an interesting question for inquiry. Does a series of ideation assessments (e.g. 30 Circle Challenge, Mind Mapping, Empathy Mapping) significantly impact student confidence and motivation in creativity as measured by the Creative Self-Efficacy and Creative Role-Identity Scale?

**Methods**

The Creative Design (TST:161) course at The College of New Jersey is housed out of the Department of Integrative STEM Education in the School of Engineering. Students from all schools in the college may choose to take the course as it fulfills a fine arts liberal learning requirement. However, the greatest enrollment comes from the engineering and technology/STEM education majors, which is a requirement of their degree programs. The course has been in existence since the early 1960s when it was part of the Industrial Arts curriculum and focused on design from an artist’s perspective. In 1969, the course underwent a reorganization, so it would bridge the chasm between the artist and the designer to prepare students to better understand a “human designed world”.

Students in two Creative Design sections of the Fall 2016 semester voluntarily participated in this study. Data collected as part of this ex post facto analysis was originally intended to be used for course improvement only and did not have a grade assigned to the completion of the study activities (Gall, Gall & Borg, 2007). Participant demographics are reported in Figure 1: Gender and Figure 2: Major.
Before the first day of class, the participants (n=39) completed the survey, Creative Self-Efficacy and Creative Role-Identity Scale via a Qualtrics link provided through an email. On the first day of class, participants were given a pair of design activities to measure creative capacity in ideation (30 Circles Challenge, Mind-Mapping, Empathy Mapping). The researcher followed the instructions provided by Kelley and Kelley (2013) to facilitate the activities and the procedures were competed as follows:

- **30 Circles Challenge, Solo Activity (Figure 3: Student Sample)**
  - The students were given a sheet of paper with 30 blank circles and were asked to turn as many of the blank circles as possible into recognizable objects.
  - Students were given three minutes to complete the 30 Circle Challenge.

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**Figure 1: Participant Gender**

**Figure 2: Participant Major**

**Figure 3: 30 Circle Challenge; Student Samples**
• Mind Mapping, Solo Activity (Figure 4: Student Sample)
  o Students were then given a blank sheet of paper.
  o Students were instructed to write a central topic in the middle of the paper.
    (e.g. making breakfast with eggs)
  o Students were instructed, “What else can I add to the map that is related to
    this theme?” Write down ideas, branching out from the center, and don’t 
    worry if they feel clichéd or obvious.
  o Students were given three minutes to complete the Mind Mapping activity.

Figure 4: Mind Mapping; Student Samples

• Empathy Mapping, Group Activity (Figure 5: Student Sample)
  o Students were randomly assigned into groups of four.
  o Students were instructed, “On a whiteboard, draw a four-quadrant map. Label 
    the sections with “say,” “do,” “think,” and “feel,” respectively.
  o Students were instructed, “Think of a shared experience that everyone is your
    group can remember clearly (first day of class). Write down each of your key
    observations from the that memory to populate the “say” and “do” quadrants.
  o Students were instructed, “When you run out of observations (or room) in
    those quadrants, begin to fill the “think and” and “feel” sections based on the
    body language, tone, and choice of words you observed.
  o Students were give ten minutes to complete the Empathy Mapping activity.
Upon completion, participants were asked to retake the original survey for a second time via a Qualtrics link provided in the course learning management system.

Results and Limitations

Data analysis consisted of descriptive statistics and a paired sample t-test to measure if the difference between each survey was significant. Analysis was carried about using SPSS statistical software. Students reported higher self-efficacy on the pretest ($M = 6.52, SD = 1.53$) than on the posttest ($M = 6.30, SD = 1.65$). The dataset meets the assumptions to perform a parametric test (near-normal distribution, adequate sample size, no outliers, homogeneity of variance). Parametric analysis indicated that while there was a decrease in student reported self-efficacy, the difference was not significant, $t(38) = 1.45, p < .155$. A closer examination of the data indicates a small effect size (Cogen’s $d = .23$). This small effect size indicates low practical significance.

The limitations of this data analysis are many. Participants in the study were recruited via convenience sampling. Thus, the results of this study may not be representative of a generalizable population and the methods would be difficult to replicate. Additionally, the ex post facto nature of the data collection does not allow for this study to imply causality as there was limited control of other potentially confounding variables. Finally, the nature in which the assessments were given could call into question the validity of the measurements. In order to be recruited as part of this study, participants had to of first voluntarily enrolled in a course titled “Creative Design”. It may be possible that participants in the study had expectations and attitudes towards creativity that is a deviation from the typical college-level student.

Discussion and Impact for Researchers

The results from this study can help guide more rigorous research with concern to measurement and assessment methods for the teaching and learning of creativity. The multidimensionality of creativity poses difficult challenges for researchers. One solution may be to use multiple
assessment methods in parallel so that researchers may examine a more holistic view of an individual’s creative capacity and what interactions may exist. One research inquiry that may be examined is the relationship between growth in creative motivation, identity and self-efficacy and the growth in creative output (design artifacts).

The results of this study support claims by Sawyer (2010) that creativity is something that takes place over an extended amount of time. The ideation activities were not prolonged experiences, each only take a few minutes. The short duration of the activities and lack of change in student self-efficacy suggests that students are persistent in their creative identity and may require a more comprehensive experience to enact positive change.

References


Rhetoric and Interpretation: The Values Students and Special Interest Groups Attribute to Design & Technology

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Abstract
This research compares special interest groups’ and students’ rhetoric about the value of Design & Technology (D&T) in England, specifically in relation to learning about technology, employment and creative endeavors.

Drawing upon the Design and Technology Association (D&TA) campaigns and interviews with students, I identify the values these two ascribe to D&T. These values will be compared with the values implied in the English National Curriculum for D&T: the current version (Department of Education, 2013b) and previous iterations since its inception into the National Curriculum in 1990.

Analysis of the two groups’ values demonstrates a disparity between the two groups’ views of the value of D&T. Whilst D&TA and students concur on some values, there are noticeable differences. Generally, students place greater emphasis on D&T’s value to their everyday lives, future employment, and personal fulfillment, whereas the D&TA campaigns focus on how D&T engenders both personal and national economic benefits; creativity is valued by both groups but in different ways. These findings imply a discord between them about the contribution D&T makes to an individual’s education and future life.

By comparing the values of these two stakeholder groups, who have no direct power to influence the enactment of government policy (Williams, 2007), this research provides an insight to some of the potential divergences that may occur as D&T teachers, who do have the power, interpret the National Curriculum using D&TA’s materials to advocate the value of D&T to their students. This research could help other special interest groups explore how D&T is valued and how they lobby government for future curriculum change.

The next stage to this study is to explore how the D&TA’s rhetoric about D&T, and the values discovered in this study, are enacted in classrooms.

Keywords: Curriculum; design and technology; stakeholders; students; subject associations; values.
Introduction
This research compares special interest groups’ (SIG) and students’ rhetoric about the value of Design & Technology (D&T) in England, specifically in relation to learning about technology, employment and creative endeavors. The SIG investigated here is the Design and Technology Association (D&TA) – a subject association representing their members who are primarily D&T teachers; the students are aged between thirteen and fourteen years old.

These two groups can be classified as stakeholders, they have an interest, or stake, in D&T. Extending this analogy further and drawing on Mitchell, Agle and Wood’s (1997) stakeholder theory, they are stakeholders who have the characteristics of urgency and legitimacy for different reasons, but neither group has any power to decide what D&T teachers teach in the classroom. In other words, only the D&T teachers decide how the National Curriculum policy for D&T will be taught although D&TA and the students can overtly and inadvertently influence what is taught. By comparing the values of these two stakeholder groups, who have no direct power to influence the enactment of government policy (Williams, 2007), this research provides an insight to some of the potential divergences that may occur as D&T teachers interpret the National Curriculum using D&TA’s materials to advocate the value of D&T to their students. Therefore, this paper highlights the congruence and disparity between the values attributed to D&T by these two non-powerful but important stakeholders.

The values examined here are a small snapshot of the data drawn from a recently completed PhD study investigating the values attributed to D&T by different stakeholders. The main study identified 32 different values across 22 interviews with participants representing seven stakeholder groups. The data analysed in this paper is from the four interviews with students who are dependent stakeholders (Mitchell, Agle & Wood, 1997) and focusses on eight values about creativity, technology and employment (Table 1).

Literature review
The subject entitled ‘design and technology’ (D&T) appeared in the 1990 National Curriculum (Department of Education and Science, 1990) and for the entirety of its history, and notably since a Coalition government took office in 2010, D&T’s stated purpose as part of the National Curriculum, and its value to an individual’s education, has been debated and disputed. However, there are several recurring political and societal justifications for the subject being taught in school. These include meeting individuals’ and society’s economic needs, and responding to the effect of new scientific and technological knowledge.

The origins of the need to prepare young people for employment in technical careers can be seen pre-1904. Primarily designed to create an educated workforce in order to maintain the country’s world economic status, the 1904 Act introduced a general education stipulating a secondary course that included ‘drawing … manual work’ (Gillard, 2011, ‘1904 Regulations for Secondary Schools’) and aimed to enable students to access technical and vocational courses at a higher level (Gosden, 1984) and prepare them for ‘advance[d] technical instruction’ (Board of Education, 1913, p. ix). When introduced it was a gendered curriculum, boys educated for future vocations, and girls given a domestic education that Heggie (2011) believes was intended to address the ‘servant problem’ and impose a form of socially engineered idealised femininity training girls to run a household. The 21st Century curriculum is not genderised but there is still evidence of disparity between girls’ and boys career aspirations (Archer et al., 2013) and students’ views are informed by activity stereotyping in the classroom (Eccles & Wigfield, 2002). Remnants of the 1904 Act is evident in the 21st century D&T curriculum:
‘High-quality design and technology education makes an essential contribution to the creativity, culture, wealth and well-being of the nation.’ (Department of Education, 2013b, p.192)

The content of the D&T curriculum has subtly changed throughout the six versions of the D&T National Curriculum since 1990, although there have been several regular features, including creativity and technological awareness. The importance of students learning technological knowledge was another early justification for design and technology being taught in schools because it enables students to ‘increase human potential’ (Association of Advisers in Design and Technical Studies, 1980, p.2). An awareness of the impact of technology has featured constantly but in various forms:

make critical appraisals of … the implications of artefacts and systems’ (Department for Education and Science and the Welsh Office, 1988, p.17.)

reflect on and evaluate present and past design and technology, its uses and effects' (Department for Education, and Employment, 1999, p.15.)

Creativity and creative thinking is explicitly mentioned in each version, or its recommendation report (for examples see Working Group Report, 1988; Department of Education, 2013a; Qualifications and Curriculum Authority, 2007). Like ‘technology’, creativity can be expressed in several ways. Definitions for creativity include words such as “Novelty ... effectiveness ... ethicality” (Cropley, 2001, p.6). Creativity has also been defined as a way of thinking, identified as a 21st Century Skill (Binkley et al., 2012). This form of thinking relates to de Bono’s (1971) ideas of lateral thinking and Fisher’s (2005) view that creative thinking involves .... Within the design and technology curriculum creativity is often used as a term applied to the design process, a skill related to design thinking (Kelly, Kimbell, Patterson, Saxton, & Stables, 1991; Kimbell & Stables, 2008). This form of creativity leads to an original or innovative product idea, system or environment, whereas creative thinking does not necessarily involve any of these. Kimbell and Stables (2008) determined this difference when discussing what was design and technology activity and what was not design and technology activity. So, both creative thinking and being creative when designing involve creative thought, but the outcome does not necessarily involve a new product idea for example. For Binkley et al. (2012), creative thinking focuses on the cognition and is transferrable. Learning to think creatively refers to thinking in a non-lateral way (e.g. de Bono, 1971) as a specific way of thinking (Binkley et al., 2012; Fisher, 2005) and refers to developing the skill of creativity.

Since its inception in 1990, D&T has moved from being a core subject when it was a compulsory subject for all students up to the age of 16, to a marginalised subject now taught to most students up to the age of 14 and a dramatically reduced number to the age of 16 (Hardy, 2015). There are complex reasons for this decline in status, which began in 2004 but accelerated with the proposed introduction of new school performance measures in 2011 (Hardy, 2016). There is not the space here to explore these reasons but D&TA ran two campaigns (Design and Technology Association, 2011; 2015), aimed at government and other stakeholders about why D&T was an essential component of a broad and balanced curriculum. I posit these campaigns run counter to the values attributed to D&T by students. In the next section my suggestion is explored by analysing the value-agreements and disparities between these two groups.
Method
The students were interviewed in small groups from two schools. Four mixed-gender groups of students were interviewed. The twelve students were aged between thirteen and fourteen.

The D&TA campaign documents (Design and Technology Association, 2011; 2015) that championed the importance of D&T in 2011 and 2015 were analysed for references to technology, creativity and employment.

Findings
Identified in the data were different facets to the three themes, not all of which were mentioned by both groups. The two groups, D&TA and students, attributed values about creativity, employment and technology in different ways (table 1).

Table 1: Overview of values attributed to D&T by D&TA and students.

<table>
<thead>
<tr>
<th></th>
<th>D&amp;TA</th>
<th>Students</th>
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<tbody>
<tr>
<td>Creativity</td>
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<tr>
<td>Making and creating</td>
<td></td>
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<tr>
<td>Being creative when designing</td>
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<td>■</td>
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<tr>
<td>Learning to think creatively</td>
<td></td>
<td>■</td>
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<tr>
<td>Technological awareness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humans as users of technology</td>
<td></td>
<td>■</td>
</tr>
<tr>
<td>Technological determinism</td>
<td></td>
<td>■</td>
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<tr>
<td>Critical understanding of the impact of products</td>
<td></td>
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<tr>
<td>Employment</td>
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<tr>
<td>Skills to use in future D&amp;T-related careers</td>
<td></td>
<td>■</td>
</tr>
<tr>
<td>Provides information, advice and guidance (IAG) about D&amp;T-related careers</td>
<td></td>
<td>■</td>
</tr>
</tbody>
</table>

Analysis

Creativity
There were predominantly two ways creativity was talked about – learning to think creatively as a generic skill and being creative when designing. Both valued the opportunity to be creative in relation to D&T activity, whereas only the D&TA campaigns mention creative thinking.

The students thought D&T gave them opportunity to be creative when they are designing. The students valued being creative when designing as an individualistic activity. Linked to this the students also talked about having the freedom to make their own design decisions:

Female student 1: It's creative.
Male student 1: Yeah it is creative.
Facilitator: What do you mean by being creative?
Male student 1: You can be creative on whatever you want to make and it's your own choice.
Male student 2: Design it yourself.
Female student 1: You can do what you want
In what appears a similar vein, D&T (2015) stated:

designing and making activity demands both creative speculation and logical decision making to arrive at valid, and better, solutions.

However, the students talk about ‘opportunity’ and D&T ‘demands’, suggesting D&T are looking at the outcome of the design activity, whereas it is the intrinsic nature of being creative that interests the students. In other words, the students value creativity for its own sake, not the end purpose of being creative. Also noteworthy is D&T’s reference to contrasting ways of thinking, lateral and logical. However, the quote’s implicit emphasis is problem-solving not creativity.

**Technological awareness**

This theme included three ideas about technological awareness. For example, the 2015 D&T campaign claims ‘[D&T] prepares young people to continue the development and control of technological advances’. This suggests there is a symbiotic relationship between humans and technology - technology damages humans and so humans must take control of the technology now (*humans as users of technology and technological determinism*). The students do not comment on their learning in D&T about needing to control technology, instead they approach it from a different angle:

Well I remember in the olden days you used to learn everything, cooking, sewing, DIY skills. If that wasn't available today I think that we'd become too dependent on technology and other things like that instead of doing it yourself. So, I think it provides skills and things for the future.

Whilst this comment raises a smile, it is interesting because here the student is not saying they are learning about technological developments but because they learn craft skills in D&T they are challenging the idea all technological developments are beneficial (*technological determinism*).

Another aspect of technology the students and the campaigns considered important was students learning to *critique the impact of products* on themselves, the environment and society. Understandably the students gave specific examples:

We learn that making one T-shirt takes 2000 gallons of water so that's obviously a lot and water's a big problem nowadays.

And

You'll think where this material's from, how they're made, et cetera. ... It shows us how hard the workers work to make those materials.

These comments show the students were learning about the impact of making products on the environment and the people who made them. This relates to the D&T campaign’s (2015) assertion:

Through modern and developing technologies we exert an ever-greater influence on our surroundings by making improvements to housing, transport, communications and the everyday objects we use, at work and in leisure. D&T helps to develop the knowledge, skills and understanding which makes this possible.
Whilst broad, the heart of this idea is an aspect of D&T featured in every version of the National Curriculum, but not the most recent version (Department of Education, 2013b). Unlike the first value in this theme, this one focuses on products, the materials used and how it will be disposed of at the end of its life – its life cycle. D&T and the students are claiming being taught about the impact of a product’s design and function, its life cycle, which will be useful for students later in life when choosing items for their home for example.

Employment
This theme had the largest number of comments from both participants, valuing how D&T provides pupils with IAG and skills for future D&T-related careers.

When talking about learning specific skills to use in future D&T-related careers, students’ comments implied how they could economically benefit from studying D&T, and mentioned specific D&T-related careers, such as designers, engineers and manual labourers. Students from each group attributed this value to D&T, referring to engineering, design and construction related careers. A male student from St John’s comments:

[D&T] helps you with making and then say if you're doing woodwork and stuff that can help you with construction and stuff, which is useful if you like doing construction

Although construction could be interpreted as the activity of constructing something, here the student is talking about ‘construction’ as a career. He may be influenced by his context because the St John’s D&T department offered post-14 vocational courses, including construction. Another St John’s male student could see the value in studying D&T for his later career choice:

I either want to be a surgeon or an engineer when I grow up and so resistant materials would be useful for the engineer job.

Likewise, the 2015 D&TA campaign claimed ‘D&T has much to offer across a wide range of career paths in engineering, manufacturing and the creative industries’ and D&T will be the ‘start-point of graduate, technician or craft level careers in the creative, engineering and manufacturing sectors’.

Within the student groups there was some gender distinction in the careers mentioned. Only male students referred to male-stereotypical careers such as construction and engineering; whereas one female student talked about becoming a textile designer when she left school, the other female students talked more generically about D&T related careers. The D&TA campaigns could have been used to challenge these perceptions and whilst they do not attribute the career paths mentioned to one gender or another, there are more ‘male’ careers (such as engineering) mentioned than ‘female’ ones (such as fashion design); this subconscious emphasis of male-dominated careers could perpetuate the idea D&T and engineering are not for girls. Given the evidence from expectancy-value theory (Eccles and Wigfield, 2002) that students’ goals and motivations, which includes their career plans, influence the attainment value the students ascribe to a subject and consequently the achievement-related choices they make in relation to that subject, the subtle messages about the careers D&T is for need to be carefully considered if D&TA and D&T teachers wish to project the subject as suitable for girls and boys.

Students also talked about being introduced to possible careers in D&T lessons. This embodies the idea of children receiving careers advice during D&T lessons - a form of subject based IAG infused into the lesson not overtly as a learning objective. Comments refer to school mimicking
D&T-related career routes, such as a designer or joiner, giving students a flavour of what's out in industry:

It creates a career option because when you start doing D&T you learn if you would like to do this professionally or not.

For this student, it represents a work-related aim of education, where school helps children create a life-plan based around a career and employment (White, 1997). The D&TA campaigns did not refer to this view of D&T, but given the campaigns were not targeting students but stakeholders interested in D&T's potential economic contribution this is unsurprising. Subject associations, such as D&TA, play a dual role for their members and policy makers (Knight, 1996) when they represent the views of members to policy makers whilst representing a cohesive view of the subject to its members.

Discussion and Conclusion
This research focussed on three themes encompassing eight values (Table 1). Initially it would appear the two groups concur on five of these, but closer analysis and interpretation shows there to be subtle nuances in the way the two groups talk about them. This probably results from their different cultural and social setting, plus their views of the purpose of education, which affects their goals and motivations in relation to D&T.

The main differences between them related to the time-context of their values. D&TA focussed on how D&T would benefit the individual in the future. For instance, learning in D&T how to think creatively will be useful later in life and gaining a critical understanding of the impact of products means they will be able to take actions to promote quality of life ... and protect the environment'. Whilst the students were interested in this aspect, the here and now was more important, how they would benefit from studying D&T today. For example, making and creating was something they valued doing in lessons today, as was the opportunity to be creative when designing.

These differences present challenges for D&T teachers. D&TA wishes to influence what they teach in the classroom and the two campaigns were their attempt to do this (teachers were encourage to ‘sign up’ and support the campaign on the D&TA website). If the teachers’ values align with D&TA’s it is reasonable to suppose their lessons will reflect D&TA’s values. However, the teachers want to engage their students, and they might choose to respond to the students' nearness rather than D&TA’s distance.

If the teachers want to address both stakeholders’ values they will need to combine the longer-term focus of the D&TA campaigns, which looked at how D&T might benefit individuals in the future, with the student’s instrumental and intrinsic values.

Note: Do not quote from this paper without the express permission of the author.

References


Technology and Engineering Education: Fulfilling Its Promise

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Abstract
Due to the essential roles technology and engineering (T&E) play in addressing global challenges, T&E should be appreciated as a contributor to sustainable development and transformative improvement in quality of life. In addition to the workforce and economic imperatives, T&E experiences can be pedagogically valuable for all students—not only in providing an effective way to contextualize STEM skills, but also in mobilizing engineering thinking as a way for young people to approach problems of all kinds.

Several issues have constrained T&E education from fulfilling its promise as a core school discipline. These fall into several categories related to public perception, systemic change, and instruction driven by content standards.

Part of the reason for the lack of public support for T&E education relates to how the general public perceives technology education. Systemic change issues relate to (1) teacher recruitment; and (2) orienting curriculum and instruction toward solving authentic societal problems.

Hundreds of content standards have been written in national frameworks, and have been criticized as vague, repetitive, and uncoordinated; and developing high-stakes assessments measuring students’ understanding of standards-based ideas has become a lucrative corporate enterprise.

This paper draws upon recent studies that argue for a context-based focus on overarching thematic understandings in lieu of a focus on atomistic content standards. A case study is presented of a large-scale $1.7M funded US National Science Foundation project, Engineering for All (EfA) (NSF DRL-1316601) that situates thematic ideas within authentic social contexts.

EfA was founded on the contention that T&E can leverage students’ interests in social equity and build awareness of how engineering can address global and community concerns. The project’s expectation is that participating students will develop dispositions to forge a sustainable future and learn that further T&E study can provide pathways to engage in socially significant work.

Keywords: Authentic Social Contexts, Engineering Education, Technology Education, Overarching Themes, Standards.
INTRODUCTION

In the United States, Technology and Engineering (T&E) education is an expansion of technology education which (as in other countries) has sprung from the roots of Crafts/Industrial Arts teaching (Lee, 1998). Over the last three decades, a metamorphosis has occurred in the discipline (Hacker, 1999) and T&E now plays a central role in STEM education. There is growing recognition that school-based T&E experiences can be pedagogically valuable for all students—not only in providing an effective way to contextualize and reinforce STEM skills, but also in mobilizing engineering thinking as a way for young people to approach problems of all kinds (Brophy and Evangelou, 2007; Forlenza, 2010).

There are estimated to be about 30,000 T&E teachers in the United States (Barbato, 2017) and most secondary schools in the US have T&E (or TechEd) programs. However, the present number of teachers represents a 45% decline from the 55,000 teachers teaching in the U.S. in 1980 (Starkweather, 2017). The number of universities granting undergraduate technology education degrees in the US has plummeted from 81 in 1988 (Moye, 2017) to 29 in 2016 (Rogers, 2017); the number of T&E undergraduate degrees awarded in the US has fallen from 815 in 1995–96 to 206 in 2015–16 (Moye, 2017), a startling drop of 75%. This paper addresses the following key question:

Why, despite the critical need for a skilled, technologically literate STEM workforce (National Science Board, 2015) are T&E education programs in decline and have not fulfilled their promise?

Several issues are surfaced that might explain why T&E education has yet to fulfill its promise as a discipline that is highly regarded for its contribution to all students’ fundamental education. Recommendations are made that might lead to elevating its place in the school curriculum.

ISSUES IMPEDING ACCEPTANCE OF T&E AS A CORE DISCIPLINE

Reasons for the discipline’s decline fall into several categories related to: (1) public perception issues; (2) systemic change issues; and (3) instruction driven by content standards and the concomitant political and profit-related issues.

Public Perception Issues

Part of the reason for the lack of public support for T&E education relates to how the general public perceives technology education (tainted by its crafts traditions). Additionally, technology is a word in common parlance which is used in different ways. Sometimes we use the term to mean technical means. Sometimes we refer to artifacts (aspirin, chairs) as technology. Sometimes we mean processes or sets of procedures.

The popular culture confuses science with technology (the moon landing was rocket science despite the central role played by engineers and technologists). Perhaps of more significance today is that although the general public expects students to become technologically literate, public focus is more centered on attainment of computer science skills than on the International Technology and Engineering Educators Association’s (ITEEA’s) conception of technological literacy as an “understanding of our vast human-made world” (ITEEA, 2000).

While still maintaining a focus on educating students to understand the human-made world, our times require more emphasis on computing. Rather than argue that computing and technology education are different disciplinary domains, it is not too late for T&E to become a major contributor to the computer science (CS) delivery system in the US and worldwide. Presently, in the US, only 25% of principals report that their school offers a CS course that includes programming but states are moving rapidly to expand K–12 computing in education (desJardin, 2015).
Over the past decade, a strong case has been made for teaching all students to become computational thinkers. Computational thinking (CT) is being promoted as “a fundamental skill used by everyone in the world by the middle of the 21st Century” (Wing, 2006). CT has been defined to include: formulating problems to enable us to use a computer to solve them; logically organizing and analyzing data; representing data through abstractions such as models and simulations; automating solutions through algorithmic thinking; identifying, analyzing, and implementing solutions to achieve the most efficient and effective combination of steps and resources; and generalizing this process to a wide variety of problems (Barr, Harrison & Conery, 2011). The need is real; T&E can help to fill that need. This requires a transformational change in professional mission and in pre-service education.

The ITEEA is actively supporting initiatives to add computational thinking as a competency T&E teachers (and students) should assimilate. The Association is devoting an issue of its Journal, the Technology and Engineering Teacher, in the fall of 2017 to the role T&E can play in teaching students to engage in computational thinking. Additionally, the ITEEA is a partner with Hofstra University and North Carolina State University on a $2.5M grant proposal to the US National Science Foundation to investigate the feasibility of integrating CS and CT skills into T&E curriculum. Integrating computational thinking into T&E could potentially expand the pool of teachers who might be interested in teaching T&E including at the elementary school level.

**Recommendations.** Instructional leaders might consider better aligning T&E’s content and mission with the general public’s perception of what students should learn. For example, T&E education can address the demand for workers skilled in CS and CT (in contexts that resonate with the T&E community such as computer control, robotics, and game design). Computational thinking can become a new priority for T&E curriculum and instruction. Refocusing curriculum to include integration of computer science principles and skills within T&E contexts would be a major step toward achieving core disciplinary status.

**Systemic Change Issues**
The decline in T&E university teacher education and school-based programs might be stemmed by addressing two related systemic change issues: (1) teacher recruitment; and (2) orienting curriculum and instruction toward solving authentic societal problems.

**Broadening Recruitment of Teachers.** Martin and Ritz (2012) found that T&E research generally focused on content issues, but suggested that “as the number of educators in technology education continues to dwindle, our research attention needs to be directed to best practices in recruitment, specifically identifying and implementing strategies to recruit new members into the teaching profession” (Martin & Ritz, 2012, p. 40). Increasing the pool of teachers is related to the degree to which young people are attracted to the discipline’s mission.

**Orienting Curriculum and Instruction toward Solving Authentic Societal Problems**
We might consider focusing curriculum and instruction on designing solutions to community-based or global issues that relate to authentic societal problems. The profession has been rather slow in addressing the myriad grand challenges for engineering (NAE, 2010). Teens become especially interested in engineering when they learn about its potential to help others (Intel, 2011). Doing so would apply design-based teaching and learning to problems that inspire students to seek solutions related to human needs: potable water, sanitation and waste disposal, energy, sustainable transport, and food production. A reasonable expectation is that students will develop dispositions to forge a sustainable future and learn that engineering is a route to engage in socially significant work.
A consensus regarding appropriate social contexts for T&E curriculum was confirmed by a research study (Concepts and Contexts in Engineering and Technology Education, CCETE) involving 32 T&E experts from nine countries, conducted jointly by Hofstra and Delft (The Netherlands) universities in 2010. These social contexts related to food, energy, health and safety/security, shelter, transport/mobility, and water (Rossouw, Hacker, & de Vries, 2010).

**Recommendations.** Regarding broadening recruitment of teachers, alternative career paths can be opened for technical professionals (e.g., engineers and architects) to become certified as technology teachers. Particularly with the reconceptualization of content to include a focus on computational thinking and problem solving in authentic social contexts, the pool of interested preservice teachers has the potential to widen by attracting young people who are interested in social equity, computer science, and data science.

Regarding orienting curriculum and instruction toward solving authentic societal problems, T&E can leverage students’ interests in social equity and their desire to make a difference in the world. By implication, teacher education programs would encourage preservice teachers to address design problems that are driven by societal need.

**Instruction Driven by Standards and the Concomitant Political and Profit-related Issues**

**Standards.** Standards in industry generally refer to a quantitative level of performance that is acceptable or desirable. ASTM (founded in 1898 as the American Section of the International Association for Testing Materials), The International Organization of Standardization (ISO), and the National Institute of Standards and Technology (NIST) provide examples as shown in figure 1:

<table>
<thead>
<tr>
<th>ASTM</th>
<th>ISO</th>
<th>NIST</th>
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<tr>
<td><img src="image" alt="ASTM" /></td>
<td><img src="image" alt="ISO" /></td>
<td><img src="image" alt="NIST" /></td>
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</tbody>
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ASTM has developed over 1300 standards for adhesives, iron, steel, and non-ferrous metal products, petroleum and construction products, paints, plastics, textiles, water, etc.

ISO provides specifications for products, services, and systems to ensure quality, safety, and efficiency. Over 21000 ISO standards have been developed in 100 categories, including health care, manufacturing, electronics, food technology, IT, jewelry, paper, and shipbuilding. For example, the international standard date notation is YYYY-MM-DD. The standard for credit cards is 85.6 x 53.98 mm.

NIST has developed standards for products and services that rely on technology and measurement in communications, manufacturing, cybersecurity, forensic science, energy and the environment, health and bioscience. Example range from standardizing fire hoses and fittings, the smart electric grid, electronic health records, atomic clocks, advanced nanomaterials, and computer chips.

**Figure 1. Examples of Industry Standards**

**Education Standards.** Education standards are descriptive, not quantitative, and are intended to describe what students should know and be able to do within a content area. Educators have become reliant on content standards to frame curriculum syllabi and instructional practices.
In the US, the Standards movement gained momentum in the 1990s and funding streams have been tied to development and attainment of standards. The Clinton administration initiated the Improving America’s Schools Act (USDOE, 1995) that supported state-based efforts to establish challenging standards, develop aligned assessments, and build accountability systems based on results. In 1994, President George H. W. Bush established the Educate America Act known as Goals 2000 (Civic Impulse, 2017); and No Child Left Behind (No Child Left Behind [NCLB], 2002) was established in 2002 during George W. Bush’s administration. NCLB mandated all states to have rigorous standards in place and required all public schools to administer statewide standardized tests and meet annual yearly progress targets in order to receive Title I funding. Despite the law, there was still considerable variation in the quality of state standards (Bleiberg & West, 2014, p.1). A great debate wages about pros and cons of Common Core standards (see table 1).

Table 1.
The Great Debate about Common Core Education Standards

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
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<tbody>
<tr>
<td>Set consistent goals for Teaching and Learning</td>
<td>Common core standards will have little impact on student attainment. (Loveless, 2012). Standardization is an industrial era model.</td>
</tr>
<tr>
<td>Ratchets up rigor</td>
<td>Rigor is more than what standards you cover; it's how you teach (Blackburn, 2011).</td>
</tr>
<tr>
<td>Advance equity</td>
<td>Some believe that Common Core is a back-door means for the government to spy on citizens and indoctrinate children (Williams, 2014).</td>
</tr>
<tr>
<td>Prepare students for college.</td>
<td>NAEP results showed a drop in the percentage of students who are considered prepared for college (Vander Hart, 2016).</td>
</tr>
<tr>
<td>May improve international rankings</td>
<td>Latest PISA rankings show US decline (Kerr, 2016).</td>
</tr>
<tr>
<td>PD would improve since all teachers would teach the same content to focus on improved student achievement.</td>
<td>Many factors influence student achievement, among them, pedagogy, curriculum, well-prepared teachers, and a strong societal/cultural commitment to education.</td>
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</table>

Aside from the Common Core standards, hundreds of learning standards have been written in national frameworks, and have been criticized as vague, repetitive, and poorly coordinated. In the U.S., a National Academy of Education (NAoE) policy white paper titled Standards, Assessments, and Accountability opines that “the political solution of adding in everyone’s favorite content area topic created overly-full, encyclopedic standards in some states, or vague, general statements in others” (NAoE, 2009, p. 3).

We are often impelled by standards (and the high-stakes assessments based upon them) into addressing competencies that even highly-educated people outside the community of practitioner-developers, might question as being necessary for all students to attain as part of their fundamental education. Questionable examples from the Common Core Standards for Mathematics (NGA, 2010) include the following performance expectations:

**HSN-CN.A.3:** Use conjugates to find moduli and quotients of complex numbers.

**HSF.LE.B.5:** For exponential models, express as a logarithm the solution to \(ab^c = d\) where \(a\), \(c\), and \(d\) are numbers and the base \(b\) is 2, 10, or \(e\).
HSA.APR.C.4: Prove polynomial identities and use them to describe numerical relationships. For example, the polynomial identity $(x^2 + y^2)^2 = (x^2 - y^2)^2 + (2xy)^2$ can be used to generate Pythagorean triples.

Concomitant Political and Profit-related Dimensions Related to Standards
Although educational concerns such as the content base for T&E, development of instructional and assessment strategies, and evolution of contemporary pedagogical approaches have been at the heart of the reform effort, it is also true that the reform agenda has had significant, and often underestimated, political and profit-driven motivations.

Standards and Politics. Politics has the potential to scuttle progress by focusing debate not on instructional issues, but rather on issues that are not openly surfaced—hidden agendas held by groups with vested interests; winners and losers in the zero-sum game of seven and one-half hour school days; resistance to change, generally; and values that privilege classical core academic disciplines (with their longstanding traditions), over emerging disciplines with little history. This has resulted in high-stakes assessments being mandated in some subjects and not in others. The lack of state or national assessment programs is a double-edged sword for T&E. On the one hand, it undermines broad implementation of programs; on the other hand, it allows for curricular flexibility and innovation.

Standards and Profit-related Issues. The establishment of standards, especially the Common Core standards in the US has created a national market for book publishers and test developers (Weiss, 2011). Test items have become “crude proxies” for standards (NAE, 2009) and hundreds of millions of dollars have been allocated for the development of standardized assessments. In the US state of Texas alone, Pearson Corporation will have been paid $428 million for the current five-year assessment development contract (Weiss, 2015). The person (David Coleman) who has been dubbed “the most influential education figure you’ve never heard of” helped design the Common Core standards but has never taught and has no formal education training (Klein, 2013). He is now the head of the Educational Testing Service (ETS) so it is inevitable that the Scholastic Aptitude Tests (a key measure influencing college acceptance in the US) will reflect these competencies.

Thematic Big Ideas vs. Content Standards
Since concepts must be placed in a conceptual framework to be well understood (Donovan & Bransford, 2005), overarching and thematic understandings in T&E, which emphasize transferable “big ideas,” can serve to improve holistic understanding and helps solve the problem of the overloaded curriculum.

The Next Generation Science Standards (NGSS, 2012) identifies practices (e.g., constructing explanations and design solutions; developing and using models, carrying out investigations); and crosscutting concepts (e.g., systems, stability and change, structure and function). Still, there are 312 disciplinary core ideas for students to learn.

The International Technology and Engineering Educators Association (ITEEA), published the Standards for Technological Literacy (STL) to identify educational outcomes needed for life in a technological world (ITEEA, 2000). STL classifies a set of “core concepts” (e.g., systems, resources, tradeoffs), however, within STL, there are 286 Benchmarks, 98 at grades 9–12.

Two recent Delhi-based research studies have identified important thematic understandings and related concepts that all students should learn by the time they complete secondary school. The
first of these, Concepts and Contexts in Engineering and Technology Education (CCETE) (Rossouw, Hacker, and de Vries, 2010) identified five thematic concept categories including design, modeling, systems, resources, and human values. The second study, the Comparison of Perceptions study (Hacker, 2014; Hacker and Barak, 2017) furthered the work accomplished by the CCETE study by adding more specificity about the most important T&E concepts and skills within the five overarching thematic categories. The study identified a set of 38 domain-specific competencies (12 related to design; six related to modeling; six related to systems; seven related to resources; and seven related to human values) that all high school students in the U.S. should learn as part of their fundamental education.

**Recommendations.** The focus on content standards has constrained, rather than broadened, possibilities for teaching and learning. The assumption that all students and teachers must focus on discrete content limits learning rather than encourages creative exploration of topics that are of particular interest to learners. That is not to say that engaging activities cannot be used to promote learning of key (standards-based) ideas, but to privilege learning of discrete concepts over engaging students in areas of endeavor that drive them to delve deeply, and thus learn deeply, is a pedantic approach which can disenfranchise rather than stimulate people to learn.

An alternative to developing standards-based curriculum is to invite curriculum developers and decision makers to think less atomistically (i.e., less in terms of specific standards-based performance indicators) and more holistically (i.e., more in terms of thematic big ideas) about what is important for all students to learn as part of their fundamental education.

**A CASE STUDY OF A CURRICULUM FOCUSED ON THEMATIC IDEAS AND AUTHENTIC SOCIAL CONTEXTS**

*Engineering for All* (EfA) (Hofstra, 2017) is a large-scale $1.7M US National Science Foundation-funded project (Grant # DRL-1316601) that introduces middle school students to engineering, not only as a career path, but for its potential as a social good. Hofstra University and the ITEEA are leading the Project. EfA meets the needs of today’s students who are “civic-minded, team-oriented, and want to make a difference in the world” (Gleason, 2008). The Project represents a new paradigm for T&E in that learning is situated in contexts that relate to authentic social issues—those that are important and relevant to students. The instructional intent of EfA is to illustrate how instruction in technology and engineering education can be driven by overarching thematic ideas (design, modeling, systems, resources, human values). EfA “big ideas” were contextualized in two important social contexts: Food and Water. The curriculum units address a limited and manageable number of standards-based ideas and these are revisited within both the Food and Water units. The major EfA Project drivers are to:

- Promote the potential of engineering as a social good.
- Illustrate how the overarching themes of design, modeling, systems, resources, and human values are central to engineering and technological development.
- Use hands-on design activities in authentic contexts to convey STEM ideas and practices.
- Use informed engineering design as the core pedagogical methodology (see http://www.hofstra.edu/pdf/academics/colleges/SEAS/ctl/ctl_informeddesign_001.pdf).

Two engineering design-based six-week curriculum units have been developed, classroom tested nationally, evaluated, and revised. The units address urban food scarcity (designing hydroponic vertical farming systems); and water contamination (designing filtering systems to provide potable water to populations in need). A video overview is at:
EfA’s expectation is that students will experience first-hand how the development of understanding and skills in technology and engineering can lead them to engage in further study and in work that can make the world a better place. It is the intention of the curriculum design team to add a computational thinking component (through students’ designing and programming control systems) to the next iteration of the curriculum.

Figure 2. Student-designed hydroponic and vertical farming systems. Courtesy of Stephen Haner

Figure 3. Two middle school student vertical farm designs. Courtesy of Stephen Haner

Figure 4. Water unit students designing filtering systems. Courtesy of Sandra Cavanaugh
SUMMARY

Three issues have constrained the acceptance of technology and engineering education as a core school discipline. These fall into several categories related to: (1) public perception issues; (2) systemic change issues; and (3) instruction driven by content standards and the concomitant political and profit-related issues.

Recommendations to mitigate these issues include: Aligning T&E’s content and mission with public perception of need and integrating computational thinking into T&E programs; focusing curriculum and instruction on the contemporary needs of the society and on the interests students have in addressing authentic social issues; broadening recruitment of teachers to include alternative career paths toward certification; and changing the learning goals from a focus on disciplinary content standards to context-based thematic ideas.

Two recent Delhi-based research studies have identified important thematic ideas and concepts that all students should learn by the time they complete secondary school: CCETE (Rossouw, Hacker, and de Vries, 2010); and the Comparison of Perceptions Study (Hacker, 2014; Hacker and Barak, 2017). These can provide a basis for T&E curriculum reform.

A case study, Engineering for All, a Project funded by the US National Science Foundation, has been offered as an example of how thematic concepts can be integrated within social contexts that are authentic and engaging to today’s learners.
References


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Abstract  
Teaching technical systems is a way to introduce specific technological knowledge in Technology Education (Ginestié & Tricot, 2013). Understanding technical systems requires different thinking (Gero & Kannengiesser, 2004). During an engineering process, the functional analysis is particularly adapted to the phase of conception (von Bertalanffy, 1973). In teaching context, the pupils cannot easily understand systems (Ginestié, 2005). It is not easy for them to use a 3D printer, they must first enter the logic of this system to be able to use it. They face problems of design, modeling, transfer from a virtual to a real product, and settings (Simon, 1995). The activity has two types of orientation: the completion of the task and the development of resources for the subject to carry out the activity (Bannon, 1991). In such a situation, what kind of method should teachers choose? Is the functional approach suited to understand this logic?  
To answer these questions, this research examined an activity, in situ, of four pairs of 13 -14 years old students. The task was to carry out the operations of using a 3D printer to create a ball. All of the pupils were initiated to the functional approach. We analyzed interactions between the pupils and their relationships with the system (discussions, actions on artifacts, questions). Our research results indicated that if they approach the 3D printer in a functional way, the pupils can have both a global vision and understanding the interactions of the distinct parts of this
system. We also noted that pupils with academic difficulties were thus able to describe and use the printer without the fear of failing. Finally, the practice of the functional approach, which is not common in primary and middle schools, is identified as a useful instrument to help children understand the complexity of systems.

**Keywords:** systems, functional analysis, learning, problems, middle school.

**The teaching of technical systems**

The objects and technical systems in the teaching of technology are used to introduce specific knowledge and skills in technological education. The curricula name the skills but do not specify the object or system that can be used as a support. Neither do they name a preferred method for the teacher to use (MEN, 2015). Thus, in France, beyond the institutional requirements, teachers are given the choice of the medium and the choice of a pedagogical approach. Technical systems are usually selected from locally available educational resources. They mostly are chosen for their attractiveness among the students. This is true for the 3D printers, they are introduced as a medium of study in many middle schools. Two main methods can be associated with the study of systems. Most often teachers use a descriptive, analytical and scientific approach. Less frequently they choose an approach based on the functional analysis of technical systems. The latter, part of the systemic analysis, describes an object both in the whole and with the different elements that compose it. A such functional approach permits to design and describe precisely a system. Technical systems are today largely democratized through the simplification of human-machine interfaces. The use of such systems by common people mainly depend on these interfaces and their implementation. For example it is not easy to enter the functionality of systems used daily such as a new phone or a computer. The problem is equivalent to the one encountered during the setup of a 3D printer and the adjustment of the different parameters to get visible results on the final product.

**Theoretical framework and hypothesis**

The 3D printer can be used in the classroom as an instrument for the activity of learning. In an educational context, this use presents problems that should be solved (Ginestié, 2005). Different problems appear, for examples: problems of design; of 3D modeling; of transfer from an object designed digitally (virtual) to a real product; of settings to achieve a satisfactory result (Banon, 1991; Simon, 1995; Visser, 2009). In this context, the activity has two types of orientation. The first one is the completion of the task, an activity with the purpose of a production. The second is the development of internal and external resources: a constructive activity where the subject produces the conditions and means of carrying out the activity (Rabardel, 1995; Rabardel & Samurcais, 2003). Thus, the mobilized theoretical frameworks include the theories of activity. For our research, the students must construct a ball with a 3D printer. We analyze their activity to find common denominators that are identified during this process (Gero & Kannengiesser, 2004). This analysis explores the process of teaching-learning from the point of view of the students (Ginestié & Tricot, 2013).

The coding of the cognitive process allows to identify distinct phases such as the identification of the problem, the development of workable solutions and the application of the solution (Wilson et Al, 2013).
Then we get specific markers. They are presented in the following table.

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>MARKERS</th>
</tr>
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<tbody>
<tr>
<td>Classification</td>
<td>Classify the guide sheets</td>
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<tr>
<td></td>
<td>End of the classification</td>
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<tr>
<td>Manipulating the system</td>
<td>Manipulation</td>
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<td></td>
<td>End of manipulation</td>
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<td>Printing</td>
<td>Start of printing</td>
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<td></td>
<td>End of printing</td>
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<tr>
<td>Speech between pupils</td>
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<td>End of speech</td>
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<td>External help</td>
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<td>End of the help</td>
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<td>Contact with the laptop</td>
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<td></td>
<td>Contact with the mouse</td>
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<td>End of contact</td>
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<td>Contact with printer</td>
<td>Start of contact with printer</td>
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<td></td>
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<td>End of contact</td>
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<tr>
<td>Problem</td>
<td>Identification of the problem</td>
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<td>Solution</td>
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<tr>
<td>Final result</td>
<td>Success</td>
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<td></td>
<td>Failure</td>
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Table 1. Identifiable items used for the video analysis

Our research question is about the approach and the functional understanding of a system. Are such tools useful, what kind of benefits do they bring, does it works for all the children?

To answer this question, we assume that not only the technology teachers use tools but also that the functional approach leads students towards an understanding of complex technical systems. (Chatoney & Gunther, 2014). The efficiency of this teaching is based upon the study of systems. (Gunther & Chatoney, 2016) The purpose is to demonstrate that the learning of specific languages plays an important role in the construction of technical thinking.

**Methodology**

This approach is based on an experiment with a pre-analysis of the task. The analysis of the task carried out by the students will tell us what kind of knowledge or skills they use to perform the task. The purpose is not only the use of the system but also to understand it.
Eight students are concerned by this experimentation, they form 4 pairs. These students all belong to 9th grade in a middle school where the distribution of the socio-professional categories of the parents is close to the national average.

It should be noted that each pair of students belong to the same class. This constraint and the choice of the pairs are due to the organization of the school. The activity of the students is filmed and transcription of the speeches are made.

The video and audio recordings were made in the following configuration:

![Diagram of video and audio configuration]

*Figure 1. Positions for the experimentation*

Video recordings have been analyzed with the Kronos-Actogram software that allows to count and locate the indicators from the analytical framework during a specific time (table 1).
The next figure shows the tasks the students must perform and how many time was allowed for each task.

![Diagram showing tasks and time allocations]

*Figure 2. Methodology and chronology*

We now detail these tasks.

**Ordering the sheets explaining the different operations to use the 3D printer**

This is the first task.

The students have indications sheets on which operations to be performed are detailed. The task is to put these sheets guides needed to use the 3D printer in the correct order. Students are also in front of the real system consisting of the printer connected to a computer as photographed here.

![Image of the 3D printing system and laptop]

*Figure 3. The 3D printing system*

The software to drive the printer is included in the laptop. Some operations are already made to gain time and to simplify the task. For example, the cables are already in place, and the laptop is switch on. This allows to focus on what matters for us, namely the chronology of the task that involve different elements of the system.

The goal is to see if students understand the interactions between the distinct parts of the system. The way the students order the sheets allows us to check the complementation of this goal.
All the operations for the implementation of this material requires several steps that can be summarized as follows:
- create a 3D virtual model using the software. This model must be an understandable code for the printer.
- connect the computer to the printer. The communication will be allowed with a driver installed on the computer.
- prepare and calibrate the printer.
- print the object.
- present the finished object.

**Manufacturing a ball with the 3D printer**

This is the second task.

We want to know if the pupils have a conception of the system. Conceptualize means for us, that students have a general mental representation of this system. The students must perceive and understand the links and interactions between the main function, the technical functions and various components of the system.

Description of the main function and the technical functions are necessary ways to conceptualize the system. The main function is linked to the need (why this system has been created?) and the technical functions are linked to the structure.

To give meaning to this task, we tell students that balls from a solitaire game (figure 4) have been lost. These balls had a specific size, and are not easy to find. A solution is to fabric them. To make a ball with wood or other materials requires certain skills and specific knowledge. An uncomplicated way to proceed is a 3D printing of the ball and the school possesses such a printer.

![Image](image.png)

*Figure 4. The solitaire game*

One of the main challenge during the printing procedure is the calibration of the printer. The way this process is performed results in obtaining or not a ball. The adjustment of the relative high between the extrusion head and the worktable of the printer is one of the key parameters that allows to get a piece of quality. On some printers, this adjustment can be done automatically. In this case, we use a sensor that is located on the nozzle and which provides the distance between the nozzle and the worktable. However, the manual setting remains an adjustment that must be done for most of the 3D printers. Checking the adjustment can be made by inserting a sheet of paper between the nozzle and the worktable. The distance between these two elements should be 0.1 to 0.2 mm. The paper sheet should not be completely blocked. This setting is subjected to a certain appreciation from the operator, the traction needed to pull is not specified and the notion of blocking or not is relative.

For the other operations, the students can rely on the guide sheets they had put in order. The adjustment of the height of the printer worktable is crucial and could drive the students to a problem. The printing will not be correct if a right adjustment is not set properly.
This two figures well demonstrate the obviousness of the appraisal regarding the printing success. The link between this result and the possible systemic comprehension is not direct. It mainly depends on how students will interpret and make the adjustment. To analyze the cognitive process, we try to understand how this setting operation has been understood by students (Charnay, 2003). The software had generally a specific menu with a function for the adjustment of the height of the worktable. The way the software is designed allows the operator to use specific knowledge. If no connection can be made by the user between the window open in the software and the necessary knowledge, the first activity will be the understanding of the software. It is at this moment that some structural and functional knowledge about the system are mandatory. It is only under these conditions that the students can go through the next steps in a logical and sequential way.

At this stage, the students must perform actions on the interface, these actions will have a direct application on the machine. It seems however that if the students have a good knowledge of the machine or if they are used to that kind of manipulations, the time to perform the task will be shorter.

**Results**

*Discourse analysis*

First, we note that some pairs were proud to finish the task with success, they even called the other students to report this. For these students, the relation to the machine goes clearly beyond the manufacturing functions. Other pairs remained on a purely pragmatic and material plan and kept a certain distance with the system. They used phrases such as: “you must not touch, have you seen it works, yes it works”. Some did not understand why their printing was not a success. The explanations were vague and contradictory: the ball took too much height, the edge was too low, we should have decrease the value. For them the process of trial and error did not work. Even if they conducted two tests, they did not provide the correct explanation. They acknowledge the existence of a problem with the height, but they linked this problem to the ball or to “an edge”. The pupils did not tell what is this ‘edge’; the nozzle, the worktable? The correction they offered goes against the right solution, they believed they had to reduce the value of a parameter instead of increasing it.

The pupils were not completely guided through the task. In the prior analysis, during the adjustment of the height of the worktable phase, testing if the sheet of paper is blocked or not involves a concept of personal feeling. Here, according to this analysis we can say that some students have followed the correct procedure and apprehended the setting in a satisfactory manner. We also note that all the students have followed the guide sheets.
In the students’ speeches, clues appear clearly about the interaction, or the lack of interaction, between the command and the operative part of the system: “whoa it almost touches, it should react, it moves a lot, it seems it doesn’t move in fact there, ha yes it moves just a little bit”. Some were even a bit surprised when an automatic sequence started up when printing, but reacted by explaining the phenomenon as: “it works alone”.

It is much more difficult to find traces and to see if the pupils understand that they can send a command to the printer by clicking on the computer interface. For some pairs of students, it is only an effect of surprise that is very clearly marked: “put a piece... it's done, click on Center, then on Go, she (the machine) scares me, she does it all alone”.

During the theoretical pre-study, we have detailed that the problem the students must solve is the adjustment of the height of the worktable. We believe that if they can take in account the importance of this setting, they can understand the role played by the height of the worktable in the fabrication process. This concept can also allow the general understanding of the system.

The blocking or not of the paper sheet between the nozzle and the worktable permits to validate the adjustment. This notion of blocking was chosen because it is subject to the discretion of the manipulator. Behind this gesture there is a cognitive process that takes place and it is this process we are trying to identify in the discourses between students.

For the students, the link between blocking the paper sheet and the success of the printing is not as obvious as it seems. If we analyze the speech when they remove the sheet, we have the following observations: “here it starts to block well, it gets - it's good, take the sheet, it's blocked...”

We realize that for some pairs the speech clearly indicates that the sheet is blocked. For others, this is not the case, it's even the opposite, they knew that this part of the task is not completed but this did not prevent them from continuing the activity as if everything was all right.

Students work very sequentially in the face of the system. Once they have identified the problem and before applying a solution they seek confirmation from the teacher. This can be seen in the next figure. This diagram is the chronological analysis of the indicators for of one of the pairs.
This figure is quite the same for all the pairs of students. It allows us to introduce this chronological action as the first step of a model for studying technical systems. We notice that at the beginning the entire system is explored, both the printer and the laptop are manipulated. After a while it is mainly through the interface that the system is manage. Even when a problem occurs, the interface stays the main way to find a solution. That can be crossed with the discourse analysis, the conclusions are almost the same: the interactions between the distinct parts of the system are not very well integrated.

Conclusions and perspectives
It is difficult for the students to have a global vision of the system. The practical approach, which is motivating and fun, does not seem to let appear as essential the different interactions between the components of a system. This even if it is complemented by the resolution of a problem. But if the pupils are aware of the functionalities of the systems, they can apprehend in a better way these interactions. This systemic thought is not an usual approach for these pupils, even if they could be initiated to a few basics concerning the functional analysis.

Nevertheless, while our experiment involved pupils from different level and was followed by other tests, we notice that the pupils with scholar difficulties were rather able to describe the system in a better way when they knew the functional analysis of the system. They had no fear to fail while doing the experiment and were very proud of their success, success which is not so usual for them.

We see that the teaching and learning of the functional analysis bring advantages. But these practices are little anchored in the primary and middle school. In high school they appear only in specific sections that are oriented toward science and technology of the engineer. However, it is an initial step that could be part of the education in our actual society where the technology is omnipresent.
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Enhancing Teachers’ Understanding of Young Students’ Learning in Technology

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Abstract
This paper describes a study of a tool used to develop teachers’ understanding of teaching and learning and the formative assessment of students aged four-seven years of age in technology education. The research is aimed at assisting teachers’ understanding of learning in technology through the use of an observation and questioning framework, a tool to formatively assess aspects of technology. This study applied aspects of the theory of building learning power to facilitate the development of dispositions and attitudes including the building of students’ confidence and self-belief in their capabilities, within four aspects of learning and across five pre-determined behaviours relevant to technology education. The study employed qualitative research methods to assist teachers in the use of the observation and conversation framework aimed to improve their ability to formatively assess their students and their ability to give specific feedback in technology. The framework was presented to the teachers in three countries, England, Sweden and New Zealand, prior to teaching. Subsequent observations and interviews were used to gauge teachers’ developed understandings of students’ thinking and learning in technology. Their opinions and recommendations for improvements of the framework were also sought. The study shows that framework presented a number of benefits for teachers in two areas. It gave them considerable insight into aspects of technology and how students learn in technology and it also enhanced teachers’ understanding of technology and student behaviours that influence learning.

Keywords: Formative Assessment, teachers’ understanding, dispositions, primary, early childhood, aspects of technology, technology education

Introduction
Research undertaken to develop a tool, the Technology Observation and Conversation Framework (TOCF), to assist teachers’ understanding of and students’ learning in technology for students aged from four to six years is reported in this paper. It presents the final framework and teachers’ views on how they were assisted by the framework. The study offers an international perspective on ways to broaden and deepen students’ understanding in technological literacy and contributes to the field of formative assessment in technology education. This research was undertaken in three countries, New Zealand, England and Sweden, all with a high reputation in technology education. Teachers of four to six year old students were given the proposed framework, which they used to inform their conversations with their students while engaging in technological activity.

Learning in Technology Education
Learning technology presents teachers with a challenge of equipping students with skills and knowledge necessary to thrive in their current and future worlds. Technology education should recognise and enable students to be mindful of the future as they use, critique, design and develop technological outcomes (Snape & Fox-Turnbull, 2011). Wagner (2008) advocates seven skills vital for success: critical thinking and problem solving; collaboration across networks and the learning by influence; agility and adaptability; initiative and entrepreneurialism; effective oral and written communication; accessing and analysing information and curiosity and imagination. Claxton, Chambers, Powell and Lucas (2013) discuss the building of learning power within students through
the development of dispositions and attitudes including the building of students’ confidence and self-belief in their capabilities, within four domains of learning rather than the building of specific sets of skills. Within Claxton et al.’s four domains: resilience, resourcefulness, reflectiveness and reciprocity sit a number capabilities, some of which are particularly relevant to technology education such as: noticing, perseverance, managing distractions and absorption in the resilience domain; making links, questioning and imaging in Resourcefulness; planning and distilling in Reflectiveness and collaboration, empathy, inter-dependence in Reciprocity. Claxton and colleagues (2013) state that increasing students’ curiosity, sense of adventure, perseverance, and independence along with teaching students how to be better learners increases also their capabilities.

Conversation and collaborative learning play important roles in the learning of technology (Fox-Turnbull, 2013). Most of the capabilities and behaviours mentioned above are better facilitated if students are working collaborative and talking to each other and their teachers. Funds of Knowledge (González, Moll, & Amanti, 2005) also play an important role in learning in technology. They include knowledge and skills students bring to learning from their cultural and community experiences and that subsequently influences their learning. Fox-Turnbull (2016) in previous study identified that students draw on their funds of knowledge to inform their technology practice.

Assessment of students’ learning and development in technology involves intelligent observation of and conversation with students by teachers with the purpose of improving students’ technological literacy (Compton & France, 2007). National or state curricula such as New Zealand’s national curriculum technology achievement objectives (Ministry of Education, 2007) and the United Kingdom’s Key Stages (Department of Education, 2013) in design and technology (d&t) go some way to identifying progression in technology. Compton and Harwood, (2005) Jones (2009) and Pellegrino (2002) suggest more research is needed around the notion and specifics of progression in technology.

This Study
This research was situated within a sociocultural paradigm and employed interpretative qualitative research method (Ritchie, Lewis, McNaughton Nicholls, & Ormston, 2014) through the application of the TOCF by teachers to assist them in broadening their understanding of students’ learning and to facilitate the giving of relevant feedback to students as a part of the formative assessment process in technology. Data was gathered over a six month period in 2016. The main data came from pre and post semi-structured interviews with six teachers. Data was triangulated through researcher observations and audio recording of teachers’ conversations with students. Data analysis occurred through repeated coding and recoding to enable a rich description of the teachers’ experiences using the framework. After the analysis of early data the framework presented in this paper was modified after all the initial interviews were undertaken.

The Participants
Six teachers took part in the study, two each from New Zealand, England and Sweden. All teachers taught five and six year old children, teachers in UK and Sweden also taught four year olds. In Sweden this was in an Early Childhood setting, in New Zealand a primary setting and in England the school included both early childhood and primary children. Pseudonyms are used to protect the identity of the teachers.

- Teacher 1 (M) had taught for nine years and learned technology education as a part of his initial teacher training. He enjoyed teaching technology although admitted he was not hugely experienced at it.
- Teacher 2 (Am) was a beginning teacher who had no specific technology education in her initial teacher training programme. She had never taught technology before the study but did observe it being taught on one of her practicums.
- Teacher 3 (K) was an experienced primary teacher of nine years who moved into just teaching technology three years previously. K had no formal training in technology before
obtaining her position. She took a number of classes to upskill herself in technology but was given limited professional development in the technology curriculum.

- Teacher 4 (Ji) was a very experienced primary teacher with 19 years’ experience. She then took an 18 year break before joining her current technology department as a specialist teacher assistant. When entering her current department she was given some ad hoc professional development in safe use of machinery.
- Teacher 5 (Je) has 18 year teaching experience who worked with students from 1 - 6 years of age. As an ECE trained teacher she received no technology education training in her initial teacher education programme.
- Teacher 6 (An) was also an experienced teacher of 19 years who worked with students from 1 - 6 years of age. Again as an ECE trained teacher she received no technology education training in her initial teacher education programme and was heavily influenced by the Reggio Emilio philosophy of teaching.

At the point of the first interview teachers had varying understandings of technology. All understood that technology was about the ‘made world’ and that students designed and developed technological outcomes. Only some understood the need to understand the impacts of technology on people and places.

**Technology Conversation Framework (TOCF)**

The Technology Conversation Framework (TOCF) identifies five behaviours: resilience, transference, flexibility, reflection and socialisation. The first behaviour is Resilience and includes capabilities of perseverance especially after initial failure, managing distractions from peers, other activities and people around them, and absorption in any given task. Absorption, likened to Csikszentmihalyi’s (1990) state of ‘Flow’ is described as a state of deep absorption in an activity that is intrinsically enjoyable, as when artists and athletes are focused on their play or performance (Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2003). Transference includes making links to technologies experienced or seen, and experiences undertaken previously such as using existing cultural knowledge and experiences or Funds of Knowledge (González et al., 2005). Flexibility and Sophistication indicate a depth to understanding as well as an openness to new and potentially strange ideas. It involves use of reasoning to evaluate and distil information received in order to understand what is learned from an experience. Spendlove (2015) identifies strong societal benefits of being creative within technology education and that increased sophistication of ideas may lead to improved creativity. Reflection describes the strategic and self-managing aspect of learning and includes the planning and anticipating of needs and potential issues and distilling information for potential of future use. Finally Socialisation identifies with the inherently social nature of technology and its huge physical, social and environmental impacts. Whether engaging in the use or the development of technology students will be interacting in a social manner. They may be collaborating with others to develop single or parallel technologies, they will experience interdependence, or the balancing of self-reliance and socialisation, as the need for resources and skills arise. Even when interacting with technology in a solitary manner students are still engaging with people.

These behaviours incorporate cognitive, social and physical behaviours. Within each behaviour are a number of capabilities which informed the development of the questions and the "look for" statements in the framework and to assist teachers in the recognition of the behaviours. The behaviours and capabilities are outlined in Table 1 below.
Table 1: Potential Behaviours Underpinning Success in Technology

<table>
<thead>
<tr>
<th>Behaviours: Demonstration of:</th>
<th>Resilience</th>
<th>Transference</th>
<th>Flexibility &amp; Sophistication</th>
<th>Reflection</th>
<th>Socialisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capabilities</td>
<td>Perseverance</td>
<td>Making Links</td>
<td>Planning</td>
<td>Questioning</td>
<td>Empathy &amp; Listening</td>
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<td></td>
<td>Managing</td>
<td>Imaging</td>
<td>Distilling</td>
<td>Distilling</td>
<td>Collaboration</td>
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<td></td>
<td>Distractions</td>
<td>Noticing</td>
<td>Reasoning</td>
<td>Revising</td>
<td>Interdependence</td>
</tr>
<tr>
<td></td>
<td>Absorption</td>
<td>Questioning</td>
<td>Imagining</td>
<td>Meta</td>
<td>Imitating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Planning</td>
<td>Capitalising</td>
<td>Learning</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distilling</td>
<td>Evaluating</td>
<td>Evaluating</td>
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</table>

Each behaviour was subsequently extrapolated through five aspects of technology education common to the three countries involved in the study. The aspects include students gaining:

1. an understanding of their technological (made) world
2. the ability to evaluate (analyse and critique) current technologies
3. the ability to identify potential technological problems, needs or opportunities
4. the ability to design and make technological outcomes to meet identified needs using a range of materials
5. understanding of key concepts and processes unique to technology and deploy these in their practice where applicable.

In each aspect and across all behaviours potential student actions and teacher questions were written to assist teachers in developing understandings and recognition of students learning in technology. The teachers were given the framework at their first interview. Modifications were made to the TOCF after each round of interviews in response to participants’ feedback. The completed TOCF can be found in Appendix 1.

Using the Framework
During the study the framework was used by all teachers as they worked with their students undertaking technology activities. The teachers felt they that needed to be familiar with the framework before using it with the students and most found the questions more useful that the aspects to ‘look for’. Most said this was because they were easier to recall. All teachers indicated that framework assisted in developing their understanding of the breadth and depth of learning in technology and that it assisted their questioning and teacher/student conversations about technology.

Findings
The Technology Conversation framework (TOCF) offered assistance to teachers in understanding underlying key aspects and concepts in technology through the recognition and identification of the identified behaviours. Assessment occurred as teachers and peers listened to, watched, and interact with each other. In this research teachers used the TOCF to inform their interactions and observations of students thus assisting their ongoing formative assessment.

The findings from the study indicate that the teachers found using the TOCF as useful tool for developing their understanding and insight into student learning in technology. They also benefitted by developing deeper understanding of technology education (reported elsewhere). A number of recommendations for using the framework were suggested as well as feedback on potential disadvantages or issues with using the TOCF. Within the main theme reported in this paper five sub-themes emerged and are outlined in the Table 3 below.
Table 3: An Overview of Research Findings in the Main Themes

- Insights into students’ learning and benefits for students when teachers were using the TOCF.
- Understanding technology practice process and concepts reflective practice and role of questioning
- Working collaboratively/ interactions between students including modelling
- Transference
- Motivation and engagement including using creativity and imagination
- Importance of resilience and ability to make mistakes without failing.

Insights into Students’ Learning

Teachers felt they gained a better understanding of students’ learning in technology in a number of ways. “The framework helped me to see that we can help the children even further in their progression of learning technology than we try to do today” (An). Participants gained an understanding of student technology practice and the role of reflection in student learning in technology as illustrated by A.

They were really reflective and quite honest during that process…. They were very self-critical, which was interesting …as it doesn’t come naturally to this age. So we were able to seem them develop those skills of being critical of their own work and their own thinking. It was quite incredible (A).

And this by An “It has been fantastic to see how the children worked with the material and trying to build things from the real world, or new creative constructions that they are proud of”. M realised that students were making ongoing design decisions to improve outcomes.

I think the conversations of some of the kids, I was going to use paper’, ‘well why didn’t you use paper?’ ‘Because paper wasn’t strong enough so that had to change’ showed that they understood that it was still their design but they have made these changes to make it stronger (M).

Teachers gained insight into the benefits of the questions, illustrated by M in the following quote “It was so amazing really to see how much the questioning did enrich the learning and how it kind of lifted it up a level from where it would have been in the past…..Children think at higher levels” (M). Teachers also realised the benefits for students of working collaboratively, how they modelled and learned from each other. Jn was surprised to see her four and five year olds working together.

“Yeah, and solve problem, and I think it’s possible to do it ……and they can do it together, and they find material, so built together to, and have own ideas when they collaborating together”. Teachers also observed that students were also able to recognise that working with other people assisted their learning.

When we asked ‘How did working with someone else help you and they kind of stopped and went ‘yeah it did help’ or they’d say ‘no that didn’t help’, but they would stop and think about it and then give reasons why it was helpful (M).

The following extracts indicate that the teachers identified that the students were very motivated and engaged in their learning and therefore became more resilient as they were motivated to do a good job. “I asked them how they learned to build so fantastic together. For a month ago we built separately, and now we build together. So we have learned to use each other” (Jn).

I think because it was relevant to them so the idea that technology just this sort of farfetched thing for the professional, it can be something that relates to your needs and your life and the people around you so they kind of realised. ‘Ok so I might not grow up to be a person who designs technology but I can still follow that process now through to the end’, which is something quite cool (Am).

Teachers also developed insight into how students transfer knowledge from other areas of their lives to technology. In Sweden the students were engaged in designing a three dimensional
railway. “They had that three dimensional thing in their mind and then they pick up trains and try to use it so I saw we could work together. The students selected the context themselves, and Jn noted that most students used the train regularly with their parents and some parents were employed in railway construction. “It is very big project and for trains too, so I think, and we have parents who work to build train[s]” (Jn). In England K was impressed how her students transferred collaborative skills to technology to achieve positive results”.

I thought it was one of those moments as a teacher where you go, they were there, they were listening. It had sunk in, it had made a difference. It wasn’t just me going blah blah blah. That gave me great joy, really gave me great joy, cos that’s a life skill and they transferred it (K).

Teachers also noted how seriously the students took their work and that they were motivated and engaged in their technology practice as illustrated by Am in the following extract.

It was like a fun activity but to see how seriously they took it. It was like ‘this is my plan and I’ve got these materials and I need to make it’. They were thinking about how they were going to make it and what it was going to look like at the end (Am).

In New Zealand the teachers also specifically commented on the need to for the students to develop resilience. On seeing the framework for the first time M commented on the need for his students to develop resilience as they tended to give things a go once and then give up. The following extract from the researcher’s journal “M very enthusiastic and excited. Could immediately see the applications in resilience particularly” (Researcher Journal 15 June 2017). This understanding also assisted the teachers’ recognition of resilience within the students later in their project.

so they understood that there wasn’t a process of failure but that is something that everybody does and you can always look for what you can do better, and it was like ‘Oh, Okay!’ Mr M and Miss A can make mistakes so therefore so can I, I can admit them because it’s not that I have failed.

Discussion and Conclusion
Snape and Fox-Turnbull (2011) state that technology and the principles of twenty first century learning are particularly compatible, this is clearly evidenced in this study. Through the asking the questions and observing student learning based on the five identified behaviours in the TOCF teachers were assisted in their teaching of technology by giving them insight into learning behaviours with the identified aspects of technology. Teachers tended to focus on one or two aspects of the framework at a time, but drew on questions from all of the five behaviours. In New Zealand and Sweden the teachers focused on Design, Make and Evaluate. In England Understanding the Technological World and Evaluate current Technologies. All teachers indicated that the other aspects would be useful in other units or projects, especially if available during the teacher planning process.

Teachers in this study stated that they could see the benefits of students developing resilience through the understanding that making mistakes in technology is a normal and indeed useful part of technology practice, rather than failure. This supports Claxton and colleagues (2013) stance on the role of resilience plays in successful learning. Transference was also identified by the teachers as making a positive contribution to students’ learning in technology. In all classrooms students were clearly influenced and brought their Funds of Knowledge to their activity, as particularly illustrated by the students in Sweden who design a complex railway system. This supports in the literature on Funds of Knowledge (Fox-Turnbull, 2012; González et al., 2005) that students benefit from funds of knowledge transference to classroom learning, especially in technology.

The framework assisted teachers’ recognition of the need to develop higher level skills and abilities of their students in technology. The study clearly illustrates that higher level questioning, reflection and collaboration play an important part in developing deep understandings of technology and technological practice. Teachers in England, including K who was the most experienced
technology teacher highlighted 53 of the 91 questions from the framework that they had previously or regularly used. Teachers in New Zealand and Sweden commented on how the questions assisted their teaching practice in technology. The ability for students to work collaboratively and to be reflective and self-critical surprised all the participants. The findings from the study clearly support Wagner’s (2008) proposed essential modern survival skills and Claxton and Carr’s (2010) dispositions necessary for learning and ability to build learning power (Claxton et al., 2013). Collaborative technology practice is common place, but perhaps less so in technology education, especially with young students who are perceived as not being able to work well collaboratively. This study indicates that collaborative practice not only occurs in technology but that students benefit from working with their peers, as was illustrated in both New Zealand and Sweden and supports Fox-Turnbull’s (2013) study on the role of conversation in learning. Teachers developed insight into a range of ways students were able to work collaboratively, even at quite young ages.

A number of recommendations emerged from the study. Teachers suggested that the framework would be very useful as a tool to not only assist with conversations with students but also with their planning.

Also having it alongside when you are doing your planning and looking at times …we went through and highlighted certain questions, it was suited to the activity that we were doing, so having that alongside your plan then you kind of look at it and going this is a skill that that we are really really rubbish at and need to build on this, you know like resilience is [one] of the big things that we are working on, and the transference and looking at those questions and go ok these are the ones we need to start feeding into and putting into what we are doing (M).

The New Zealand teachers suggested that a number of earlier activities they had completed before getting the framework might have been enhanced if the TOCF had been available. It would also have guided their earlier conversations with the students possibly maximizing the planned learning opportunities. The teachers in England wanted further clarity about contextualising the questions, rather than talking about technology in a generic way. All teachers suggested that users of the TOCF should become quite familiar with it before using it and felt that although this process was time consuming, it was worthwhile. Several teachers thought that the questions could be separated from the framework and enlarged and put on a ring binder system for implementation so that the questions were close at hand and easily accessible as teachers work with the students. One teacher was concerned about the amount of talking that using the framework involved but understood that the talking did not need to replace any practical activity rather occur in conjunction with it.

In conclusion the study’s participants stated that using the TOCF assisted their understanding of how and what to teach in technology education and in helping their students’ development in technology through the identified behaviours and across the identified aspects of technology. A further study could apply the framework over a larger number and wider range of students, in terms of ages, culture and nationality and accurately measure the impact of learning for students. Changes in teachers’ understanding of technological pedagogical and content knowledge that occurred while using the framework could also be studied.

References


### Appendix 1: Technology Conversation Framework (Where the words have an * replace with the specific context of learning)

<table>
<thead>
<tr>
<th>Behaviours Aspect</th>
<th>Resilience</th>
<th>Transference</th>
<th>Flexibility &amp; Sophistication</th>
<th>Reflection</th>
<th>Socialisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding of the technological world</td>
<td>Look for: using technology* and having repeated goes at getting it right or improving use of an existing technology.</td>
<td>Look for: transferring knowledge and skills in the use of one technology to another technology that might involve similar skills. Recognition of the similar skill sets.</td>
<td>Look for: increasing understanding that technology is made for purpose. Different needs lead to different outcomes.</td>
<td>Look for: talk about why some things are made by people and some things are not.</td>
<td>Look for: understanding that technology is usually made by groups of people working collaboratively.</td>
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<td></td>
<td>Total absorption while others are playing / working around them.</td>
<td>Deploying skills and knowledge used at home with a different technology at school.</td>
<td>Students finding relevant information from unexpected sources.</td>
<td>Questioning of how and why things work.</td>
<td>Technology is made for people.</td>
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<tr>
<td></td>
<td>Not letting others distract them.</td>
<td>Recognising a range of ‘made’ things.</td>
<td>increasing under standing that technology is made for purpose.</td>
<td>Thinking about their thinking about technology.</td>
<td>Understanding that many people influence technology design.</td>
</tr>
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<td></td>
<td>Hunting for the best device to do a particular job.</td>
<td>Have you done anything like this at home or with your family?</td>
<td>Understanding different needs lead to different outcomes</td>
<td></td>
<td>Attempting to use technology by copying the actions of adults.</td>
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<td></td>
<td>Ask: How might you get better at using this technology*?</td>
<td>Where have you seen this before?</td>
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<td>Ask: Tell me why this is technology?</td>
<td>Ask: Who makes stuff (technology)*? Why?</td>
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<td></td>
<td>Who might help you with this*?</td>
<td>Have you used this before? Imagine what this might look like in 20 (50/100) years time.</td>
<td>How might this be improved?</td>
<td>How might this be improved?</td>
<td>Do you think people worked together to design and make this?</td>
</tr>
<tr>
<td></td>
<td>What might be a better thing to do this job?</td>
<td>What are the benefits of this?</td>
<td>What works well?</td>
<td>What works well?</td>
<td>How do you know?</td>
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<tr>
<td></td>
<td>What can I do to help you with this?</td>
<td>What would you like to ask the person who made this to find out about how and why it works?</td>
<td>What does not work well?</td>
<td>What does not work well?</td>
<td>How do people work together to make this technology*?</td>
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<td></td>
<td>Say: Have another go. You are just not there yet.</td>
<td>Which do you think is the better/ best (comparing a range of similar technologies*)?</td>
<td>Which do you think about when you use this technology? Why is this important?</td>
<td>How can thinking help you understand this?</td>
<td>Give me an example of something that is/ is not made by people.</td>
</tr>
<tr>
<td>Behaviours Aspect</td>
<td>Resilience</td>
<td>Transference</td>
<td>Flexibility &amp; Sophistication</td>
<td>Reflection</td>
<td>Socialisation</td>
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<tr>
<td>Evaluate current technologies</td>
<td><strong>Look for:</strong> willingness to have a go at articulating the physical and functional features and nature of existing technologies.*&lt;br&gt;Having several attempts at explaining the success or not, of technologies</td>
<td><strong>Look for:</strong> use of evaluative language used to discuss technologies in one context transferred to another. Ability to imagine a better version of technology. Noticing similar features from one technology to another.</td>
<td><strong>Look for:</strong> increased awareness about the complexity of technology and that evaluations from different people will be very different. Understanding why what works for one person might not work for another. Imaging a more complex version or different version to better meet identified need.</td>
<td><strong>Look for:</strong> the ability to experiment with a technology and talk about how they might make it better. Children asking of questions as to why technology is the way it is. Questions about functional features. Questions about physical features.</td>
<td><strong>Look for:</strong> recognition that designing and making technology* is frequently undertaken in teams. Understanding that to evaluate technology* a range of stakeholders - groups of people with a stake in the technology need to be considered. Comparing technology* using language of more advanced peers or adults.</td>
</tr>
<tr>
<td>Say: Try again to see if you can get a different result. Use different words such as: better than, different to, similar to, not as good as .... when talking about this technology?</td>
<td><strong>Ask:</strong> How could you improve this for another group of people (state actual group)? Why was this technology made? Who else might want to make this? What changes would they make? Why? Have you seen this feature in something else? How have you used what we found out earlier about X in your plan?</td>
<td><strong>Ask:</strong> Why does this technology work so well? Who might this technology not work for? Why? Who might it work better for? What makes this technology safe to use?</td>
<td><strong>Ask:</strong> What makes this X* a good one? How could you improve it? Why do you think this? How could this technology* be made safer to use? Would your parents (Mum, Dad etc.) use this technology*? Why? Would your parents (Mum, Dad) like this technology*? Why? Do you have the same or different ideas about this technology* than your parents? Why?</td>
<td><strong>Say:</strong> Talk about successful design and ideas.</td>
<td><strong>Say:</strong> Talk about successful design and ideas.</td>
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<tr>
<td>Behaviours Aspect</td>
<td>Resilience</td>
<td>Transference</td>
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<td>Identify technological problems or needs</td>
<td><strong>Look for:</strong> an understanding that investigation is need to identify potential solutions. Understanding and practice that the design process may have to be repeated to obtain eventual success.</td>
<td><strong>Look for:</strong> the ability to transfer potential solutions from other situations to an identified need. Ability to recognise that a problem can be solved with a technological solution.</td>
<td><strong>Look for:</strong> ability of offer a range of innovative solutions to a single problem. Ability to recognise that a technology solution is needed. Imaging a more complex version or different version to meet a different need. Recognising that a solution in one area might be modified to assist in another.</td>
<td><strong>Look for:</strong> Recognition of what circumstances led to a particular technological need. The ability to recognise a range of possible solutions and that some solutions are better than others. Ability to justify the above. Recognising opportunites for developing technologies.</td>
<td><strong>Look for:</strong> the understanding that conversation and working cooperatively can assist the process of problem/solution identification. Understanding that working together can mean doing different tasks on the same project. Imitating adults in the articulation of a technological problem and/or solution. Listening to others for ideas.</td>
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<td><strong>Ask:</strong> How many ideas do you think you need? What would you change the second time if the first idea does not work?</td>
<td><strong>Ask:</strong> What have you seen that is a similar problem/need to this? What do you know about recognising a technology problem from doing technology in school another time?</td>
<td><strong>Ask:</strong> Rank the ideas you have to this problem from best to worst? Tell me why they are in this order? What do you think might be the best solution to this problem? Why?</td>
<td><strong>Ask:</strong> Which is the best design to meet this need, do the task required? Why do you think this? What might be a better idea? Within this situation or scenario what is the technological need? (What needs to be developed? Why?)</td>
<td><strong>Ask:</strong> How can working together help you decide the best solution to the problem? Who might help you think about doing this better? How might you help others to recognise an opportunity or identify the need?</td>
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<tr>
<td>Behaviours Aspect</td>
<td>Resilience</td>
<td>Transference</td>
<td>Flexibility &amp; Sophistication</td>
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<tr>
<td>Design &amp; make technological outcomes to meet needs including evaluating their design ideas and outcomes</td>
<td>Look for: ability to continue working on a technology drawing/model/outcome to improve quality. Total absorption while others are playing / working around them. Not letting others distract them. Repeatedly giving things a go after initially failing.</td>
<td>Look for: skills learned in skills based lessons such as drawing, gluing, etc. used when making the actual drawing/model/outcome. Transfering identified attributes from design to the technology outcomes. Use of safe practices Use of research/investigation findings evident in planning/drawing.</td>
<td>Look for: detail in designs, ability to draw in 3D and annotate design ideas. Use modeling to inform technology practice and improve technology outcomes. Understand how modeling helps improve technology outcomes. Ensure design reflect required or desired attributes. Students drawing on relevant information from unexpected sources.</td>
<td>Look for: ability to self and peer evaluate outcomes against established attributes or characteristics. Ability to recognise and justify changes for the next iteration of the design.</td>
<td>Look for: ability to work collaboratively with others. Ability to engage in intercognitive conversations, let own ideas go if necessary and move to new thinking with others. Embrace knowledge and skills brought to the group by others. Listening to others for ideas. Ask: How does working with other people help you ? What ideas did you change after talking to X/group ? What knowledge and skills did you know that the others didn’t know and that helped your group ? How can other people help you make your design ?</td>
</tr>
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<td><strong>Ask</strong>: If your first idea does not work what will you do ? What other detail can you put in your drawing/model? How might you improve the quality of your technology outcome ? <strong>Say</strong>: Try again to do this, but in a safer way. Like this (demonstrate skill)</td>
<td>Ask: What have you/we already learned that might help you with your drawing/model/outcome? Why? How will this be useful? How did you determine the attributes? Who taught you to do that? How did you know that? Can you use (a feature) from something else? How can we do this safely? How have you used in your planning what we learned about?</td>
<td>Ask: Improve your design so that another person could make your technology outcome. Why and How does making a model improve you technology outcomes? What attribute/feature is the most important why? What is the best bit of your design? What is your favourite part of the design/outcome?</td>
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<td>Behaviours Aspect</td>
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<td>Understand key concepts of technology &amp; deploy in their practice</td>
<td>Look for: ability to continue working on problem solving or developing a solution repeatedly after failure. Ability to name alternative suitable materials used.</td>
<td>Look for: key concepts (these will differ according to curricula) learned in one unit transferred to another. Tasks that are identified in real technology practice transferred to students’ technology practice. Increasing complex drawing and modelling skills in subsequent units or projects.</td>
<td>Look for: increased vocabulary sue when describing technology outcomes. Increasingly complex technologies recognised as technology. Increased complexity when considering factors that influence technology practice (theirs and others).</td>
<td>Look for: describe the technological outcome they are making. Identify why they are making a technological outcome. Use of attributes to evaluate design ideas. Discuss what is and is not technology and why. Identify who might use a technology and why. Comparing of their outcomes with pre-determined attributes. Ability to undertake self and peer assessment against identified attributes. Ask: What would a 'bad' technology look/ sound/ smell/ taste/ feel?</td>
<td>Look for: understanding the social and collaborative nature of technology and technology practice. Understanding the technology influences people and people influence technological development.</td>
</tr>
<tr>
<td>Ask: How can you make this better? What changes would you make next time? Who will benefit most from this design? Can you design it so others will benefit?</td>
<td>Ask: What groups of people may not like this technological outcome*? What are the main tasks for a technologist (a person who designs stuff)? What have we already learned that will help us with this design?</td>
<td>Ask: What would a 'bad' technological outcome look/ sound/ smell/ taste/ feel?</td>
<td>Ask: What groups of people may not like this technological outcome*? What groups of people will like this technological outcome*? Next time you made this what changes would you make? Why?</td>
<td>Ask: What groups of people will like this technological outcome* best?</td>
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</table>
'It is mainly about problem solving ...'
Knowledge of Instructional Strategies Expressed by Swedish Technology Teachers

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Abstract
Successful teaching and learning require teachers to have knowledge within many different fields. Since what pupils learn depends on the teachers’ knowledges and skills, it is of interest to further examine teachers’ competences. Based on interviews with four experienced teachers this study explores how they describe their teaching and what knowledge content they highlight.

The model of pedagogical content knowledge (PCK) of Magnuson, Krajcik and Borko (1999) has been used to analyse interviews. This paper will present findings for one of the
subcomponent of the model - knowledge of instructional strategies for teaching technology. The aim is to further investigate teachers’ descriptions of their teaching in order to frame and discuss what could be described as acquired PCK for a technology teacher within this category.

Findings indicate that respondents are well acquainted with the curriculum, including the goals and objectives. They organize teaching to link the technology subject’s abilities and core content to themes of teaching. Teachers’ objectives are to a large extent activity-driven, working with the design process or hands-on activities connected to specific content. They describe the importance of pupils’ developing problem-solving abilities. Differences between teachers consists primarily of what instructional strategies they use in the classroom.

Few studies have been done around technology teachers’ PCK. The outcome from this study is useful for discussions concerning technology teachers’ knowledge base, and how to organise teacher education and professional development courses.

**Keywords:** Technology teachers, experience, pedagogical content knowledge

1. **Introduction**

   In recent years, debate about Swedish teacher’s skills and subject knowledge has created a need for further research into teacher practices. This paper is part of a study where experienced technology teacher’s views on their own teaching are explored (Fahrman, Gumaelius & Norström, 2015; Fahrman & Gumaelius, 2016). Additionally, because successful teaching, to a high degree depends on a teacher’s teaching ability, subject knowledge and teaching skill (Håkansson & Sundberg, 2012; Hattie, 2009) our aim is to develop this knowledge.

   Data provided from interviews with four experienced technology teachers was analysed using the theories of pedagogical content knowledge (PCK) as a lens to explore the teacher’s statements. The data was analysed according to a model by Magnusson, Krajcik and Borko (1999). In particular, this paper looks at what the teachers expressed concerning knowledge of instructional strategies for teaching technology.

2. **Background**

   2.1 **The technology subject**

   In 1980, technology was introduced as a mandatory curriculum subject for pupils in grades 1–9. This curriculum has since been revised twice, in 1994 and again in 2011. The 2011 curriculum (Skolverket, 2011a) stipulated a stricter design compared to the earlier versions by stipulating the knowledge requirements for school years 6 and 9 and the abilities that pupils were expected to develop (Hartell, 2015). In order for pupils to develop the core content stipulated in the curriculum, a number of areas are to be covered by the teacher. These areas included mechanics, materials, electronics, automatic control, product development processes and technology’s relation to science, society at large and the fine arts (Norström, 2014; Skolverket, 2011a).
2.2 Technology teachers in Sweden
In Sweden there is a lack of qualified technology teachers. In an annual report, the Swedish National Agency for Education (Skolverket, 2015) stated that between only 38% and 60% of technology teachers, depending on the grade they teach, were formally qualified and licensed to teach technology. This situation affects the content and practice of the subject (Norström, 2014; Skogh, 2006; Teknikföretagen & Cetis, 2012), the pupils’ achievements (Nordlander, 2011; Skogh, 2006) and make teachers feel insecure about their teaching (Association of Swedish Engineering Industries, [ASEI], 2005; Nordlander, 2011). According to Hartell et al. (2014) non-qualified teachers, to a greater degree than qualified teachers, stated that they lacked the necessary competencies for teaching technology.

3. Aim and research questions
In light of the above information, for a subject where teaching practice needs to be further established, the question of identifying the qualities and competences of importance to technology teachers has become increasingly important. In their 2014 report, The Swedish School Inspectorate (Skolinspektionen) expressed concern about how the purpose and content of the technology subject was not clear to the pupils.

Consequently, the aim of this study was to develop our understanding of the specific practices that secondary school technology teachers use when they teach technology.

Therefore this paper specifically presents what the teachers expressed around their knowledge of instructional strategies for teaching technology.

The research question put forward in this paper is:

What pedagogical content knowledge concerning instructional strategies for teaching technology do experienced technology teachers express?

4. Theoretical framework of this study
The theoretical framework and analytic tool used in this study, having the potential to capture the knowledge teachers’ use in the process of teaching, is the theory of PCK. The concept of PCK was initially presented by Shulman (1986, 1987) as a contribution to the debate around teacher’s knowledge and teacher’s competencies. The idea that teachers hold a unique knowledge base caught the attention of many researchers particularly in the field of science and mathematics (Gess-Newsome, 2014). Within technology education research studies focusing on a teacher’s pedagogical content knowledge is relatively rare (Williams et al., 2013). In addition to Williams et al. (2013), Jones, Bunting and de Vries (2011) emphasised the importance of constructing a knowledge base for technology teachers in order to make technology teaching more effective.

Over the years many researchers have further developed the initial PCK model, and highlighting both its strength and weaknesses (Fernandez, 2014). Researchers have explored specific parts
of the PCK model in relation to a specific subject, teacher’s profession, or to a pupil’s learning in relation to one particular knowledge base (Ball et al., 2008; Ellis, 2007; Gess-Newsome, 1999; Grossman & Richert, 1988; Jones & Moreland, 2004; Leach & Moon, 2000). The model of Magnusson, Krajcik and Borko (1999) was developed around the teaching of science subjects.

In Sweden studies focusing on a teacher’s knowledge in connection to PCK – in particular in the STEM-subjects – are rare. One exception is Nilsson (2008) who studied PCK in relation to science teacher’s learning and teaching. She noted that:

The concept of PCK can be helpful in our continuing discussions about what is teacher knowledge and how is it developed. It can be used as a theoretical as well as a methodological framework to structure research on teachers’ knowledge and how it is developed (Nilsson, 2008, p. 40).

In framing what can be discussed and understood as technology teachers PCK this study used the model of Magnusson, Krajcik and Borko (1999) as a lens to analyse the data. In order to capture the properties, discussed by Magnusson et al., the suggested (science related) categories were adjusted and applied to the subject/teaching of technology. The model for the analyses of the data comprised the following five components:

- knowledge of the technology curriculum.
- knowledge of students’ understanding of specific technology topics.
- knowledge of assessment in technology
- knowledge of instructional strategies for teaching technology, and
- orientation towards technology teaching.

For this paper data from the subcomponent knowledge of instructional strategies for teaching technology are presented as this category specifically presents the qualities and competences of the teachers’ technology teaching practice.

5. **Method**

5.1 **Data collection and analysis**

Data was collected from semi-structured interviews using an approximately followed questionnaire with follow-up questions for clarification (Kvale, 1997). Data collection was performed according to the rules of the Swedish Ethical Review Act (2003). The analyses process included multiple readings of the transcripts. Material was encoded with the help of subgroups contained in the chosen PCK model.

The questionnaire focused on individual teaching practices and how teachers worked with theoretical and practical activities. This produced data material that did not cover all aspects described by the PCK model. The teachers spoke mostly about how their teaching was conducted; the data contained statements focusing on planning, teaching and how the teachers looked at their teaching practices.
5.2 Respondents
All participating teachers had attended an academic outreach initiative in the Stockholm area during 2.5 years. This school development program aimed at (1) boosting the technology subject in Swedish compulsory schools in the Stockholm area, and (2) to raise the level of knowledge among teachers in order for them to teach the subject. Teachers took part in seminars, workshops, lectures, etc. They discussed, planned and wrote their own school’s local technology curriculum including suggestions regarding how to teach it in the classroom. During the program, all the teachers worked substantially with the core content, the mandatory national curricular and the design of their local curricular (work plan). By choosing this group of teachers, the study reached teachers with documented experience in teaching technology in lower secondary schools (Tekniklyftet)

All respondents taught technology to pupils in grades 7–9 at the time of the interview (pupils aged 13–16). Their backgrounds and qualifications are accounted for below (Fig. 1)

<table>
<thead>
<tr>
<th>Name (not real)</th>
<th>Gender</th>
<th>Subjects and educational background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adam</td>
<td>M</td>
<td>M.Sc. in Engineering, Qualified to teach mathematics, physics, chemistry, biology and technology. Teaching for 13 years.</td>
</tr>
<tr>
<td>Bertil</td>
<td>M</td>
<td>Qualified to teach crafts, and technology. Teaching for 27 years, 10 years as a technology teacher.</td>
</tr>
<tr>
<td>Cesar</td>
<td>M</td>
<td>Qualified to teach mathematics, physics, chemistry, biology and technology. Teaches in a school where, for the majority of pupils, Swedish is a second language. Teaching for 16 years.</td>
</tr>
<tr>
<td>Dagny</td>
<td>F</td>
<td>Qualified to teach physics, mathematics, and technology. Teaching for 16 years.</td>
</tr>
</tbody>
</table>

Figure 1 The respondents’ name, gender and teaching subjects with their educational background

6. Results
Here are results, from the subcomponent knowledge of instructional strategies for teaching technology, presented.

The teachers all described their teaching to various degrees as being practical. They said they combined theory, in their particular topics, with practical activities that related to the subject content and described methods, in technology classrooms, as more problem and solution-oriented.

Dagny stated: ‘Practical work in technology, it is mainly about problem solving. In other subjects maybe more about making, but in technology, it is more solution-oriented.’

All the teachers mentioned the design process in technology as important to integrate in their teaching.
Adam said that through practical exercises he can connect the goals of the curriculum. He also said that working with practical exercises helps his pupils to understand the underlying theories. Additionally, he said, that practical exercises are very much about testing, building and constructing with different materials, to visualise and present the various projects. He also wanted to convey his teaching, in connection with the design process, as a process that mediates industrial thinking.

Bertil described his teaching starting in theory, with discussions to engage pupils, and then always providing practical sessions for the pupils to work on. He asks questions to challenge the pupils in class more; to find out and reconnect with earlier findings; to test materials and to find ways to construct and design. He described how he uses an experimental approach with the pupils, and he believes the practical activities always engage pupils, even the ones who are not too interested in the subject prefer to be active.

Cesar said, his teaching is mainly practical, as too theoretical teaching, or teaching that is only theoretical, does not work in the student body he teaches. Pupils need to build and construct, and test their constructions, and in this he has to play an active part and help, support and guide them to reach their targets and understand the contents of the subject.

Cesar stated:

At this school, the theoretical part disappears into the practical part. It will be very much a hands-on job, if you work with materials you have to have materials there to be able to feel and squeeze. It makes no sense to lecture on various material types and plastics and stuff. It runs together more here.

Much of the teaching is about processes; the pupils are given a problem which needs to be solved. Cesar usually has pupils working in equally strong teams as he finds that pupils become more active, which results in increased participation in all groups. Cesar has to plan his teaching with language support. Words and concepts that emerge during the lessons are written up and given as homework and later repeated in upcoming lessons. Cesar divides all the different subject content areas into smaller work areas, and for these areas the information needs to be clear, structured and well-planned. He spends time working out pupil documents to make it clear to the pupils what the learning outcomes are; and to clarify the subject matter and criteria for the specific topic. He recognises that teaching that has a thorough structure, that holds the group together and works with small subject areas at a time provides an increased basis for assessment, and more pupils will understand and keep up with set goals.

Dagny said that all parts of her teaching have practical exercises where pupils work with problem solving. Pupils can work on exercises that help them identify and analyse technological solutions, based on their appropriateness and function, and how to consider building structures that solve problems. The pupils must show that they can use words and concepts in connection to the topic. During the work process the pupils must be able to describe their design solution. Dagny says she works with themes like Future City, Inventors Project or First Lego League, which involve competitive elements. She believes that contests, of various kinds, are good projects as they have a given structure to work with.
7. Discussion

PCK is described as an individual form of professional knowledge explicit for each teacher. By using the model by Magnusson et al. as an analysis lens, one may put forward the respondent’s particular views on matters around different knowledge areas. With a small sample of teachers one cannot discuss technology teacher’s PCK in general, but as these teachers are well acquainted with the curriculum, subject matter and teaching of the subject, it may shed light on an area that lacks research. Using the model of Magnusson et al., one can map several aspects of the teacher’s statements of their technology teaching practice and discuss these statements in relation to the research question - What pedagogical content knowledge concerning instructional strategies for teaching technology do experienced technology teachers express?

First noted was the importance of using practical activities when conducting technology lessons. Traditionally, school activities are centered on designing and making. The teachers highlighted the design process as significant for pupils to develop their knowledge and work strategies around. The respondents chose practical activities, which related to the subject content and methods in the technology classroom that were problem and solution-oriented. To support learning that connects the learning objectives and the activities chosen, the teachers had different approaches to support the learning process. Cesar talked of structures that help his student body, like working with language support and well-defined areas of activity and subject content. He had pupils work in equally strong teams when working in groups as it helps the pupils to collectively construct knowledge. Dagny focuses on problem-solving instructions where pupils are asked to identify and analyse technological solutions. Bertil wants his teaching to be as hands-on as possible and Adam focuses on the design process.

They respondents support their pupils learning by asking questions to challenge; and promote discussion, and frequently check pupils’ understanding. They use written instructions and documents to link activities to the core content and abilities, and plan activities like material testing, model construction, and applications of design-based learning – trying and retrying, evaluating and changing models, construction or solutions with pupils also evaluating their own work process.

According to Magnusson et al. (1999) teachers with greater knowledge in subject matter are more likely to have the knowledge to teach and plan teaching and activities in connection with specific areas, and are also better at detecting pupils errors and misleading statements so they can suggest ways, or make it simpler, to aid pupil understanding. The teachers in this study all said how important the ongoing communication they have with their pupils is in particular during all practical activities, they do not let pupils work by themselves, they interfere, lead/scaffold and have discussions with them. They can see when pupils understanding are in error and when their reasoning is not working, which can lead the teachers to change their teaching in connection with pupils understanding as they detect it. The teaching is planned and divided into small sections of subject content to maintain a common understanding of knowledge in the class and keep students groups working together effectively.
It was also noted that the respondent’s teaching is influenced by their beliefs which in turn influences their strategies when planning and conducting lessons (cf. Magnusson, Krajcik & Borko, 1999, p. 111). The teachers have different backgrounds and how this is used could be observed in their statements. Adam, with a M.Sc. background, expressed that technology education should convey an ‘industrial mind-set’. His strategies of instruction concern learning that focuses on design process and finds errors early. Bertil, also a craft teacher, talks of how he plans his teaching to be mostly practical. He has skills and subject matter knowledge that support his teaching strategies.

The respondents also described teaching that needs to be different, when planning and conducting practical activities, for technology as it is more about problem-solving. Fahrman and Gumaelius (2016) note that this is specific for technology subjects and other subjects do not include this as a feature. The respondents talked about problem solving, in connection with building and constructing, where pupils are to develop knowledge of a process where they design, test, evaluate and redesign their prototype, design or project. Earlier research has pointed out this area as important to develop pupils’ capabilities around and an important part of the characteristics of the subject (Stables, 2008). In order to support the opportunity for future teachers to develop in this area, this knowledge practice with instructional strategies which are different, needs to be visualised, described and discussed.

8. Conclusions
Examining knowledges expressed by experienced teachers can provide further insights into teachers' practice as they have experience and know their profession. From findings in the subcomponent knowledge of instructional strategies, one can conclude that despite expressing different strategies in their technology teaching, the respondents share a similar approach to a teaching that focus on problem-solving and design and making. They all expressed the importance of a teaching practice that includes practical activities.

This paper only describes analysis from one of the subcomponents of the model of Magnusson et al. (1999). To gain a more complete picture of technology teachers’ PCK, all parts of the analysis model will be further explored.

The outcome from this study is useful for discussions concerning technology teachers’ knowledge base, and how to organise teacher education and professional development courses. It will specifically contribute towards knowledge about areas in which technology teachers can develop a continued knowledge growth. As discussed in earlier research (Fahrman, Gumaelius & Norström, 2015) technology education needs to be conducted by teachers who have knowledge of subject matter and knowledge of pedagogy. Identifying the qualities and competencies of experienced teachers can help develop the education of new technology teachers as well as complementing established teachers’ knowledge.
References:


Tekniklyftet. http://www.tekniklyftet.se


Abstract:
The latest Quebec Education Reform for secondary level has integrated technology education and science education into one discipline called Science and technology. The application of the reform occurred even though most science and technology teachers were not trained in teaching technology education (Conseil supérieur de l’éducation, 2013). Consequently, the aim of this paper is to present the survey’s findings of how teachers implement and assess the technology design processes during the design activities. Firstly, we will elaborate on the specific circumstance of technology education in Quebec. Secondly, we will analyze not only how teachers implement the technology design process in their classroom, but also how they assess their students’ learning within this process assumed as a mainstay of technology education.

For the first purpose, we have asked teachers to describe how they have implemented one or two technology design teaching and learning situations. The goal is to investigate
the approaches taken by teachers when they implement the design process. The outcomes show three implementing modalities: modality aligned with the inquiry method, modality based on trial and error and modality focused on a linear process.

For the second purpose, we have explored how technology teachers assess students’ learning as a part of the design process. Our survey shows that most participants assess practical techniques, the use of machine tools and the final product, the artefact.

Based on these various results of the survey, we will discuss the impact of teaching the design process on the students' learning, and recommend helpful avenues for technology education.

**Keywords**: technology education, technological practices, technology design process, learning assessment, teaching modalities.

Technology Education [TE] in secondary level in Québec is introduced by the recent Quebec Education Reform (2005-2009). This new discipline, called “Science and Technology” [S&T] includes five scientific fields (astronomy, biology, chemistry, geology, physics) and technology ones. In addition, the new Quebec Education Program [QEP] adopts the competency-based approach and aims to develop a basic scientific and technological literacy for all students.

On the structural level, the content of the S&T Program are grouped into four following Worlds: 1) The Material World; 2) The living World; 3) The Earth and Space; and 4) The Technological World [TW].

The issue dealt with in this article is specifically about the TW.

The disciplinary competencies targeted by QEP are:

- Seek answers or solutions to scientific or technological problems.
- Make the most of his/her one’s knowledge of science and technology.
- Communicates in the languages used in science and technology.

(Gouvernement du Québec, 2004, p. 2)

The first competency focuses on the methodology used to solve technological problems (hands-on approach). The second competency focuses on the students’ ability to conceptualize and apply what they have learned in S&T. The third competency involves the different types of languages used in technology.

Our study focuses on the teaching of TDP and the learning outcomes associated with this process. According to the S&T Program, the TDP should place an important emphasis on the search for ingenious ideas to satisfy a need. Furthermore, our study deals also the assessment of the students' learning.

The QEP designs the assessment of learning as a support for learning that focuses on the development of disciplinary competencies for which the mastery of concepts is essential.

Although the S&T Program is designed to encourage students to develop their technological literacy through disciplinary competencies, there is no clear prescription for both the TDP and the learning assessment framework. In this educational context, we present the outcomes of a study that examines the ways in which secondary-level science
and technology teachers understand and implement the TDP and assess its associated learning.

**Technology Design Process**

**Various components of the TDP**
The TDP has been the subject of several studies throughout the world (Barlex, 2011 and Ginestié, 2002). According to these authors, this process is used to design and create new objects and communicate these solutions to others in a comprehensible way. From these studies, three theoretical orientations seem to be important for our study.

A first orientation considers the TDP as a process providing learners not only with the experience of “the hand in action” but also to approach sociotechnical practices including technical careers (Lebeaume and Martinand, 1998). In this orientation, school activities should refer to real-life techniques (industry, services, crafts), research and innovation.

A second orientation considers the TDP as a practical process aiming at developing effective solutions by exposing learners to technological challenges presenting several possible solutions (Barlex, 2011). The student's experiences enable him/her not only to become proficient, but also to master technological knowledge and processes.

A third orientation considers the TDP as a practical process enabling students to solve real technological problems (ITEA, 2007). This process also provides learners with the opportunity to work collaboratively with others and to get the experience, which may transfer to their real-life.

Despite this diversity of orientations, several authors often report the same steps to describe this process. Most approaches of the TDP share three common characteristics: 1) identifying the need and understand it; 2) developing specifications and planning; and 3) making, iterating and assessing the solution.

**Purposes of the TDP**
Taken as a whole and objectively read, the technological writings show three points of view. The first one draws from the psychopedagogical basis. In this logic, the know-how is compatible with the aim of this discipline.

The second point of view addresses the aims of the technological content from the sociological stand. Consequently, Wicklein (2005) focuses on the value and culture of a society.

The third point of view considers the ends from the epistemological angle. In this perspective, the choice of curricular content is made according to both the function of meaning and the utilitarian action.

Whilst the purposes of the TDP are well established, the assessment framework is to be reviewed.

**Learning assessment in TE**
According to Lebeaume and Martinand (1998), assessment in TE still deserves special attention. Largely, regarding the assessment of learning in the context of TDP, we can draw two main directions from the literature.
The first direction considers assessment a measurement process that provides information expected by students, their families and the education system (marks for school cards).

The second direction assigns the assessment the purpose of educating and improving students’ performance and learning (Ibid.). In this perspective, not only should assessments be designed to measure the intended content, also to teach it as well by revealing to learners what adult work is like (Wiggins, 1998). This logic joins the socioconstructivism point of view, which states that the assessment is considered an interactive, dynamic and collaborative process rather than an external and formalized activity (Compton and Harwood, 2003).

Although what was mentioned above is true, we may wonder what assessment modalities are supported by scientific research.

For students’ learning, Lebeaume and Martinand (1998) argue that it is important to clearly explain to learners the competencies associated with the tasks. This clarification of the agreement allows students to perceive the route they will take to achieve the targeted performance.

Even if the assessment in several academic disciplines is well established, it remains problematic in TE (Kimbell, 1997). Many technological authors argue that the TE as a whole is a process of designing and developing rather than a body of knowledge and skills as in other curriculum areas (Fox-Turnbull, 2006).

Assessment

According to De Ketele and Gérard (2005), the three vital conditions to obtain a quality assessment are relevance, validity and reliability. The relevance measures the adequacy of the objects. Validity refers to the degree of adequacy between what the assessment tool measures and what it claims to measure. Reliability refers to the degree of confidence that can be attached to the results observed.

Moreover, Lebeaume and Martinand (1998) point out that the assessment in TE should have three components: 1) an assessment of the student's involvement in the collective activities proposed to him/her; 2) an estimate of the student's progress for each of the expected competencies; and 3) a control of the minimum mastery required for the continuity of studies.

In addition, it appears that the assessment requirement in TE cannot be satisfied with students’ written work (Lebeaume and Martinand, 1998) or multiple-choice questions (Lenz, Wells and Kingston, 2015); whereas the preferred practice approach in TDP leads to this requirement. It is, therefore the students’ actions, which must offer the opportunities to observe that skills are mobilized in new situations (Lebeaume and Martinand, 1998).

Several other authors have addressed the question of the teacher knowledge role in the assessment process in TE. According to Fox-Turnbull (2006), the essential factors in learning and evaluating in TE are the teacher’s knowledge and the nature of the educational tasks.

The first factor has a direct impact on the quality of the feedback provided to the students. The second factor is the relevance and authenticity of the task in relation to the real-life of the children. The purpose of the learning is to provide learners with authentic experiences that promote both active learning and the transfer of learning to their real-life.
Rubrics
Several authors suggest using the evaluation grid to assess students’ learning. However, Lenz (2015) insists on teachers having to bear in mind that an evaluation grid is not simply an evaluation tool; more fundamentally, it is a communication tool. The criteria included in the grid should be established to ensure that students’ progression of practice occurs. By using words instead of numbers, the rubrics communicate to the students both what is expected from them and what doing a good job means. To make this communication as effective as possible, the rubrics must be used across multiple competencies, providing many opportunities to respond to a clearly articulated set of expectations. Mastering a competency comes not only from practice, but also from a thorough understanding of expectations. For this purpose, the learner needs more than one opportunity to demonstrate the progress in relation to the expectations. This is aligned with Martineaud (1995) point of view, which claims that competencies are not directly and immediately related to the activities in progress (that have just taken place), they correspond to tasks that have been met a long time before. Their assessment, in the current activity or task, must certify that they are available. In case some learners have not reached them, some direct learning may make them up.

Method
The data analyzed here is based on the work we carried out in the framework of our doctoral research. This study examined the degree to which technology teachers were implementing the TDP in their classrooms. Nineteen participants were selected (convenience sampling). Despite the fact that all participants taught technology education and TDP, only six teachers said that they had been trained in technology (1 or 2 courses in Technology Education (didactics)); while two others claimed to be trained in engineering fields (civil and electrical).

All interviews were recorded, transcribed verbatim, coded and analyzed based on the techniques of thematic categorization (Bardin, 2007) as shown in figure 1.
Main results and discussion
Given the large amount of survey data, we limit this analysis to findings about the implementation of the TDP and the assessment framework.

TDP modalities
According to El Fadil (2016), the analysis of declared practices shows that the situations described by the respondents can be classified into two categories: those presenting a “well-defined” problem for the students and those exposing the “puzzle” situation.

A second level of analysis leads us to note that the situations with a “well-defined” problem can be subdivided into two distinct modalities: modality aligned with the inquiry method and the orientations of the recent S&T Program; and modality focused on the trial-and-error method. All these modalities are shown in figure 2.
Figure 2: TDP implementing modalities

Modalities aligned with a “well-defined” problem

**Modality focused on the inquiry method**

The analysis of the pedagogical intents expressed by the majority of the respondents (left-hand modality in FIG. 2) shows that the TDP is shouldered mainly by students but with different specificities. In this view, the learners are involved in applying some features of the TDP based on the technological investigation. Respondents argue that this process provides the student with the opportunity to learn through classroom experiences. This logic is not only forms part of the experiential learning (Kolb, 1984), also in the logic of the S&T Program.

With regard to the learning assessment within this modality, it is carried out in two distinct ways: a formative evaluation and a summative evaluation.

The formative evaluation is conducted throughout the design process as evidenced by the following excerpt.

> There was simply in the provided document, the planning guide, the actions student must perform, all needed planning and drawing. The document was quite complete. There were some pages where he/she had to complete his/her planning and write what he/she did daily. Everything he/she did was evaluated. (Excerpt 1)

According to the respondents, the formative evaluation focuses on the interactions between the teacher and the learners in order to identify the needs and to adjust the pupils’ learning. This perspective is in line with the orientations of didactic research.
In the majority of the situations within this modality, teachers provided an evaluation grid (rubrics) and collected a portfolio containing all of the student's plans, diagrams, drawings and reflections at the end of the design unit.

I assess the document completed by students. In other words, the reflection they made at the end of the activity. (Excerpt 3)

One respondent only made the link between the TDP and QEP competencies. He stated that he assessed disciplinary competencies 1 and 3 as witnessed the following excerpt.

It was an assessment of the competency 1 and the competency 3 achieved by using the rubrics, which are familiar to the students. (Respondent 18)

**Modality focused on trial-and-error**

Figure 2 also shows that among the situations presenting a “well-defined” problem, a set of four situations (modality in the middle of FIG 2) focuses on trial and error as a process. In these situations, the problem solving is left to the chance. No process, no method is required.

While the trial-error approach is a main feature of the technology design, the trial-and-error process carried by the teachers ignores the role of the effort (planning) and the role of the prerequisite knowledge.

These situations are far not only from the results of the didactic research, but also from QEP orientations.

In respect of the assessment in this modality, the respondents aim at the application of the scientific concepts acquired during previous science courses and/or the acquisition of new technological concepts. Therefore, they assess students’ learning in two distinct ways emerged from the analysis: either through a portfolio or through a summative exam at the end of the unit.

Considering the assessment, respondents informed us that they provided their students a written examination of the unit as stated in the following excerpt.

I have scheduled a written examination provided by the teacher’s guide. (Excerpt 4)

All things considered, we realize that the assessment of the final product, the artefact, is not included in the second modality assessed elements list. This absence of assessing the object can be explained by the fact that the trial-and-error method may not lead up to a product that meets the initial need.

Obviously, it could happen that the student, for several reasons fails to produce a prototype meeting the specifications. However, throughout the project, he/she did a considerable amount of work. (Excerpt 6)

**Guidance-oriented modality**

Ten of the twenty-seven situations analyzed appear in this category (right-hand modality in FIG 2). A scenario and a provided solution mainly characterize them (“puzzle” problem). It is obvious that puzzle problems have their shortcomings because on one hand, the solution is given as the image of the puzzle; on the other hand, the product is identical for all learners.

The teachers in this category provide students with a document containing all the steps to follow and all the diagrams and drawings necessary to manufacture the object. The students copy only the given drawings on the pieces of wood or plastic and cut them with the technician assistant. They, then, assembles the pieces and the object is ready.
As pointed out by Fox-Turnbull (2006), this modality does not offer the opportunity to students to develop their ability to innovate, to solve problems in a creative way, and to develop skills such as critical thinking, communicating and collaborating that are far more important than the list of academic knowledge and technical skills. This situation raises the primary role of the TE teacher.

By the guidance-oriented modality situations, the respondents, first, guide their students’ action in a systematic manner inviting them to follow the step-by-step approach towards the wright solution planned by the expert (the teacher). Second, these teachers focus on the development of manual skills and the use of machine tools. Thirdly, they aim at the validation of scientific concepts acquired during science courses.

In regard to the assessment in this modality, the respondents focus on the manual techniques, the use of tools and organize a competition to select “the best final product” as illustrated by the following excerpt.

What I assess is the car (artefact) itself. Then, at the end, we organize a competition. Obviously, we pick up all the vehicles and then choose a jury to select the most successful car. (Excerpt 8)

In this perspective, the respondents report that they are guiding the student's learning to ensure the success of the task. By doing so, they believe that they remove the failure on the learner’s path.

**Conclusion**

The results presented in this paper show that teachers maintain a wide range of the TDP and learning assessment understandings, which is accompanied by a variety of implementation modalities and assessment.

The motives put forward behind using these modalities reveal mainly a centration on the psychopedagogical and sociological views. For the first view, the reasons are painted by the desire to highlight and enhance the student's motivation so that he/she could engage in the learning process. For the second view, the choices are motivated by a concern for accessibility of knowledge for all.

The results of this survey raise a fundamental problem in implementing the TDP epistemological dimension. Only four teachers have considered this dimension. Indeed, when we analyse the TDP characteristics from the declared practices, we can notice that the TDP psychological and social dimensions are the most dominant.

The results of our survey show that even situations with a problem are unfit in TDP, because all the problems proposed are “well-defined”. This kind of problems does not allow the student to develop an intimate and multidimensional experience (cognitive, affective and operative) (Chevrier and Charbonneau, 2000).

Likewise, the perspective that considers the assessment of learning a measurement process remains the most dominant.

In a nutshell, this study shows that teaching and assessing one of the central contents prescribed in QEP, the TDP, creates significant challenges for teachers. Even though they make efforts and pay more attention to this process in their teaching, the implementation modalities and the understanding they hold do not benefit them to design activities reflecting practices in real-life.
On the whole, this analysis highlights the problematic of the referential social practices introduced by Martinand (1981), which leads to relaunching some questions such as: 1) what are the essential contents for TE programs at secondary level?, 2) what is the purposiveness of TE in general and of TDP in particular?, 3) what pedagogical approaches should be used to meet the intended aims?

References


Professional Continuity: Investigating the Alignment of Technology Teachers’ Internal Capability Constructs

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Abstract
In contemporary education, teachers’ epistemological beliefs governing what and how to teach are important due to their influence on practice, pedagogy, assessment, and the learner. Teachers’ beliefs are perhaps of more significance in technology education as defining clear subject boundaries regarding ‘what to teach’ has traditionally proven difficult. Despite this, there are recognisable practices, processes and outputs that are considered of value to the learner. This research sets out to explore the level of professional continuity among educators regarding such outputs in technology education.

Initial data collection involved the generation of authentic evidence in response to an open design task. Participants were sought from five schools across Ireland. The cohort consisted of first- and second-year technology education pupils (n=64) in post-primary education. Following this, technology teachers (n=27) were engaged in the holistic assessment of pupil
work utilising the Adaptive Comparative Judgment (ACJ) method. The ACJ method relies on a series of binary judgments between two pieces of evidence, effectively producing a rank order of evidence.

In alignment with previous studies utilising the ACJ method, teachers generated very high levels of reliability when tasked with the adjudication of pupil work, despite the lack of assessment criteria. This suggests an implicit understanding of capability among teachers, irrespective of variables such as culture, context or curricula. Interestingly however, not all teachers engaged in judgements agreed consensually. Taking cognisance of this, an analysis of constructs of capability highlighted five criteria that governed teachers' adjudication on portfolios. The significance of these criteria and the continuity between teachers' constructs of capability is discussed.

**Key Words:** Technology Education, Constructs of Capability, Professional Continuity

**Introduction**

In the Irish educational context, the concept of technological capability has come to the fore as the ultimate aim of technology education (NCCA, 2004, 2007). Although the term has traditionally proven difficult to define (Gagel, 2004), several conceptions have contributed to a collective understanding of what it means to be technologically capable. Black and Harrison (1985) base a definition on one’s capacity to combine designing and making skills, cognisant of the process, and content required. The NCCA (2004) developed a framework for technological capability based upon a foundational knowledge and skills base which focuses on the variety of tasks involved, including designing, production, and evaluation. Similarly, the Assessment and Performance Unit (APU) presented a dialectic model emphasising the importance of the process, suggesting that technological capability cannot be developed solely from an underpinning knowledge base (Kelly, Kimbell, Paterson, Saxton, & Stables, 1987). Instead resulting from interactions between the mind and hand, where ideals are bounced back and forth until suitable solutions are found (Kimbell, Stables, & Green, 1996).

Apparent from all conceptualisations is the task-centred nature of technological activity, Kimbell (2011) develops this further by suggesting that the development of technological capability requires interactions between skills, knowledge, and values. A consolidation of conceptualisations was offered by Gibson (2008), defining technological capability as “meaningful practical solutions to real problems framed within an appropriate set of values and underpinned by appropriate knowledge” (p.11). To be considered technologically capable, it is necessary to apply both knowledge and skills in solving practical problems while acknowledging and engaging with value-laden decisions, also ensuring that the traditional task centred nature of technology education is not lost.

As a free agent, teachers have the opportunity to embrace, reject, or modify new knowledge, skills, and practices. Regulated by teachers’ belief and value system, constructs of capability in technology will influence teaching and learning in the discipline. This is perhaps of more significance in technology than most subjects due to the nature of the domain. For example, in defining technology education from a content perspective, McGarr and Lynch (2015) highlight the nature of the domain as having blurred boundaries, residing in the weakly classified and weakly framed quadrant of Bernstein’s (1975) framework of curriculum codes, as the domain tends to draw on the subject knowledge of a range of areas. Despite the weakly classified nature of the domain, there are recognisable practices, processes, and outputs that are indicative of technological capability. As well as this, the advantage of not having prescribed content is that ownership lies with the teacher, who can draw upon their own as well as their students’ interests, and recent developments to engage learners with relevant concepts when required (Spendlove, 2012). As highlighted by Jones and Compton (1998),
issues do arise when teachers’ understanding of technological capability is limited as there is a tendency for the teacher to focus on the production of a product rather than the thinking skills, creativity, processes, issues, and key learning involved.

**Research Focus**
This study set out to explore the level of professional continuity between technology educators in terms of the level of consensus between teachers’ understanding of evidence of capability in the discipline, and was guided by the following questions; when presented with evidence of capability, without mandated criteria, do teachers respond collectively in the same way, identifying standards and qualities? If so, what are these standards and qualities (criteria) relevant to the task? Adaptive Comparative Judgment (ACJ) provides an idyllic platform for this research as it has the potential to illuminate both level of consensus and teachers’ constructs of capability.

**Method**
To capture the level of continuity between technology educators’ constructs of capability, a mixed methods approach was devised. Creswell (2009) highlighted that a combination of both qualitative and quantitative methodologies provide greater insight into a research problem. Similarly, Reams and Twale (2008) argue that mixed methods are necessary to uncover new information and perspectives that will result in less bias and more accurate conclusions.

Although the focus of this research was on capturing the level of professional continuity between technology educators, it was first necessary to generate authentic evidence that is typical of an Irish technology classroom. Thus, in phase one of this research, five qualified and practicing technology teachers were approached to engage with the research. All teachers were teaching technology education at lower secondary level (12-15 years) at the time the study was conducted. Teachers were afforded approximately five weeks to facilitate engagement with a conceptual design task in a way that was flexible and that suited their original targets for that period.

Secondary school pupils (n=64) were tasked with developing “a product to separate and store coins” within individual student portfolios. However, before implementation in schools, a scheme of work was designed to capture evidence of pupil learning through a multiple of communicative tools in solving the design task. Within the scheme, the focus of the design task was place on the authenticity of the learning experience as recommended by Kimbell and Stables (2008). The task was designed so that pupils could engage in creative endeavours facilitated by a disposition of enquiry. Pupils were required to respond to the design task on A3 sheets of paper. Furthermore, students were asked to audio record their thoughts, problems, and/or findings in real time, as previous studies have highlighted that requiring participants to articulate their ideas through audio recordings may refine cognitive processes (Seery, Lane, & Canty, 2011). A pilot study was conducted to highlight any shortfalls with the scheme prior to wider implementation. No major amendments were required within the facilitation of learning experiences. Due to the open nature of the task, the portfolios generated ranged from two to six pages in length. Once the portfolios were collected, they were scanned and compiled into individual PowerPoint files. Audio files were added at this stage in preparation for the ACJ session.

<table>
<thead>
<tr>
<th>School</th>
<th>No. of Pupils</th>
<th>Subject</th>
<th>Year Group</th>
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<tbody>
<tr>
<td>1</td>
<td>19</td>
<td>Technical Graphics</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>Materials Technology (Wood)</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
</tr>
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<td>3</td>
<td>14</td>
<td>Technical Graphics</td>
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<td>4</td>
<td>8</td>
<td>Technology</td>
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<td>5</td>
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Phase two of data collection involved the ACJ software. Qualified technology teachers unfamiliar with the project were contacted via email to engage with the ACJ session. A total of 31 teachers were contacted for this phase of the research; 27 engaged with the study. The ACJ method relies on a series of binary judgments between two pieces of evidence, effectively producing a rank order of evidence. Practicing teachers were tasked with the adjudication of pupils’ portfolios independent of set criteria. However, in an effort to unpack teachers’ constructs of capability, participants were required to highlight the specific criteria that influenced judgment on each portfolio. Once this commentary had been provided, teachers also had the opportunity to leave adjudicating comments, detailing precisely what influenced their binary decision.

The subsequent data was analysed through a process of inductive development of codes and categories supported by the qualitative data analysis package NVivo 11. All judge commentary was inductively coded and allocated to categories using the thematic coding process advocated by Braun and Clarke (2006). Following this, a deductive analysis of adjudicating commentary was undertaken for each of the 505 judgment made.

Findings
To analyse the data it was first necessary to elicit the performance rank created during the ACJ session. Each portfolio attained a specific parameter value based on the judgments it was involved in. The rank order stabilised statistically after nine rounds with judging continuing until 15 rounds were completed. The rank (Fig. 1) illustrates a very high level of interrater reliability of 0.968.

![Fig. 1 Portfolio parameter values and standard error bars indicating ACJ rank position](image)

**THEMATIC ANALYSIS**
The thematic review of judging commentary revealed that the criteria that influenced judgments could be grouped into five broad themes; ‘conceptual’ and ‘unique’ ideas, ‘sequence’ and ‘order’, alignment with design brief, ‘thinking’ and ‘telling’, and judges implicit values.
‘Conceptual’ and ‘unique’ ideas
Judge responses indicated that presenting evidence of the generation of initial ideas was of value. Cited most often when pupils were generating ideas, participants valued the presentation of “conceptual” and particularly “unique” ideas. Much of the commentary surrounding this theme centred on how an “interesting idea” distinguished a portfolio from the norm, or more “basic” solutions. In addition, it appeared important to detail how an idea was generated as presenting a particularly unique idea without specifying the origin of the idea generated suspicion regarding authenticity.

‘Sequence’ and ‘order’
Inextricably linked to the model of the design process presented by the NCCA (1991), judges cited the different “stages” or “sequence” of the design process as important criteria. A common response was that a portfolio followed the “correct order”. In addition, participants highlighted where pupils’ portfolios “missed” a stage of the design process. To some participants, evidence of pupils detailing a “journey” through their project was important, due to its perceived alignment with pupil learning. Clarity in presenting the evolution of the portfolio was cited as important, and an “improvement” or “progression” of initial ideas distinguished this from theme one. As well as the development of the design solution, judges consistently referenced evidence of “logical” and “coherent” progression through the design process as important to the project.

Alignment with design brief
Given the open nature of the design brief, it was interesting to see that judges were quite particular about pupils meeting the requirements. Some participants viewed the “sorting” or “separation” element of the brief as paramount, to the point that it overrode pupils’ creative skills evidenced in portfolios. Where cited, this criterion often specified that a solution was merely a “container” for storing loose coins, leaving the user to sort coins themselves, highlighting the importance of functionality.

‘Thinking’ and ‘telling’
In keeping with the visual nature of the discipline, participants valued the use of “sketches”, “working drawings”, “mind-maps”, and “graphic organisers” in the effective communication of design ideas. It was notable that this theme permeated almost the entire commentary. However, it appeared to be most influential where there was a clear discrepancy between two portfolios in terms of presentation. The way in which the quality of presentation so readily influenced decisions suggested its position as a tacit skill expected of pupils, and that effective communication skills were not necessarily rewarded, rather poor communicative skills were penalised.

Judges’ implicit values
Furthering this, some judges’ implicit criteria regarding what was relevant to the task informed their decision, with criteria such as the “use of electronics”, “consideration for function” or, level of design “sophistication”. It was unclear if this criterion governed each judgment by participants or if this arose as a “delta” criterion (Seery, Canty, & Phelan, 2012, p. 224) that distinguished a pupil as having gone above and beyond the status quo.

ANALYSIS OF ADJUDICATING COMMENTRY
A deductive analysis (Cohen, Manion, & Morrison, 2007) of adjudicating comments was carried out once the inductive thematic analysis of initial comments was conducted. Of the 505 judgments made, adjudicating comments accompanied 338 judgments. Due to a lack of specificity by participants, it was only possible to code 314 of these comments. The findings of which are presented in Fig. 2.
MISFIT PORTFOLIOS AND JUDGES

ACJ has the capacity to measure the consistency of judgments, which in turn has the potential to highlight misfit portfolios and/or misfit judges. The adaptive nature of the software will identify and re-send portfolios for further adjudication to confirm its position on the rank (Pollitt, 2012). Two portfolios (portfolio 5 and 25) remained outside the misfit criterion (WmnSq = Mean ± 2 x SD) at the end of the 15 rounds of judgments, identifying the position of these portfolios on the rank as contentious. Similarly, two judges (judge 13 and 25) were identified as misfits. Upon purposive sampling (Cohen et al., 2007), it emerged that judge 25 did not provide individual portfolio commentary or adjudicating commentary on judgments. The findings from judge 13’s sampling are presented in Fig. 3.

Fig. 2 Correlation of themes with adjudicating commentary

Fig. 3 Judge 13 purposive sampling
Discussion and Conclusion

In alignment with previous studies utilising the ACJ method (Seery et al., 2011), teachers generated very high levels of reliability when tasked with the adjudication of pupil work. Achieving a high level of reliability despite the variables of culture, context, curricula, and the lack of assessment criteria suggests continuity in understanding of capability amongst 25 of the 27 teachers engaged with this research. This continuity, although implicit by nature, was made explicit through engagement with the ACJ software.

The five criteria outlined through the thematic analysis; ‘conceptual’ and ‘unique’ ideas, ‘sequence’ and ‘order’, alignment with design brief, ‘thinking’ and ‘telling’, and judges’ implicit values, are useful as they depict the communal understanding of capability between judges. Particularly interesting is the commonality between the findings presented herein and the results presented by Kimbell et al., (2004). Specifically, the alignment between having (‘conceptual’ and ‘unique’ ideas), growing (‘sequence’ and ‘order’) and, proving ideas (alignment with design brief), confirming the nature of technological activity through aligning evidence with that presented from the UK context.

The inclusion of both ‘thinking’ and ‘telling’ and judges implicit values indicate levels of implicit values about the nature of technological activity, both generalizable to the task, and more specific to individual teachers. The generalizable nature of the evidence supporting the ‘thinking’ and ‘telling’ theme suggested the effective communication of ideas as an expected standard of student work. Used to discriminate against evidence that was sub-standard the magnitude of this finding is corroborated by its prevalence in 151 (Fig. 2) of the 314 coded adjudicating commentaries. The inclusion of judges’ implicit values is interesting due to its variability between teachers. Described as a delta criterion (Seery et al., 2012), the ability to recognise and reward evidence of capability that moves beyond the status quo is the unique province of ACJ. It’s absence from judge 13’s (Fig. 3) commentary suggest its importance in depicting competency in adjudications, as exposure to a broad range of pupil responses required judges to develop appraisal skills beyond their initial interpretation of the task, engaging their construct of capability. For the most part, teachers illustrated their ability to recognise evidence of capability that has traditionally been difficult to represent on criterion-based assessment (e.g. critical thinking). However, the lack of a tacit understanding of capability, exposed where two very similar portfolios were presented together, highlighted misfit judges from the rest of the cohort. Further research, determining the reasons for such misfits may provide useful insight on the consistency of judgments and understandings of capability espoused by judges. By proxy, highlighting specific attainment targets and judges for continual professional development has the potential to increase the degree of professional continuity between teachers in the discipline.

References


Engaging Students in Hands-On Adaptive Technology Design Projects

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Abstract

The products of technology and engineering include countless applications that allow individuals to use their technical skills to help others; however, jobs in these fields are often perceived as lacking such opportunities. This misconception may in part explain why students from certain underrepresented groups are less inclined to pursue careers in technology or engineering. To further explore this possible connection between some students’ interest level in technological careers and their beliefs about the humanitarian opportunities these jobs afford, faculty at Central Connecticut State University are engaging students in hands-on adaptive technology (AT) projects. Students also participate in disability awareness activities and gain exposure to careers in AT and related fields.

AT is an interdisciplinary approach whereby existing technologies or tools are modified to make them accessible and affordable to people with special needs. The modifications can be low- or high-tech in nature. One low-tech example is “cardboard carpentry,” or the use of corrugated cardboard to create custom devices that are lightweight, strong and inexpensive. High-tech AT requires more technical skills and devices, such as adaptive switches and microcontrollers, and includes projects such as Go Baby Go!, created by researchers at the University of Delaware.

Research is being conducted to evaluate the impact of students’ engagement in AT activities on their interest in fields related to technology and engineering using the National Science Foundation-funded AWE pre-college outreach surveys, “Pre- and Post-Activity Survey for High
School-Aged Participants – Engineering " (Assessing Women in Engineering (AWE) Project 2008. National Science Foundation. Retrieved from: https://www.engr.psu.edu/awe/misc/about.aspx). These pre- and post-activity questionnaires are self-report instruments designed to measure the degree to which specific activities aimed at increasing interest in STEM-related careers have achieved their stated objectives. The aim is that these experiences might inspire some students, especially those from underrepresented groups, to pursue these subject areas further.

**Keywords:** adaptive technology, technology and engineering education research, hands-on design projects, problem-based learning

**Student Perceptions of Engineering and Related Fields**

Engineering is an unpopular college and career choice for many women. For instance, only 18% of bachelor's degrees in engineering were earned by women (National Center for Education Statistics, 2013) and while 9% of male freshmen chose engineering as their major in 2011-2012, only 1% of their female counterparts made the same selection. A similar trend appears even before college. Comparable disparities emerge when analyzing the data by race. Black students accounted for only 3% of students who took the calculus BC or either physics C exam in 2016. And according to Georgetown University's recent report, *African Americans: College Majors and Earnings* (2016), members of this demographic account for only 8% of general engineering majors, 7% of mathematics majors, and 5% of computer engineering majors in the U.S., despite the fact that these majors are associated with some of the fastest-growing, highest-paying occupations.

The majors where African-American students are highly represented, however, are often associated with serving the community, although these tend to be low-earning occupations such as human services (20%) and social work (19%). While a career in engineering can provide countless opportunities to help others, jobs in this field are often perceived as involving little human contact, and many students find it difficult to connect engineering with helping people (National Academies of Sciences, Engineering, & Medicine, 2008). Most people value working with and helping others, but having a career which affords ample opportunities to do so may be especially important to members of groups that are underrepresented in engineering, including African Americans and females (Carnevale, Fasules, Porter, & Landis-Santos, 2016; Eccles & Williams, 2007). A report from the American Association of University Women recently advised, "The more that engineering and computing educators and employers can incorporate communal goals into their environment, the more open the doors of these fields will be" (Corbett & Hill, 2015, p. 74).

To further explore this possible connection between some students' interest level in technological careers and their beliefs about the humanitarian opportunities these jobs afford, faculty at Central Connecticut State University (CCSU) are engaging students in hands-on adaptive technology (AT) design projects.

**Adaptive Technology – Definition and Examples**

AT is an interdisciplinary approach whereby existing technologies or tools are modified to make them accessible and affordable to people with special needs. The modifications can be low- or high-tech in nature. One low-tech example is “cardboard carpentry,” or the use of corrugated cardboard to create custom devices that are lightweight, strong and inexpensive. High-tech AT requires more technical skills and devices, such as adaptive switches and microcontrollers, and includes projects such as Go Baby Go!, which was created by researchers at the University of Delaware who demonstrated how toy ride-on cars can be modified for children with mobility
limitations, thereby empowering them to participate in play with their peers. Go Baby Go! is one example of what is more broadly referred to as “toy hacking,” or the adaption of commercially available toys for children with special needs.

Adaptive Technology at CCSU

AT has been integrated into a variety of courses and programs at CCSU and the varied nature of these settings has allowed for students from a wide range of majors and grade levels to participate with primarily Technology and Engineering Education students and faculty providing leadership roles.

Student Club Activities

In April 2015, CCSU held its first “Go Baby Go!” workshop during which members of the Technology and Engineering Education Collegiate Association (TEECA) student club adapted eight off-the-shelf, electric toy cars so they could be used by disabled children who were present that day with their families. Since that first event last April, CCSU faculty and students have held a total of 11 additional Go Baby Go! events and provided cars to 75 children with disabilities. The program has become increasingly interdisciplinary as faculty and students from a variety of other departments, including social work, physical education and human performance, and special education, have gotten involved. For instance, at our November 2015 event, physical education majors enrolled in an Adaptive Physical Education class developed recreational activities to entertain the disabled children while teams of students from a variety of other majors worked on their cars.

In January 2016, a group of CCSU students formed a new club, Central C.A.R.E.S. (Collaboration for Assistive Resources, Equipment and Services). The mission of Central C.A.R.E.S. is twofold: education and outreach. Members learn to solve real-world problems for people with special needs while fostering the spirit of community service. Operating under the auspices of the CCSU Foundation, a 501c3 nonprofit, Central C.A.R.E.S. draws support from a combination of internal and external funding as well as donations, many of which were secured in collaboration with CCSU’s Alumni Association, which holds an annual fundraising campaign.

At all of the Go Baby Go! events, college students have worked alongside their middle and high school counterparts in teams. Over the course of 12 events, more than 100 middle and high school students have been involved and 76 cars have been adapted. By working in teams with CCSU students, the middle and high schoolers have opportunities to ask questions about college and careers. They also experience the reward of using their technical skills, whether previously existing or newly acquired, to help another human being, an experience that could potentially steer them toward a fulfilling profession they may not have considered otherwise. The college students have the gratifying experience of helping the younger students as well as the families receiving the cars. Some have also had the added benefit of overcoming misconceptions about their own capabilities. Several non-technical majors have admitted to having feared before their first event that they wouldn’t be “handy” or “mechanically inclined” enough to serve any purpose. Some of these same individuals then went on to be team leaders at subsequent events.

In addition to Go Baby Go!, the Central C.A.R.E.S. club is continuing to explore new avenues to help others through AT. Technology and Engineering Education majors have attended workshops including “Toy Hacking for the Holidays” and “Cardboard Basics in Adaptive Design” offered by DIYAbility and Adaptive Design Association, respectively, both based in New York,
NY. With newly acquired skills, CCSU students and faculty hope to expand the range of services and adapted devices they can provide.

Course Content

CCSU faculty have found various means for incorporating AT into course work. One example is ENGR 150: Introduction to Engineering. In this course, students can choose to participate in a Go Baby Go! event to fulfill one of the requirements for the course. At the graduate level, AT has been integrated into STEM 540: STEM Practices in the Life Sciences. Students in this class “hack” a remote-controlled toy so that it can be controlled by any standard capability switch. Most recently, students enrolled in their senior design course, TE 498, have elected to modify a larger ride-on car for an older child. Such projects will involve a higher level of technical skills and a longer time commitment than the typical Go Baby Go! event entails.

Tech It Out Summer Program: The Power to Move

In July 2016, Go Baby Go! was incorporated, along with other approaches to adaptive technology, into a weeklong summer program for middle and high school students as part of a larger series of summer courses offered through CCSU’s “Tech It Out” summer programming. The program, which was titled “The Power to Move,” engaged participants in hands-on projects which required them to use their technical knowledge and skills in order to help children with special needs. Students also participated in disability awareness activities and games, and gained exposure to possible careers in adaptive technology and biomedical engineering. The hope was to present applications of technology and engineering that might inspire students to pursue these subject areas further. In turn, this could address another problem: the need for more students, especially those from underrepresented groups, to choose technology and engineering as their course of study.

Research

Pre-College Outreach Surveys

To evaluate the impact of The Power to Move program activities on students' awareness of and interest in fields related to science, technology, engineering and math (STEM), as well as their perceived preparedness to pursue STEM-related careers, research is being conducted using the National Science Foundation-funded AWE pre-college outreach surveys, “Pre- and Post-Activity Survey for High School-Aged Participants – Engineering ” (National Science Foundation, 2008). These pre- and post-activity questionnaires are self-report instruments designed to measure the degree to which specific activities aimed at increasing interest in STEM-related careers have achieved their stated objectives.

Of the 12 student participants, six students selected “White American” as their ethnicity, five selected “African American/Black American,” and one selected “Other.” Seven of the students were female. As this was the first time The Power to Move was offered, the sample size is small (n=12); however, some interesting observations can still be made from this pilot data. Table 2 summarizes the number of males and females in all 16 classes available through the Tech It Out program offerings. Interestingly, The Power to Move had the greatest female/male ratio (with the exception of one all-girls class) perhaps, at least in part, due to its description, which made it clear that participants would have opportunities to help children with special needs.
Figures 1 through 4 show students' responses to several statements regarding their attitudes towards STEM and confidence in their STEM skills and competencies both before and after their experience in The Power to Move program. Nearly all responses were more positive after the program, but both females and African Americans appeared less confident overall in their ability to “build something mechanical that works” (Figure 1). Females also seemed less confident about using their knowledge to design solutions (Figure 2); however, both of these underrepresented groups gained the most confidence in their ability to lead a team to design and build a hands-on project (Figure 3). The African American students reported the greatest gain in their interest in belonging to a science or technology club (Figure 4).
Figures 5 through 8 show students’ responses to questions regarding their impressions of The Power to Move program (these questions were only included in the post-surveys). Again, the students’ responses were very positive overall. All groups felt that the activities increased their interest in STEM (Figure 5); however, females were less inclined than males to believe their ideas were valued by their teammates (Figure 6), and both females and African Americans were less likely to think their involvement was critical for the project to succeed (Figure 7). This latter result is particularly interesting as students’ self-efficacy and confidence have been shown to influence their success in studying engineering (National Science Foundation, 2008). Figure 8 shows very high support from all groups for offering the activity again, indicating that participants found the experience valuable, perhaps due to the hands-on nature of the activities, the opportunity to help another human being, their interest in the various topics, or some combination of these and other factors.

In response to a question regarding students’ plans after high school, one student changed his or her answer from “Attend a technical school (for example: business school, beauty school, technology school, etc.)” to “Go to a college or university”; all other participants were planning to go to college both before and after the program. The surveys also asked students about their
interest in studying a STEM-related subject in college as well as their interest in attending CCSU; while the former was unchanged (80% both post/pre) the latter increased from 43% to 62%.

Focus Group Findings

As an additional source of feedback, a focus group interview was conducted with the students immediately after the post-survey was administered to learn more about their reactions to the program and why they chose to enroll in it. The majority of students decided to attend the program because they were interested in biomedical engineering and/or wanted to learn something new. Overall, the students’ feedback about the program was very positive and their interest in attending a similar program in the future was high. They especially liked the hands-on nature of the activities and the insights they gained into the challenges faced by people with special needs. They also offered some suggestions for improvement, including more field trips and guest speakers, and more time spent on the Go Baby Go! portion of the program. One student suggested that a two-week program might be preferable.

As noted above, this pilot data represents only a small number of students (n=12) so the conclusions that can be drawn from it are limited. In addition to the small sample size, it should also be noted that the students were likely to already have an interest in STEM due to their voluntary enrollment in a summer program with STEM components. Nonetheless, these preliminary results can serve as a basis for future studies, both at CCSU and other institutions that may wish to develop similar programs.

Multi-State Collaborative – Civic Engagement Assessment

While the AWE surveys help to assess how the described activities affect middle and high school students, another goal of this work is to evaluate the impact on the CCSU students involved. According to a 2008 report from the Association of American Colleges & Universities (AAC&U, 2008), service learning and community-based learning are among the “high-impact educational practices,” which “have been widely tested and have been shown to be beneficial for college students from many backgrounds.” In an effort to explore this idea in a quantitative manner, CCSU is participating in a Multi-State Collaborative (MSC) Project, an initiative designed to provide meaningful evidence about how well students are achieving important learning outcomes. In its initial phase of work, the project evaluated student achievement in written communication and

Reflecting on Your Service-Learning Experience

Last week, you participated in an event called “Go Baby Go!,” during which you worked with classmates and other members of your community to modify a toy ride-on car for a child with special needs. Please reflect back on your experience and respond to the following questions. There are no wrong answers – your honest feedback is appreciated.

1. Did this experience provide opportunities for you to incorporate knowledge acquired from your academic field and directly connect it to your experience? If yes, please describe how.

2. Did this experience impact your desire to “get involved” by volunteering within your community in a positive or negative way? Explain your answer.

3. Through this experience, do you think you made a significant contribution to CCSU and/or any other members of the community? Why or why not?

4. Did this experience enhance your ability to learn and/or work individually or with others to participate in or accomplish a goal?

5. Would you consider taking advantage of another service-learning, volunteer, or civic or community engagement opportunity? Why or why not?

6. What would you consider to be the most important points that you took home from this experience?
quantitative reasoning, examining student work from 68 colleges, community colleges, and universities in nine states. For the first time this year, CCSU has also begun collecting data for the MSC project to evaluate the impact of civic engagement activities. Figures 9 and 10 provide a sample assessment device and rubric currently being used to assess ENGR 150 students' experiences after participating in Go Baby Go! The results are expected to inform future Go Baby Go! events and to serve as a preliminary set of data to evaluate the impact of these activities on CCSU students.

---

### Figure 10: MSC Project - Civic Engagement Assessment Rubric

<table>
<thead>
<tr>
<th>Diversity of Communities and Cultures</th>
<th>Reflects on how own attitudes and beliefs are different from those of other cultures and communities.</th>
<th>Has awareness that own attitudes and beliefs are different from those of other cultures and communities.</th>
<th>Expresses attitudes and beliefs as an individual. From a one-sided view, is indifferent or resistant to what can be learned from diversity of communities and cultures.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connects and extends knowledge (facts, theories, etc.) from one’s own academic study/field/discipline to civic engagement and to one’s own participation in civic life, politics, and government.</td>
<td>Begins to connect knowledge (facts, theories, etc.) from one’s own academic study/field/discipline making relevant connections to civic engagement and to one’s own participation in civic life, politics, and government.</td>
<td>Begins to identify knowledge (facts, theories, etc.) from one’s own academic study/field/discipline that is relevant to civic engagement and to one’s own participation in civic life, politics, and government.</td>
<td></td>
</tr>
<tr>
<td>Provides evidence of experience in civic-engagement activities and describes what she/he has learned about her or himself as it relates to a reinforced and clarified sense of civic identity and continued commitment to public action.</td>
<td>Provides evidence of experience in civic-engagement activities and describes what she/he has learned about her or himself as it relates to a growing sense of civic identity and commitment.</td>
<td>Provides little evidence of her/his experience in civic-engagement activities and does not connect experiences to civic identity.</td>
<td></td>
</tr>
<tr>
<td>Tailors communication strategies to effectively express, listen, and adapt to others to establish relationships to further civic action.</td>
<td>Effectively communicates in civic context, showing ability to do all of the following: express, listen, and adapt ideas and messages based on others’ perspectives.</td>
<td>Communicates in civic context, showing ability to do one of the following: express, listen, and adapt ideas and messages based on others’ perspectives.</td>
<td></td>
</tr>
<tr>
<td>Demonstrates independent experience and shows initiative in team leadership of complex or multiple civic engagement activities, accompanied by reflective insights or analysis about the aims and accomplishments of one’s actions.</td>
<td>Demonstrates independent experience and team leadership of civic action, with reflective insights or analysis about the aims and accomplishments of one’s actions.</td>
<td>Has clearly participated in crucially focused actions and begins to reflect or describe how these actions may benefit individual(s) or communities.</td>
<td></td>
</tr>
<tr>
<td>Demonstrates ability and commitment to work collaboratively across and within community contexts and structures to achieve a civic aim.</td>
<td>Demonstrates ability and commitment to work actively within community contexts and structures to achieve a civic aim.</td>
<td>Experiments with civic contexts and structures, tries out a few to see what fits.</td>
<td></td>
</tr>
</tbody>
</table>

---

### Table: Full Rubric – Civic Engagement

<table>
<thead>
<tr>
<th>Capstone - 4</th>
<th>Milestones 1</th>
<th>Benchmark - 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demonstrates evidence of adjustment in own attitudes and beliefs as a result of working within and learning from diversity of communities and cultures. Promotes others’ engagement with diversity.</td>
<td>Reflects on how own attitudes and beliefs are different from those of other cultures and communities.</td>
<td>Expresses attitudes and beliefs as an individual. From a one-sided view, is indifferent or resistant to what can be learned from diversity of communities and cultures.</td>
</tr>
<tr>
<td>Connects and extends knowledge (facts, theories, etc.) from one’s own academic study/field/discipline to civic engagement and to one’s own participation in civic life, politics, and government.</td>
<td>Begins to connect knowledge (facts, theories, etc.) from one’s own academic study/field/discipline making relevant connections to civic engagement and to one’s own participation in civic life, politics, and government.</td>
<td>Begins to identify knowledge (facts, theories, etc.) from one’s own academic study/field/discipline that is relevant to civic engagement and to one’s own participation in civic life, politics, and government.</td>
</tr>
<tr>
<td>Provides evidence of experience in civic-engagement activities and describes what she/he has learned about her or himself as it relates to a reinforced and clarified sense of civic identity and continued commitment to public action.</td>
<td>Provides evidence of experience in civic-engagement activities and describes what she/he has learned about her or himself as it relates to a growing sense of civic identity and commitment.</td>
<td>Provides little evidence of her/his experience in civic-engagement activities and does not connect experiences to civic identity.</td>
</tr>
<tr>
<td>Tailors communication strategies to effectively express, listen, and adapt to others to establish relationships to further civic action.</td>
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<td>Has clearly participated in crucially focused actions and begins to reflect or describe how these actions may benefit individual(s) or communities.</td>
</tr>
<tr>
<td>Demonstrates ability and commitment to work collaboratively across and within community contexts and structures to achieve a civic aim.</td>
<td>Demonstrates ability and commitment to work actively within community contexts and structures to achieve a civic aim.</td>
<td>Experiments with civic contexts and structures, tries out a few to see what fits.</td>
</tr>
</tbody>
</table>
References


Abstract

This report is on the methods, results, and implications of a study of the first years of STEAM PD training. A five-year progressive exploratory-based transformative triangulation mixed-methodology study has been done and this is an overarching review. The purpose of STEAM Education™ is to provide professional development (PD) training to a variety of K-12 school system stakeholders with the goal of creating curricula that is integrated across subject areas. Our integrative curriculum mapping framework was based on using backwards design and mapping the standards from nine US-based widely used K-12 subject area groupings. We learned a lot about what made STEAM PD successful and what were hindrances.

Keywords: STEM, STEAM, interdisciplinary, integrative, integrated, integration, multidisciplinary, theme, curricula design, curricula mapping, backwards design, professional development, in-service education

Research History and Framing

Framing Question: How will receiving professional development on how to use backwards design to create fully integrated thematic plans result in educators being able to write and deliver substantiated lesson plans including the broad spectrum of technology and engineering?

A five-year progressive exploratory-based transformative triangulation mixed-methodology study, (Borrego, Douglas, & Amelink, 2009), has been done on STEAM Education’s™ professional development (PD) training and certification program. This has been offered to a variety of K-12 school system stakeholders with the goal of creating curricula that is integrated across subject areas. Curricula is developed using backwards planning design based on alignment mapping of educational standards (Table 1). The ‘A’ has been growing in popularity of being added to STEM and used often without research to back the inclusion of the letter or
where or how it fits into STEM. The A is becoming popular to be used to refer to as design and fine, musical and performing arts. This would still leave out some areas of K-12 curriculum for fully thematic standards-based curriculum. This STEAM framework is based on well accepted US-based western educational system structures of course structures in K-12 curriculum, ‘silos.’ This includes Science and Maths as half of the commonly recognized core curriculum, often tied to Technology and Engineering as STEM/CTE, with the liberal arts areas bringing the other two core groups of Social Studies and Language Arts and extension multi-disciplinary areas of Fine Arts, Music and Physical Education. (Yakman, 2008). We used integrative common concepts found across the standards benchmarks to show when and how subject content and methodologies overlapped and differentiated among the benchmarks. An additional goal is to create and contribute to a common bank of dynamic curricula. Here we report on the methods, results, and implications of a study of the first four and a half years of STEAM PD training.

Table 1.

<table>
<thead>
<tr>
<th>Subject area groupings and correlating links to US standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social Studies</td>
</tr>
<tr>
<td>Science</td>
</tr>
<tr>
<td>Math</td>
</tr>
<tr>
<td>Language</td>
</tr>
<tr>
<td>Technology</td>
</tr>
<tr>
<td>Engineering</td>
</tr>
<tr>
<td>Fine Arts</td>
</tr>
<tr>
<td>Musical Arts</td>
</tr>
<tr>
<td>Physical Ed</td>
</tr>
</tbody>
</table>

In 2007 the first professional development sessions on research-backed STEAM professional development appeared at state and national level conferences. The first professional development course offered to in-service educators to customize and deliver STEAM lessons and programs began in 2011.

**Participants & Study**

**Participant Population**

Participants represented a spectrum of primarily K-12 educators from primary, middle, and secondary groupings and included some professors, informal educators, after school coordinators, competition, camp and museum directors, home schooling professionals, and parents from 39 US states/territories and 15 countries. (See Table 2). From 2012 to 2014, 799 participants had 2-day hands-on training. Approximately 1/3 of them had at least one in-person small group and large group follow-up. From 2014 to 2015, 910 participants had a hybrid training with 2 days of on-site training: one day included a filmed virtual training about the theory and epistemology of the STEAM framework and one day of hands-on training. Approximately 1/3 of them had at least one in-person small group and large group follow-up. Forty-six people received entirely virtual PD. From 2015 to 2016’s end, 328 participants had a hybrid training with a one day hands-on training. Approximately 1/4 of them had at least one in-person small group and large group follow-up. One hundred thirty-nine received an entirely virtual PD.
Digital surveys since October of 2014 were collected from 198 participants during the training process. 78 participants from 2014-2016 with access to virtual training also completed a post-training survey. There was a well-balanced spread of participants in this group, 35.9% were virtual, 37.2% attended an on-site camp alone or in a small group and 26.9% were part of a customized school group on-site training.

Table 2.
Participant involvement and resulting certifications

<table>
<thead>
<tr>
<th>STEAM PD</th>
<th># of Staff Groups</th>
<th># in Groups</th>
<th>Solo Trainees</th>
<th>Solo Certification Applicants</th>
<th>Total Trained</th>
<th>Total Certified</th>
<th>% Certified</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/1/12 to 6/30/13</td>
<td>2</td>
<td>82</td>
<td>n/a</td>
<td>n/a</td>
<td>82</td>
<td>41</td>
<td>50%</td>
</tr>
<tr>
<td>7/1/13 to 6/30/14</td>
<td>19</td>
<td>717</td>
<td>n/a</td>
<td>n/a</td>
<td>717</td>
<td>145</td>
<td>20.22%</td>
</tr>
<tr>
<td>7/1/14 to 6/30/15</td>
<td>26</td>
<td>910</td>
<td>4</td>
<td>42</td>
<td>956</td>
<td>216</td>
<td>22.59%</td>
</tr>
<tr>
<td>7/1/15 to 6/30/16</td>
<td>13</td>
<td>219</td>
<td>44</td>
<td>47</td>
<td>310</td>
<td>109</td>
<td>35.16%</td>
</tr>
<tr>
<td>7/1/16 to 12/31/16*</td>
<td>4</td>
<td>109</td>
<td>33</td>
<td>15</td>
<td>157</td>
<td>7</td>
<td>4.45%</td>
</tr>
<tr>
<td>Totals</td>
<td>64</td>
<td>2037</td>
<td>81</td>
<td>104</td>
<td>2222</td>
<td>518</td>
<td>23.31%</td>
</tr>
</tbody>
</table>

Methodology

The program was evaluated with pre-, during-, and post-experience surveys, interviews and lesson-plan process submissions. These were analyzed for consistencies, discrepancies, and trends. This paper covers some main points of feedback synthesized over the first four and a half years of professional development training. It covers the span from interviewing the first program leaders to analyzing digital surveys from participants.

Since its inception, STEAM PD has adapted it's content and delivery based on collective feedback to meet the needs of most educators and school systems by offering a solid base in ways that are adaptable to access and customize. See Table 3.
Table 3.
Annual Changes to PD

<table>
<thead>
<tr>
<th>STEAM PD</th>
<th>On-Site</th>
<th>Virtual</th>
<th>Adaptations</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/1/12 to 6/30/13</td>
<td>+</td>
<td>-</td>
<td>2-Day Intensive Training with 3 follow-up days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Theory offered Day 1, Practicum, Teams and Application</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Day 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Both introductory programs began 27 lesson plans as integrative team projects.</td>
</tr>
<tr>
<td>7/1/13 to 6/30/14</td>
<td>+</td>
<td>-</td>
<td>2-day Intensive Training – optional follow-up days.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Introduced lesson plan briefs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Added links to standards in mapping and lesson templates.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Practicum and Application Blended into Day 1</td>
</tr>
<tr>
<td>7/1/14 to 6/30/15</td>
<td>+</td>
<td>+</td>
<td>Added virtual access videos of training at end of year</td>
</tr>
<tr>
<td>7/1/15 to 6/30/16</td>
<td>+</td>
<td>+</td>
<td>Transition away from 2-day trainings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Added single and small-groups globally with virtual access</td>
</tr>
<tr>
<td>7/1/16 to 12/31/16*</td>
<td>+</td>
<td>+</td>
<td>Programs offered 1-day workshop after on-line theory training.</td>
</tr>
</tbody>
</table>

Lesson Plans Produced
Table 4 shows the published lesson plans produced by our participants. Unpublished lesson plans for 2012-2016 are a hybrid of digital and hand-written and not all have been digitized. Over 150 unpublished digitized lesson plans have received at least one review by the PD team.

Table 4
Published Lesson Plans by Grade Cluster

<table>
<thead>
<tr>
<th>Grade Cluster</th>
<th>Published LPs</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-12</td>
<td>01</td>
<td>00.015%</td>
</tr>
<tr>
<td>K-2</td>
<td>21</td>
<td>32.31%</td>
</tr>
<tr>
<td>3-5</td>
<td>26</td>
<td>40%</td>
</tr>
<tr>
<td>6-8</td>
<td>11</td>
<td>16.92%</td>
</tr>
<tr>
<td>9-12</td>
<td>06</td>
<td>02.82%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>65</td>
<td></td>
</tr>
</tbody>
</table>

Limitations of the Study

The primary limitations of the study come from the limited amount of a cross-section of data complete enough to study from the larger group of participants all the way through the process. Of the 2222 educators included in this study, 1699 educators in the first three years received their PD on-site and had access to only paper versions of surveys. At many of our 60 school sites, educators chose to have meetings and give collective answers to surveys, almost all of our
programs the second year did this. Having individual and group consensus responses made tallying the numbers of feedback responses difficult. We attempted to separate surveys into known individuals, known groups, individual answers and group answers to calculate the weight of each survey. We did not have the resources to mandate our surveys nor to tally all the handwritten responses. Much of the collected data before 2014 is not included and only the digital survey response records from 2014-2016 were used.

Findings

This report includes quantitative data on the post-training survey only because the correlation of responses from the 78 participants of the post training survey has not been done with their answers on other surveys. We had 568 respondents to the pre-survey and 164 to the during-training survey.

Q3 What is your overall impression of the STEAM training?

<table>
<thead>
<tr>
<th></th>
<th>Poor</th>
<th>Mediocre</th>
<th>Fair</th>
<th>Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>6.41%</td>
<td>7.69%</td>
<td>12.82%</td>
<td>43.59%</td>
<td>29.49%</td>
</tr>
</tbody>
</table>

Table 5 - 57 Independent Learning Comments

<table>
<thead>
<tr>
<th>% of 57</th>
<th>Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.32%</td>
<td>Appreciated the Scope of Information</td>
</tr>
<tr>
<td>22.81%</td>
<td>Appreciated the Theoretical Background</td>
</tr>
<tr>
<td>15.79%</td>
<td>Good Practicum Included</td>
</tr>
<tr>
<td>15.79%</td>
<td>Requested More Worktime</td>
</tr>
<tr>
<td>15.79%</td>
<td>Frustrating User Experience</td>
</tr>
<tr>
<td>14.04%</td>
<td>Good User Experience</td>
</tr>
<tr>
<td>14.04%</td>
<td>More Hands-On</td>
</tr>
</tbody>
</table>

Q5 Do you believe you learned more or less than you have at other PD trainings?

<table>
<thead>
<tr>
<th></th>
<th>Poor</th>
<th>Mediocre</th>
<th>Fair</th>
<th>Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>10.26%</td>
<td>5.13%</td>
<td>21.79%</td>
<td>35.90%</td>
<td>25.92%</td>
</tr>
</tbody>
</table>

Q7 What did you like most about the training?

Table 6

<table>
<thead>
<tr>
<th>% of 78</th>
<th>Enjoyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.4%</td>
<td>Practicum</td>
</tr>
<tr>
<td>12.82%</td>
<td>Theory</td>
</tr>
<tr>
<td>11.54%</td>
<td>Networking</td>
</tr>
<tr>
<td>10.26%</td>
<td>Personal Connections</td>
</tr>
</tbody>
</table>
Q8 What did you like least about the training?

Table 7

<table>
<thead>
<tr>
<th>% of 78</th>
<th>Issue Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.18%</td>
<td>Concentration of Information in Allotted Time</td>
</tr>
<tr>
<td>29.49%</td>
<td>Frustrating User Experience</td>
</tr>
<tr>
<td>8.97%</td>
<td>Wanted More Planning Time</td>
</tr>
<tr>
<td>7.69%</td>
<td>Wanted More Practicum</td>
</tr>
</tbody>
</table>

Q9 How do you foresee using STEAM in your classroom?

Table 8

<table>
<thead>
<tr>
<th>% of 100</th>
<th>Likelihood to Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>07.69%</td>
<td>Already avidly applying</td>
</tr>
<tr>
<td>07.69%</td>
<td>Already have started some</td>
</tr>
<tr>
<td>41.03%</td>
<td>Will start avidly</td>
</tr>
<tr>
<td>29.49%</td>
<td>Will start slowly</td>
</tr>
<tr>
<td>12.82%</td>
<td>Neutral</td>
</tr>
<tr>
<td>01.28%</td>
<td>Won’t start</td>
</tr>
</tbody>
</table>

Q10 How do you feel about the future of STEAM Education?

Table 9

<table>
<thead>
<tr>
<th>% of 100</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.51%</td>
<td>Very Positive</td>
</tr>
<tr>
<td>61.54%</td>
<td>Positive</td>
</tr>
<tr>
<td>11.54%</td>
<td>Neutral</td>
</tr>
<tr>
<td>05.13%</td>
<td>Negative</td>
</tr>
<tr>
<td>01.28%</td>
<td>Very Negative</td>
</tr>
</tbody>
</table>

Q11 What are your suggestions for helping STEAM to grow?

Table 10

<table>
<thead>
<tr>
<th>% of 78</th>
<th>Growth Suggestions</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.51%</td>
<td>Marketing</td>
</tr>
<tr>
<td>19.23%</td>
<td>Improve the User Experience</td>
</tr>
<tr>
<td>16.67%</td>
<td>Networking</td>
</tr>
<tr>
<td>14.10%</td>
<td>Application</td>
</tr>
<tr>
<td>12.82%</td>
<td>Advocacy</td>
</tr>
</tbody>
</table>
Conclusions & Implications

The results of this study include insights into successes and challenges educators faced in creating a backwards planning design interdisciplinary-based curriculum. The collective voice of this group of integrative STEAM pioneers has resulted in some things to try and things to watch out for as others investigate the compatibility of this path with their programs. They also lay a foundation for future researchers in the developing field.

Our participants results grew stronger as we learned from them how to provide more structured support. We received over 215 integrated plans to be considered for certification review. Of the published ones that made it through the review process, 72.3% of them were elementary focused. (Table 4). Approximately ¼ of our trainees go on for certification. (Table 1). This number is partially skewed by including the last ½ year without giving those groups a chance to show their certifications that usually happen in the spring after training in the fall. Having 27 unfinished plans submitted the first year led to adding a brainstorming sheet year two and also a plan to add videos to supplement the on-site training that were accomplished by year three (Table 3).

We learned from both pilot programs that formatting of the lesson plans needed to be more concise. The second year that we had to create a mechanism by which people could contribute individually to an overview sheet where they would be able to see the alignments of benchmark cluster topics. From there they could more easily coordinate those to projects and assessments. We received overwhelmingly positive responses to the addition of an introductory brainstorming sheet to pre-frame the lesson plans. We saw a shift in the quality of the first submissions of the lesson plans.

Brainstorm charts helped show the gaps in the educators plans, especially when no subject area experts in a subject were available. When educators worked without the brainstorming sheet in person with us, fewer of them volunteered to attempt to fill in connections outside of their subject areas on the lesson plans. Of particular interest was that creating the brainstorming sheet highlighted for the educator the gaps of justification for its being fully integrated. The brainstorming sheets more easily showed that the reviewer was not against any particular project being done, but was based on cross-curricular alignment and generally finding areas where standards would more strongly overlap across the subject areas to support a more valuable variation or a different project.

Prior to our adding in links to the standards directly, most participants were aware of the standards in their own fields and also most often the recent updates to the science standards with the new release of NGSS in 2013 and Common Core being heavily adopted since 2009 and they included references to those standards in their plans. Many educators appreciated links to the standards outside of their own fields, especially for the non-core of PE, fine and musical arts. The grand majority of our participants did not know that standards existed for technology and engineering and that ITEEA standards were revised in 2007 and ASEE standards were developed in 2008.

The inclusion of certain content experts impacted curricular development. For instance, PE educators contributed many ideas for in-class, hallway, and outside relevant movement activities for classroom educators to add in to the learning content. They often connected larger SS related content to their PE spaces/time and used data related to the physiological sciences so students
could practice grade level math skills. Music teachers helped find resources, especially in backing up social studies and math standards. Many projects included instrument making creating songs related that to social studies or the physics of sound for projects was studied. Fine arts teachers often cross-referenced standards with science related to the mediums, processes related to technology, planning and design related to engineering, and structure and layout related to maths. STEM-focused schools transitioning to STEAM primarily had science-based projects presented by staff. The staff with the most successful adoption process in rigor, attitude and results had a full spectrum of subject experts and a coordinator to help with coordination of the subject and grade level educators and connection to outside resources. Very few schools had curriculum coordinators or had previously created curriculum maps or pacing guides for the subject areas.

Our participants attitudes about what they valued and how they felt about the program were generally very encouraging. Participants by far enjoyed the practicum part of the training the most, but significant comments were supportive of clients appreciating the theory. And either making personal connections or sharing or hearing personal connections to others using this methodology was important to a large percentage of people (Table 6). Based on 57 independently added comments from Table 5 and 78 responses from Table 7, the scope, theory, practicum and worktime were the most appreciated elements of the trainings. Many of the participants, especially seasoned educators commented that the theoretical framework gave a research-based vocabulary to link to standards and methods that they could relate to most other multidisciplinary programs with which they were familiar. An example of one is, “I truly support this movement, and have over the last 20 years of my career…I just didn't know it had a title.” Survey Response 8/8/2015. The primary learning frustrations were with the learning experience, not the content. When the comments were analyzed, most of them specifically referred to the website being slow, needing more collaborative worktime, wanting more hands-on experience and for our on-site clients, mentions of physical comfort and presentation condition comments were positive and negative for trainees. Programs responded with three primary solutions for networking time: planning at least once monthly half days for collaboration, utilizing after-school meeting times, and creating on-line sharing networks, mainly using Google Docs. All of these things further helped attitudes towards the program.

A major issue was the need for cross-discipline time to make and maintain the paradigm shift. Public school administrators reported almost unanimously not being able to accommodate enough of this time to easily make and effectively maintain their programs’ paradigm shifts. One program networked all their middle schools to have 2-3 grade-level district-wide networking events per year, which helped with collaboration and idea and resource sharing. Programs with educator collaboration time and a designated curriculum coordinator, who understood the development process, had the most cross-support within the developing local team instead of needing extra support from us.

Despite frustrations and this being a new methodology for many, collectively 85.9% of our participants left the experience expecting to or already utilizing the STEAM framework in their classrooms. (Table 8) 82.05% have a positive outlook about the future of STEAM Education (Table 9) and the majority of suggestions to help the growth of the movement had to do with marketing, improving the user experience for educators and helping them apply it better, and for everyone to support networking and advocacy (Table 10).
Abilities and attitudes of educators varied: some were exceptional at creating lesson plans, some excelled at linking them to projects meaningfully, some were excellent at delivering the plans, a very small percentage were good at all three primary elements. The administrators’ most significant challenge was finding the time for the staff to collaborate. Digital Learning Management Systems can help to meet those needs, but in-person or live-time virtual networking with dynamic conversation with educational depth experts is clearly the key to a successfully planned, implemented, and maintained integrative program. Our school systems recognize that all the coaches need to be present to have a cohesive set of practices and games and that there needs to be time for coaches to have meetings, but when one looks at the purpose of the school being academics, the school systems do not provide time for their educators to network and develop the best plan to address the standards collectively and then we end up with academic coaches not having the structure to coordinate the curriculum. If school systems can address the issue of educator collaboration time, there are strong indicators that is should significantly contribute to the structural stability of developing and maintaining integrative educational programs.

Many developing STEAM programs exist with a very wide variety of parameters and definitions of what STEAM is. An increasing demand for further inquiry exists, a few notable calls include Science and Mathematics programs research from S. Korea, (Kim, Han, Park & Lee, 2013). STEAM conferences and journal articles in China, (Zhao & Lu, 2016), and the development of a research journal on the topic (Drew, Grogan, Kapadia, DiasEditor, Easton & Pagel, 2017). Also of importance to note are silo-based perspective papers on the topic that are as politically framed as they are researched reviews, such as a paper on STEM including the arts from University of Arkansas professor, (Daugherty, 2013). Now there is there is a national STEAM house bill (H.R. 4159, 2014), with an official STEAM national caucus and political movement to contribute to national government funding becoming available for STEAM-related research efforts.
References

Teaching Algebra through Functional Programming: 
An Analysis of the Bootstrap Curriculum

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Abstract
Bootstrap is a computer-programming curriculum that teaches students to program video games using Racket, a functional programming language based on algebraic syntax. This study investigated the relationship between learning to program video games from a Bootstrap course and the resulting effect on students’ understanding of algebra. Courses in three different schools, lasting about six weeks each, were studied. Control and treatment groups were given a pre and post algebra assessment. A qualitative component consisting of observations and interviews was also used to further triangulate findings. Statistical analysis revealed that students who completed the Bootstrap course gained a significantly better understanding of variables and a suggestive improvement in understanding functions. In the assessments, students failed to demonstrate a transfer of the advanced concepts of function composition and piecewise functions from programming to algebraic notation. Interviews with students demonstrated that with coaching, students were able to relate functions written in
Racket to functions written in algebraic notation, but were not yet able to transfer their experience of function composition from programming to algebra.

**Keywords:** Bootstrap, Racket, functional programming, algebra, functions, variable

**Introduction**
This study evaluated the effects of participation in a course of Bootstrap on students’ understanding of algebra, namely functions and variables. Bootstrap is a computer-programming curriculum for secondary age students that teaches programming video games through Racket, a functional programming language. While the curriculum is an introduction to programming using a gamification approach, the intent of the curriculum is to introduce students to algebra.

This study was conducted by (1) giving students of Bootstrap courses and corresponding control groups pre and post evaluations consisting of several algebra problems, and (2) interviewing students regarding their experience in the Bootstrap course. The differences of the post and pre evaluation scores were analyzed using multiple regression and effect size. The statistical results showed that students made a significant improvement in understanding variables, and suggestive improvement in understanding functions. It was demonstrated in the interviews that students could transfer the simpler concepts of functions from programming to algebraic notation, but struggled with the advanced concepts of composition and piecewise functions.

**Statement of Problem**

The 2008 President's National Mathematics Advisory Panel (U.S. Department of Education, 2008) stated,

*The panel recommends that computer programming be considered as an effective tool... for developing specific mathematics concepts and applications, and mathematical problem-solving ability.* (p. 52)

There has long existed a highly correlated relationship between academic success in mathematics and computer programming (Wright et al., 2012). Using computer programming to teach secondary school students the mathematical concepts of variables and functions has been researched since 1967 (Feurzeig, 2010). Despite years of research, the practice has not been generally adopted by secondary education (Johnson, 2000). Schanzer (2011) argues the reason for minimal adoption of algebra pedagogy through programming is because much of the curricula use imperative programming styles with languages such as Logo and BASIC. Contrariwise, Schanzer’s Bootstrap curriculum uses the functional language Racket. The curriculum is an effort to help students with algebra while programming computer games (BootstrapWorld). But because of restrictions placed on the afterschool programs using Bootstrap, no formal studies have been conducted examining the value of the Bootstrap curriculum with regards to students’ understanding of mathematics. This study researched both quantitatively and qualitatively how participation in a course of Bootstrap affected students’ understanding of the algebraic principles of functions and variables, and the transfer from programming to algebra.

**Background**
Bootstrap is part of the outreach program TeachScheme! (Felleisen, 2010), which is a project that addresses the weakness of beginning computer programming education. The curriculum and tools developed from TeachScheme! address many of the issues of industrial languages, such as difficult syntax and complex development environments, that often repel secondary students away from studying computer science (Krishnamurthi, Felleisen, & Fisler, 1999). Further, the curriculum uses functional programming, which has the benefit over imperative languages of simple syntax and style (Schanzer, 2011). TeachScheme! was later expanded with the intent to become a basic part of secondary schools’ core curriculum (Felleisen, Finder, Flatt, & Krishnamurthi, 2004a). By using functional instead of imperative programming, it was hoped that the TeachScheme! project would also help students with mathematics (Felleisen, 2011). The Bootstrap curriculum was later created as part of the TeachScheme! project, with the purpose of teaching math concepts through functional programming (Felleisen, 2010).

**Motivation for Study**

Knuth, Alibali, McNeil, Winburg, and Stephens (2005) declared that algebra is considered to be a “gatekeeper” to future study and employment opportunities (p. 48). Krishnamurthi et al. (1999) also explained that algebra skills are important “for students’ professional advancement,” regardless of the field of employment (p. 13). But there are common misconceptions among students in the categories of functions and variables. A common misconception is to think of a variable as something to be solved, i.e., solve for x (Schanzer, 2011). Feurzeig et al. (1970) explained that sometimes it represents a number, or something called a variable, or a function (p. 14-15). Few students grasp the true nature of variables, which represent a range of numbers at once (Knuth et al. 2005). Functions are also presented in mathematics curricula in a confusing manner. Simply defined, a function is a mapping from an input to an output (Hinsen 2009). But to students, functions are presented many different ways, which initially do not seem related. Functions are presented as: a domain and range, a mapping between sets, key value pairs in a table, graphs on a Cartesian plane, and as equations such as f(x)=5x+2 (Schanzer, 2011).

In July 2010, Conrad Wolfram presented a TED (Technology, Entertainment, Design) talk about “his radical idea: teaching kids math through computer programming” (Exploring Computational Thinking). Actually, the idea has been researched since 1969, with the release of Feurzeig et al. (1970) paper to the NSF (National Science Foundation). In that paper, understanding the abstract concepts of variables and functions were highlighted as an advantage to teach mathematics through programming. The paper also stated how programming could be a laboratory for mathematics.

The strong correlation between the two disciplines of mathematics and computer programming has driven studies and implementations for decades. Since the Feurzeig et al. (1970) report in 1969, significant changes in many areas have been made. Computer programming languages have matured, the microcomputer was invented, leading to the proliferation of the personal computer, and graphical user interfaces have become commonplace. Programming development practices have also improved. But using programming to supplement mathematics education has still failed to be used widely (Johnson, 2000).
In light of the many benefits of functional programming, and because past research investigating correlations between mathematics and programming have primarily considered imperative programming, it is worthy to examine how functional programming can be used in algebraic pedagogy. Bootstrap has strong potential to enhance efforts to help students better understand algebra. Felleisen and Krishnamurthi (2009) asserted, “Any attempt to align programming with mathematics will fail unless the programming language is as close to school mathematics as possible” (p. 39). Bootstrap uses the well-designed functional language Racket, one that can be understood by the general student population (Felleisen 2010). Students are introduced to the programming language on a just-in-time basis to avoid confusion.

Method

Three different groups of students using Bootstrap at different schools were studied. Treatment and control groups were given pre and post tests on algebraic concepts. The tests were analyzed using multiple regression and SMD (Standard Mean Difference) effect size statistics. The validation of the hypotheses was dependent upon statistical measurements of the data showing significant difference between the assessment scores of the experimental and control groups. Also, a sample of students was interviewed concerning the transfer of algebraic concepts learned from programming to problems written in algebraic notation.

Results

The purpose of this study was to determine if participation in a course of Bootstrap increases students’ understanding of algebra. The statistical analysis showed that students understanding of variables improved, with suggestive results that the students gained a better understanding of functions. However, the Bootstrap students’ ability of transfer between Bootstrap and algebra were not statistically significant. In subsequent interviews, students were able to demonstrate understanding the relationship between functions written in Racket and algebraic notation, but generally were not able to relate the concepts of composition and piecewise functions between the two disciplines.

Quantitative Results

For each category of each Bootstrap course, two charts will be shown. The first chart is the box-plot showing the difference in students’ scores. When only the pre-assessment score was shown to be significant, the linear regression chart for both the treatment and control groups are shown.

![Bootstrap vs. Control](image)

**Figure 1 Legend for Regression Charts**

**Results for Vista Heights Middle School.** At Vista Heights, 9 students completed the Bootstrap course and 17 students were in the control group, giving N=26 for the multiple regression and effect size calculations. Table 1 shows the multiple regression p-values and the effect size for each category.

<table>
<thead>
<tr>
<th>Category</th>
<th>Multiple Regression p-value</th>
<th>Effect Size</th>
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### Functions

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<td>-.12</td>
</tr>
<tr>
<td>Other</td>
<td>.02</td>
<td>.02</td>
</tr>
</tbody>
</table>

Table 1 Statistical Analysis for Bootstrap Course at Vista Heights Middle School

Figure 2 VHMS Box Plot for Variables

Figure 3 VHMS Regression for Variables

The results shown in table 1 indicate the Bootstrap students gained statistically significant improvement in the understanding of the categories of variables. Figures 2 and 3 show the box plot and regression analysis for the variable category. The regression in figure 3 shows a difference of two points between the experimental and control groups, for which a p-value of .0009 was calculated; shown in table 1. The effect size results findings concur with the multiple regression finding, demonstrating a Cohen’s “large” effect size of .91. The Bootstrap students also demonstrated a significant increase in understanding in the functions category, as shown in figures 4 and 5. On figure 4, the control group scores show some concern, where the box-plot for the control group is skewed down, and all but three students regressed in their scores. This skewing may be the reason for the extremely low p-value of <.0001. Figure 5 shows a difference of 5 points between the two regression lines. From table 2, the medium effect size of .54 gives a safer estimate of the general improvement of the Bootstrap students.
For the category consisting of other algebra problems, Figure 6 shows a modest improvement for the control group scores. Meanwhile the Bootstrap group scores were highly diverse.

The regression results shown in Table 1 are suggestive but inconclusive, where the p-value of .02 falls outside of the Bonferroni adjusted significant p-value of 0.01.
The analysis shown in figures 7 and 8 shows the experimental group performed about the same as the control group. From table 1, the effect size of -.12 also demonstrates no general improvement for the Bootstrap students. The outlier that showed remarkable improvement from the Bootstrap group, shown in figure 7 and figure 9, was an advanced math student.

The statistics show that the students in the Bootstrap course did not significantly improve in the category of transfer from Bootstrap to algebra over the results from the control group. The medium effect size of .43 shown in table 1 should be accepted with caution. All but three student answered the questions on the post assessment, two from the Bootstrap course and one from the control group (figure 9).
On the transfer category, the current math class showed to be significant. This significance comes from the advanced math student, whose score is the outlier in figure 9.

**Results for Lehi High School.** Table 2 shows the regression and effect size results for the LHS study. The effect size results are similar to the results in the VHMS study, but the multiple regression shows a less significant difference between the treatment and control groups in the categories of functions and transfer.

<table>
<thead>
<tr>
<th>Category</th>
<th>Multiple Regression p-value</th>
<th>Effect Size</th>
</tr>
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<tbody>
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<tr>
<td>Other</td>
<td>.0017</td>
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</tbody>
</table>

Table 2 Statistical Analysis for Bootstrap Course at Lehi High School
Data from table 2 and figures 10 and 11 shows that students at LHS Bootstrap course demonstrated a significant improvement in the understanding of variables.

![Figure 10 LHS Box Plot for Variables](image1)

![Figure 11 LHS Regression for Variables](image2)
Figure 12 shows a box plot for the Bootstrap group with the median at the top, indicating most did well, with a couple doing very poorly. The regression in figure 13 shows a clear difference between the groups, and the medium effect size of .52, found in table 2, is also indicative of significant improvement.
The statistics for the order-of-operations category are misleading. Table 2 shows a p-value of 1 and a large effect size of (t)1.26. Figures 14 and 15 show the reason behind the conflicting results. Figure 14 shows the control group to be flat, the two outliers cancelling each other out. Given that the average for the control group was 0, the situation of a p-value of 1 (as shown in table 2) is created, as shown in figure 15.

On the category of other algebra problems, figures 15 and 16 show a strong improvement on the part of the Bootstrap students. The statistics concur, where Table 2 indicates a p-value of .0017, and table 2 shows a large effect size of 1.24.
Figure 17 LHS Regression for Other

For the category of transfer from programming to algebra, Figure 18 shows reasonable improvement of up to 3 points for the Bootstrap students. Table 2 shows a weak p-value of .15, which is indicative but not conclusive, whereas the effect size from table 2 shows a strong value of .88. The mixed results should be considered cautiously.

Figure 18 LHS Box Plot for Transfer
Qualitative Results

Three categories emerged from the coding of the interview responses: current math level, cognitive-bridge, and lack of understanding. Participants struggled with the concepts being presented throughout the interview. Most of the confusion was resolved with simplification and expansion of the questions. In short, the participants were able to relate the algebraic concepts from Bootstrap based on their current understanding of mathematics. From there, the students made some connections between programming and algebra.

The interviews from LHS generally followed the same patterns found in the interviews from VHMS. In general, the participants demonstrated that the work they had done in the Bootstrap classes had prepared them for recognizing the operation of simple functions written in Racket language. Most of the students of Bootstrap that were interviewed were able to readily pick up working with simple functions written in Racket.

The cognitive bridge theme was demonstrating when each participant was able to relate functions in Racket to functions in algebra. Though one student struggled earlier in the interview, he was later able to convert times3(x)=3x to \( f(x)=3x \). The cognitive bridge came when he realized that \( f(x)=3x \) was the same as \( \text{define f x (}* 3 \ x) \). The interview with another student took a different track in that he did not recognize the correlation until the discussion of composition of functions. But at that time, he was able to write \( (+ \ (f(x) \ 5)) \) in response to moving from algebra composition of functions to notation in Racket. With some prompting from that point, he showed understanding of the equivalence of functionality outside of syntax. From going through the steps outlined in the interview script, this student came to the following conclusion,

One is a computer function, and one is a notation in math. In this case, it’s saying that whatever you put in for value will be multiplied by 3. It’s pretty much the same thing in the other case, it’s just in a math format.

The participants were generally able to discuss the topics of composite and piecewise functions in terms of the Racket programming language, but showed confusion and hesitancy when it came to the algebraic syntax for those two concepts. Throughout the interview, students were far more comfortable with the Racket syntax.
than algebraic notation. One reason may be due to having recently worked with Racket. Another reason shown in the interviews is that many students had only been recently introduced to algebraic notation.

**Discussion**

The statistical results showed a strong improvement in the understanding of variables at both VHMS and LHS Bootstrap courses. The improvement in the understanding of functions at both schools was also noteworthy. The effect size results for the Bootstrap participants at both schools were large in the category of variables and medium in functions. The interviews reflected these results where students of Bootstrap were able to converse about functions and variables, and relate them to algebraic syntax. The statistical results at both schools showed that neither treatment group gained a significantly greater understanding of order-of-operations. This result was anticipated in that the concept of order-of-operations was outside the scope of the Bootstrap curriculum.

But another pattern that emerged from both the assessments and interviews was the difficulty the Bootstrap students had with the composition of functions and piecewise functions in algebraic notation. At both schools, the statistical results for the transfer category of the Bootstrap participants were mixed. In the regression analysis, both showed no significant improvement on the part of the treatment group over the control group. But VHMS Bootstrap students showed medium effect size, and the LHS Bootstrap students showed a large effect size. A concern of the assessments was that most students, both treatment and control groups, left most of the transfer questions blank; leaving in doubt the validity of the effect size results.

The participants who were interviewed gave various reasons as to why they did not attempt to answer these questions. The common theme from the interviews on these questions dealt with unfamiliarity with algebraic notation. The instructors for the LHS course specifically discussed composition of functions and conditionals and how they relate to algebra. But given the difficulties the students showed with the concepts in both the assessments and interviews, it seems that more than one lecture during a class is required for the students to grasp the concepts.

**Conclusion**

The purpose of this study was to evaluate how participation in a course based on the Bootstrap curriculum would affect secondary education students’ understanding of algebra. The students’ comprehension of variables, functions, and transfer from programming in Racket to algebra were analyzed using a multiple regression and effect size from scores on pre and post assessments. Observational studies were also performed as interviews with some students of the Bootstrap courses. The statistical data showed that the students understanding of variables improved over the time of the course. The data from VHMS showed improvement on the understanding of functions, while the data from LHS was suggestive but inconclusive. Transfer of understanding between the two disciplines was clear in terms of understanding of functions and variables. Further, the interviewed participants showed a nearly consistent ability to relate functions in Racket to functions in algebra. The students of Bootstrap had difficulty in relating the concepts of function composition and piecewise functions from programming to algebra. Most
participants did not answer those questions concerning those topics on the assessment. When asked about it in interviews, the response generally was that the notation was unfamiliar and confusing. Even when the students had been coached on algebraic notation beforehand, the students still were not able to connect the concepts on their own. It was clear that the students understood and readily used the concepts when programming, but cognitively the students seemed to have attached the concepts to the syntax of the Racket language. Further research examining as to why Bootstrap students were able to better understand the concept of variables and functions at the end of the course would be beneficial. Likewise, future studies could examine specifically how students were able to utilize advanced algebraic concepts in programming, and research methods to transfer that experience algebra.

References


The Vocational Goals of STEM Education: Is That Enough?

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Abstract

The STEM movement began as a socio-economic response to workforce needs. It was predicted that the need for individuals with qualifications and expertise in the STEM areas would outstrip supply in the near future, and action was needed to rectify that imbalance. So the concept of how the STEM movement related to STEM education initially was rather nebulous, and represented a general amalgam of education, qualifications and careers.

Over time it was recognized that primary and secondary education had a role to play in achieving this agenda. The development of attitudes toward STEM, which may influence career choices, and then the development of appropriate skills, begins in school. Tertiary education then continues that skill development and provides a qualification for entry into the workforce.

The literature indicates that a range of vocational outcomes have been measured as goals for STEM programs – interest in STEM, subject choice, and career inclination. The question that this paper pursues is: Are vocational and workforce goals adequate for measuring success in STEM education? The research and the stated goals of STEM will be reviewed, and then alternative goals will be suggested.

If it is proposed that STEM is important for all students, the secondary research question becomes: What is it that STEM activities can contribute to every individual’s personal development that is relevant regardless of the career they pursue? This paper will discuss this question, and the research and evaluation implications for the measurement of student outcomes.

Keywords: STEM, vocational education, general education, technology education

Introduction

The current ‘STEM crisis’ resonates most in countries which are concerned with economic growth and development, supported by adequate numbers of scientists and technologists. According to Marginson, Tytler, Freeman, & Roberts (2013) the ‘crisis’ is also based upon “quantitative indicators that show a declining relative (or even absolute) performance in international comparisons of achievement and a lower rank than the nation believes it should occupy; and/or declines in participation in STEM subjects at school” (p. 55).
STEM is such a multifaceted concept in today’s discourses that to make sense in any specific conversation, the context must be described. Politicians and educators will reference STEM in different ways, and primary, secondary and tertiary educators will discuss STEM as it relates to their context. For the purposes of this paper, the specific application is integrated STEM programs in secondary schools. Integrated STEM was defined by Sanders (2009) as “approaches that explore teaching and learning between/among any two or more of the STEM subject areas” (p. 21).

The question to which this paper is seeking an answer is the extent to which research about STEM education is adequate. The research goals reflect the educational goals, which are articulated in two broad categories: goals related to economic development and goals related to personal development. The goals related to economic development are all vocational, and oriented toward increasing an innovative STEM workforce (attitudes toward STEM, choice of further study in STEM, career aspirations). The development of personal goals through STEM activities focuses on goals such as the facilitation of integrated learning, and personal attribute development such as cooperation and complex problem solving.

The separation of these two categories is however not a simple matter, as the rationale for the achievement of enhanced economic outcomes may include the development of individual personal goals such as innovation or problem solving. So the broader purpose of the STEM activity must be considered – is it for the purpose of individual development or is it to achieve economic goals?

History

The original goals of the focus on STEM have endured from the time of its initial popularising about 15 years ago. In the US the argument was that a focus on STEM will result in “reaffirming and strengthening America’s role as the world’s engine of scientific discovery and technological innovation which is essential to meeting the challenges of this century” (Obama, 2009). And similarly in the UK, “as the UK seeks to position itself against global competitors at a time of rapid economic change, the priority of increasing its capacity for innovation and enterprise becomes increasingly urgent” (STEM Programme, nd). More specifically, the route to the achievement of such pre-eminence was seen to be by rectifying the skills shortages in science and engineering areas: ‘studying STEM creates a pathway to a brighter future, opening up a wide range of interesting and exciting career opportunities” (Central Office of Information, 2008). STEM strategies are designed to develop a strong supply of scientists, engineers, technologists and mathematicians (Department for Education and Skills, 2006), and the UK government has serious concerns about how vacancies in these employment sectors are to be filled in the future (Barlex, 2007). And in the USA, “a growing number of jobs require STEM skills and America needs a world class STEM workforce to address the grand challenges of the 21st century, such as developing clean sources of energy that reduce our dependence on foreign oil and discovering cures for diseases” (The White House, 2010).

The focus on STEM in different countries has been variable. In the USA, President Obama maintained the impetus with a statement in 2013: “One of the things that I’ve been focused on as President is how we create an all-hands-on-deck approach to science, technology, engineering, and math. We need to make this a priority to train an army of new teachers in these subject areas, and to make sure that all of us as a country are lifting up these subjects for the respect that they deserve” (White House, 2013). The UK supported a National STEM Centre but then later devolved this responsibility through funding to other providers. In Australia, the attention given to STEM continues to develop momentum through state funding and the Chief Scientist’s focus on innovation. In South Africa it seems to be on the
wane, in south east Asian countries such as Thailand and Taiwan both focus and funding are increasing.

**Policy statements indicating the goals of STEM**

Many governments have something similar to a STEM policy statement. A survey of such policies is beyond the scope of this paper, and so Australia will be used as a case because of the author’s familiarity with this context, and its general similarities with other countries.

The Australian government Education Council (2015) developed a strategy for STEM school education over the 10 year period 2016-2026 which has 2 main goals:

**Goal 1:** Ensure all students finish school with strong foundational knowledge in STEM and related skills.

**Goal 2:** Ensure that students are inspired to take on more challenging STEM subjects.

Goal 2 is presented as a supplementary goal, presuming an effective pipeline from challenging school STEM subjects, to tertiary studies in STEM areas and then to STEM related careers.

The Council elaborates that:

Today’s students need to acquire core subject knowledge as well as the skills of collaboration, critical thinking, creativity and problem solving – and STEM education has a crucial role in achieving this. School systems have a responsibility to ensure that all young people have a fundamental level of STEM literacy that enables them to engage with, and succeed in, the world beyond the school gate (p. 5).

Supporting these two goals are 5 areas of national action – one of which is 'Building a strong evidence base':

Better guidance is needed for schools and teachers to determine which approaches work best for different purposes and student cohorts. Effort under the national strategy will focus on establishing a stronger data and evidence base over time to track national trends and improve our understanding of what works in Australian contexts (Education Council, 2015, p.10).

The types of evidence indicators that are mentioned related to gender equity, low socio-economic status, indigenous participation, university commencements, and employment outcomes. Reference is made to the need to “Share and synthesise research and evaluation findings to identify successful STEM interventions and inform school practice” (p. 10), but no detail is provided. This empty space represents the most urgent need of STEM in schools: evidence of what works.

Prior to the collection of evidence related to the success of STEM activities, the goals of the activity need to be clear, and in this case there is some ambiguity. The Office of the Chief Scientist (2014) elaborates on the goals: “Australian education, formal and informal, will prepare a skilled and dynamic STEM workforce, and lay the foundations for lifelong STEM literacy in the community” (p. 20). There seems to be two aspects to this goal statement – one is workforce oriented and one is related to STEM literacy, or, one could assume, one is related to the economy and one is related to the person. However further reading of the Chief Scientists statement indicates that the importance of STEM literacy, in this case, is to serve broader goals of general economic growth rather than goals of individual fulfilment and satisfaction derived from living in a technologically rich environment. So there is some ambiguity related to the economic and personal goals of STEM activities.
Vocational and General STEM rationale

There is an explicit vocational approach in the STEM agenda, mainly related to science and engineering, for national economic purposes. Typical of other governments, the UK paints a broad approach to vocational goals and refers to increasing the flow of qualified people into the STEM workforce, to counteract the large number of engineering graduates from India and Pacific rim countries and address the concurrent declining numbers of engineering graduates in the UK (Barlex, 2007). A goal of many STEM projects (for example Project Lead the Way) is to prepare students for university engineering courses. A number of technology education researchers also see STEM education as providing a career pathway to an engineering profession (Dearing and Daugherty, 2004; Wicklein, 2006).

In this context, the validity of such a strong vocational bias is debatable. Pitt (2009) questions this morality of "exposing all learners to STEM when only a few of them are going on to STEM based careers" (p 42). Millar et al (2006) brands this vocational goal of STEM education unacceptable social engineering on a grand scale. Such commentary open STEM discourses up to a vocational-general education debate.

There are two categories of argument which position STEM activities as components of general education, that is for all students, not just those going on to STEM related careers. The first is the notion of STEM literacy which is utilized as an umbrella to capture the general education philosophy of STEM activities (Holdren, 2009; Bybee, 2013; Office of the Chief Scientist, 2014). It is proposed that such literacy requires individual's to develop the knowledge, attitudes, and skills to identify real-world problems, understand the characteristic features of STEM subjects, develop an awareness and ability to explain the natural and designed world with this knowledge, and gain a willingness to engage and reflect upon STEM-related issues as a global citizen. It is debatable, however, if such a construct (STEM literacy) is philosophically and conceptually sound.

The alternative, and probably more common argument for STEM as a component of general education is the capacity to develop 21st century (21C) skills, including inquiry processes, problem-solving, critical thinking, collaboration, creativity and innovation, as well as a strong focus on disciplinary knowledge (English and Gainsburg, 2016; Marginson et al., 2013; Partnership for 21st Century Skills, 2011). Shernoff (2017) makes the point that STEM is increasingly about more than just the four disciplines, it is also "frequently rooted in project- and problem-based learning, student-centered pedagogy, and 21st century transferrable skills. It promotes students as active learners; inventiveness, creativity, and critical thinking are fundamental aims" (p. 4).

So the STEM discourse encompasses both vocational and general goals. The incompatibility of such dual attempts to satisfy both general and vocational approaches in the one course has been indicated in the past (Williams, 1998): the goals of each approach are different, the assessment methods are different and the fundamental teaching methodologies are different.

Implementation of STEM

Pitt’s 2009 summary of the ambiguous approaches to STEM remain relevant after 8 years: STEM as an educational concept is problematic. There is little consensus as to what it is, how it can be taught in schools, whether it needs to be taught as a discrete subject or whether it should be an approach to teaching the component subjects, what progression in STEM education is, and how STEM learning can be assessed (p.41).
A development relating to STEM in many countries is the establishment of STEM focus schools. Understandably these schools are very diverse in the concept of STEM which underpins their programs, and vary from the offering of optional extra curricular STEM activities to students, to a completely integrated curriculum at all levels of schooling. LaForce et al (2016) sought to develop an understanding of what the STEM schools consider is important by examining 20 schools across seven states in the US. The result was the identification of eight essential elements: Personalization of Learning; Problem-Based Learning; Rigorous Learning; Career, Technology, and Life Skills; School Community and Belonging; External Community; Staff Foundations; and External Factors.

This follows a study by Peters-Burton et al. (2014) who utilized a literature-driven approach wherein they identified 10 “critical components” of STEM schools in existing literature, and then conducted in-depth case studies of inclusive STEM programs. The 10 critical components were:

1. STEM-focused curriculum
2. Reform instructional strategies and project-based learning
3. Integrated, innovative technology use
4. Blended formal/informal learning beyond the typical school day, week, or year
5. Real-world STEM partnerships
6. Early college-level coursework
7. Well-prepared STEM teaching staff
8. Inclusive STEM
9. Administrative structure
10. Supports for underrepresented students

Much of the STEM activity in schools in Australia is organized as extra curriculum activities. This is a weakness, and sends a counterproductive message to students that STEM is interesting and fun, but not important enough to be incorporated within the curriculum. In 2011 (Williams) I warned that the resilience of the discipline based curriculum structures in secondary schools would be an impediment to the introduction to STEM, and this continues to be the case.

While the structures of STEM implementation remain varied, the literature indicates that maybe there is developing a consensus about the components of STEM programs. However, the data to determine if these goals are being achieved has yet to be developed. “There is no evidence of positive outcomes with which teachers can be enticed to take up integrated STEM education” (Blackley & Howell, 2015).

Measurement of STEM Goals

Despite the varied characteristics of STEM programs, the primary drivers of STEM in schools remain economic: “increasing the return on investment and driving future prosperity” (Australia’s National Science Statement, 2017) and workforce planning. Research and evaluation tends to follow the primary drivers, which in this case will limit research to that focused on economic ends at the expense of research about student learning and development.

The STEM goals related to socio-economic ends through vocational means seem to be able to be validated by the research that has been conducted. School based STEM projects are able to influence students to be more positively inclined toward the consideration of STEM related careers (Christensen, 2014; Bragow et al. 1995), they are more likely to study and successfully complete STEM-type subjects (Sleap, 2017), they are more motivated (Tillman et al. 2014) and seem to have the potential to partly redress gender imbalances in STEM subjects (Sleap, 2017). More longitudinal research will be required to indicate if these
changes during schooling have a longer term impact on tertiary studies and STEM career uptake.

The tradition of integration research has impacted research in STEM by focussing on the disciplinary learning related benefits that STEM integration provides, reinforced by the fact that the potential gains of employing a contextual integration approach to STEM education are significant. First, it supports a constructivist pedagogy, authentic learning, and student-centredness. Second, it can be seen as a “catalyst for helping teachers and learners out of their subject-based limitations into creative inter-disciplinarity” (Pitt, 2009, p. 42).

Several researchers have lamented (e.g., Barrett et al., 2014; Honey et al., 2014) that the effectiveness of integrated STEM education in developing students’ knowledge of core content is relatively under-researched (English 2016). Also, “not yet strongly supported by findings from research” is the “appealing but still somewhat intuitive notion” that it is useful for the STEM disciplines to be learnt in concert (National Academy of Engineering, 2014, p. 136).

The National Academy of Engineering (2014) provided a review of integration studies of various STEM combinations, which generally found an enhanced effect of the integration of science and mathematics on each other. Studies which integrated science and mathematics in an engineering design project were more ambiguous in their findings, and some indicated no gain for the students. Learning science concepts through design was beneficial in some situations but not all. Learning mathematics in a technology context enhances mathematics learning when focussed attention is given to that learning. In science education, a number of studies have indicated that an integrated STEM approach can improve learning through the application of mathematics and science (Schnittka and Bell, 2011; Wendell and Rogers, 2013).

Becker and Park’s (2011) meta-analysis of studies investigating the possible differential effects of integration types on students’ learning showed a large effect size (1.76) when all the disciplines were integrated. However they found limited literature on curriculum designs that include technology education within STEM education programs, especially literature that reports evidence-based assessments showing improved student learning.

The evaluative research that has been conducted on STEM projects falls into a number of categories:

- Disciplinary knowledge in one of the disciplines in the project
- Knowledge in all the areas of the project
- Participant choice to study further in STEM areas
- Participant inclination to study in STEM areas
- Attractiveness of STEM areas

All of these approaches reflect the notion that the value of STEM lies in either vocational goals, or as a means to enhance traditional disciplinary knowledge. It begs the question – what about the importance of personal individual development?

Integrated STEM is touted as an approach that provides opportunities for students to develop the 21st century skills of: adaptability, complex communication, social skills, non-routine problem solving, self-management, self-development, innovation and systems thinking (Bellanca & Brandt, 2010). However, there is little research that measures the effects of a STEM integrated approach on student development of 21C skills, and what there is appears inconclusive (English, 2016); “few data convincingly correlate integrated STEM education with student outcomes” (Honey et al., 2014, p. 136). There are a number of reasons for this, including the difficulty of measuring these skills, and the short term nature of
many STEM projects which do not allow for the measurement of attributes which take time to develop.

Some research is appearing which discusses attempts to measure skill development and learning attributes as a result of engagement with STEM activities. For example Fan and Yu (2017) investigated the learning performance of students studying STEM engineering compared to students studying technology education using tests of conceptual knowledge and higher order thinking skills and grades from the design project. On all three measures, the STEM students significantly outperformed the technology students.

Related to the goals of STEM in school, it seems that the easy research is being done (that related to vocational attitudes and interest), but the hard research (personal skill development) is yet to be undertaken. While it is important for education to serve the needs of society, as educators, we also have a responsibility to individual students, and to ensure that those individually oriented goals are being achieved.

Conclusion

This paper is a plea to the designers and implementers of STEM activities to ensure that the outcomes of STEM for students are articulated, measured and researched. This is not always an easy task, and it must be integrated into the initial planning of the activity. Outcomes could include:

- Ability to transfer concepts between disciplines
- Ability to make connections between disciplines
- Development of student interest and engagement
- Ways of knowing
- Development of representational fluency
- Personal attributes, and
- the range of 21C skills.

The challenge for educators is to translate an ill-defined, politically charged and narrowly utilitarian policy agenda of securing a future workforce, into a valid and coherent curriculum that is of personal benefit to all students. We need to pay more attention to 3):

The comprehensive purpose of STEM is to resolve (1) societal needs for new technological and scientific advances; (2) economic needs for national security; and (3) personal needs to become a fulfilled, productive, knowledgeable citizen (Zollman, 2012, p.12),

References


School Subject Advocacy Work as Policy Enactment: Making the Case for Design and Technology Education in England

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Abstract
In keeping with one of the conference sub-themes, this paper is an inquiry into advocacy work in curriculum policy-making as practised by one of England’s largest school subject teaching associations, the Design and Technology Association (D&TA). More specifically, I focus on the “We Believe in D&T” campaign between 2011 and 2013—an unsettling and precarious time when the government’s National Curriculum review was perceived to threaten D&T’s future status as a compulsory subject. My purpose is to better understand the processes and practices of policy advocacy, as well as to reflect on how and why this subject association was successful and not. Two questions guide this study: 1) how and why do certain actors come to be assembled in the organization’s lobby efforts, and 2) what effects or outcomes are produced and traceable in these particular networked relations? Drawing on concepts from Actor-Network Theory, I trace contingent “string[s] of actions” (Latour, 2005, p. 128) that brought together teachers, designers, business people, engineers, public affairs personnel, politicians, a manifesto, video, and press articles in the politics of curriculum reform. By shedding light on a variety of actors and activities that made up D&TA’s campaign efforts, my study details how power relations emerge in negotiations of curriculum change and considers how teachers shape and are shaped by/within policy-making processes.

Keywords: subject advocacy, teacher associations, Design and Technology education, curriculum politics, actor-network theory

Introduction
Change is the creation of different networks. (Feldman & Pentland, 2005, p. 109)
In this paper I present a partial and provisional account of an energetic lobbying campaign led by the Design and Technology Association (D&TA) —the primary organization representing Design and Technology (D&T) teachers in England. It is part of a more in-depth inquiry into the nature of school subject advocacy work and is the central focus of my ongoing doctoral project. In what follows, I present an alternative way to think about school subject advocacy in an increasingly complex and networked world. Utilizing Actor-Network Theory (ANT) as a conceptual tool for exploring networks, policy advocacy, and socio-material relations, I will try to show how curriculum reform can be understood as a “practical accomplishment,” “(co)performed” in multiple locations, in multiple ways, by many people and things that are often overlooked in educational policy studies (Perillo & Mulcahy, 2009, p. 47).
It is important to emphasize that an actor-network is neither a technical network of conduits, telephones, or computers, nor is it a social network exclusively made up of people and organizations. Rather, it is a material metaphor for “a string of actions” (Latour, 2005, p. 128) or “the trace left behind by some moving agent” (p. 132). ANT’s methodological approach to “follow the actors” maps the ways in which the movement of people, artifacts, and beliefs bring about networked relations of advocacy and practice, and shape the politics of reform (Nespor, 2002).

Context and Methodology
In January 2011, England’s government launched a “systematic and comprehensive review” of the National Curriculum to improve the current “substandard” curriculum with one that is “world-class” (Department for Education [DfE], 2011, January 20, Introduction, para. 3). The aim was to establish more rigorous standards for attainment of “essential knowledge” (DfE, Notes to editors section, paras. 2, 3, 8, 9). To achieve this goal, education secretary Michael Gove proposed to reduce the number of compulsory subjects to four: English, Mathematics, Science, and Physical Education. D&T was among the program areas slated for removal from the list of foundation subjects. This announcement spawned lively public debates involving prominent figures in education, business, and industry regarding the country’s need for innovation and the role of schools to provide creative designers, engineers, and skilled tradespeople (Doward, 2012; Saunders, 2012; Smithers, 2011). The perceived threat of loss of status as a subject tradition also catalyzed the advocacy work of D&TA—the country’s second largest subject teacher association.

For this project, taking the nonhuman explicitly into account is both theoretically and methodologically important (Latour, 2005; Law, 2009). To that end, I created situational maps (Clarke, 2005) as a way to provoke analysis of the relations among key human, nonhuman, and immaterial elements that developed around specific actions of advocacy and campaign events. Initial findings presented here are based on an analysis of textual artifacts collected from the following sources: D&TA’s (cached) campaign website, news reports that were hyperlinked to external media websites, and transcribed audio recordings of telephone or Skype interviews. Research participants were purposively selected using a snowball sampling approach. Qualitative semi-structured interview questions (Rubin & Rubin, 2012) focused on the nature of their interactions between various material, social and institutional actors (à la ANT) and how particular lobbying activities were carried out.

Preliminary Findings and Interpretation
“We Believe in D&T”
One of D&TA’s (2011) early advocacy projects was the Manifesto—a 48 page full-colour booklet featuring an array of photographs and endorsements by “eminent figures in schools, business and industry” (p. 3). As D&TA’s chief executive (CE) explained, the purpose of the Manifesto and the ensuing campaign was to persuade policy-makers that D&T was an important subject.

What we felt at that time, was that there was ... a lot of misunderstanding about what Design and Technology is, ... for many people, it's still seen as woodwork, or metalwork, or textiles, or needlework, and so the Manifesto really was a way to try and show to key decision-makers in the government that, ... by potentially putting ... a threat in the curriculum, there would be a lot to lose. (SH interview, March 23, 2012)

The primary task for D&T was to change the public’s perception of school technology. This issue was repeatedly expressed by many people with whom I spoke and by the media as well, as one article in The Guardian illustrates:

The billionaire businessman and inventor Sir James Dyson is the first to admit that, as a subject, design and technology still has a bit of an image problem: “That's probably because it has its origins in the school wood workshop in the days when everyone had
to make wooden matchbox holders," he muses, conjuring up images from the '50s of Bryl-creemed boys in baggy brown coats fashioning these curiously pointless items on old-fashioned woodwork benches. (Smithers, 2011, April 5, para. 1)

Here Dyson dismisses craft-based school projects as “old-fashioned” and “pointless,” thus defining the “image problem” in terms that he could oppose (Nespor, 2002). By setting old and new D&T worlds apart, he recasts D&T as a “modern” “STEM subject” with a “more up-to-date focus on high technology” (Smithers, para. 2). Now associated with “the academic rigour of engineering” (para. 9), D&T’s legitimacy, status, and place in the NC is asserted. Dyson also warns that if D&T is marginalized, the future for the creative and manufacturing sectors would be “very bleak” (Smithers, para. 2). Conjoining the future viability of the business and industry sectors with the fate of D&T in schools is a rhetorical move that reframes classroom activities and associated technologies into something that makes sense in business and economic terms (Kornberger & Clegg, 2011). This marks a significant shift from one discourse to another: an educational policy concern becomes a matter of business and economics.

One might wonder how this change came about. From an ANT perspective, school subjects, like other entities, are not distinct or “solid” objects. Rather, they are “sets of relations” (Callon & Law, 1997, p. 170) between people, objects, discourses, ideas, and organizations held together in particular (although temporary) arrangements. Networked relations are not fixed; their definitions change as they connect or attach in different networks (Nespor, 2002). How then, one might ask, did education and industry join up? This is partly answered when D&TA’s CE described their strategy to advocate for D&T:

…rather than us saying that, because the case is always if a subject association or if teachers actually say, “This is why this subject is important,” they always throw back, “Well, you would say that, wouldn’t you, because you’re a self-interested group.” So we thought, well, the way to do it is to get business and industry to actually make that case for us. Hence, the involvement of some key industrialists, and designers, and engineers to say, “Well, we believe that the subject is important as well.” (SH interview, March 23, 2012)

In an attempt to elude potential accusations of self-interest, the Association assembled various people from the design and business worlds to “make that case for us.”

However, the ties between Sir James and D&TA are manifoldly interlaced. In addition to being a patron who’s “been passionately committed to the role that practical education plays” (SH, 2012), “he is always prepared to write something which will go into the introduction of the awards evening, or a conference program, or in our magazines and publications” (SH). At that time, the James Dyson Foundation was a regular sponsor of one of D&TA’s annual teaching awards, funded an innovation development program for new teachers, and helped finance the 2011 campaign video. What I found particularly interesting was that D&TA has “good links with the press office at Dyson so we can feed them stories about what is going on” (SH). This implies there was a regular flow of information between the two organizations which was further relayed via news media channels.

Actor-networks and their effects become more durable, more resistant to change, and extensive in their reach as more entities or other existing actor-networks link together (Fenwick, 2011; Fenwick & Edwards, 2010; Latour, 2005). However, the network’s stability is not resolute. Instead, connections are continuously re-negotiated and precariously dependent upon associations with diverse allies to create strong webs of power and knowledge (Callon, 1986; Fenwick, 2010; Habib & Wittek, 2007). As the recursive relationship between Dyson and D&TA illustrates, work is routinely performed by actors in the network to hold all the components
together—including conference programs, magazine articles, speeches, awards, dinners, money, passion, teachers, schools, subject matter, a press office, news reporters.

“Capturing Quotes”
We went to engineering, we went to the food industry, we went to textiles, and we got quotes from schools and educationalists as well. And really since that point, ...from the Manifesto into the campaign work, again, we’ve been looking to and capturing quotes at every opportunity. (SH interview, March 23, 2012)

Capturing quotes was key to buttressing the legitimacy of D&T. According to Jan Nespor (2002), finding powerful allies and assembling them into a network is critical to “effective political action” (p. 370) and indeed, two interviewees attributed their success to canvassing endorsements from “VVIPs” (very, very important people) (LV interview, January 29, 2013), the “captains of industry,” and “the glitterati from the design world” (UE interview, January 23, 2013).

The production and distribution of texts (e.g., Manifesto, photographs, digital recordings) are materializing practices that entail translating spoken endorsements into transportable artifacts that can be gathered, combined, displayed, and circulated from one location to another. D&TA’s advocacy work involved various attempts to mobilize and extend its network, including assembling, transforming, and posting numerous written and video testimonies to the website, and sending a print version of the Manifesto to approximately 350 Members of Parliament (SH interview, December 17, 2014).

Invoking Inspirational Rhetoric
Another way D&TA (2011) claimed legitimacy for D&T was by citing a section of the recent budget statement made by the Chancellor of the Exchequer: “So this is our plan for growth. We want the words: “Made in Britain,” “Created in Britain,” “Designed in Britain,” “Invented in Britain” to drive our nation forward” (p.6). By invoking the “March of the Makers” speech, D&TA drew on the authority of the Treasury to strengthen its own position (Fairclough, 1992) and implicitly aligned school technology with the national economic policy direction. As a mediated text, strategic discourse functions as a stance-taking practice that signals to Manifesto readers (politicians), website visitors, and video viewers that D&T believers share the government’s imagined future of growth in the manufacturing sector.

A Provisional ANT Account of Relational Strategies
In this section, I illustrate how advocacy work is a matter of building networks of heterogeneous materials (Callon & Law, 1997) that generate collective action (Nespor & Hicks, 2010). A focus on strategies as performative practices (Kornberger & Clegg, 2011) brings the distributed nature of agency (Somerville, 1999) into view and reconceptualises curriculum change as a relational power-effect—contingent on the particular networks, in and through which it was generated. By following or tracing point-to-point connections between people and things, I learned how the subject association’s influence on educational policy decision-making was the upshot, at least in part, of joining up with other more powerful and extensive actor-networks beyond the education field.

Making the “Right” Connections
Using celebrity endorsements to support a cause is not a new marketing tactic, but I wondered how a teachers’ organization would ever be able to find so many prominent and influential people “interested” enough to participate in the campaign. D&TA initially had very few connections with elite actors in the creative and manufacturing industries and it was not
until they joined up with the public relations (PR) firm Weber Shandwick that they were able to meet face-to-face with policy decision-makers.

**Having a Campaign Spokesperson**

...it was the work of the public affairs agency that eventually allowed us to contact and talk to Sir Kevin Tebbit ...we needed someone who was relatively high profile, respected within the business community within it, and with his company Finmeccanica that he’s chair of, it’s the engineering community, the aerospace industry. But the other thing about him was he used to be a top civil servant, so he knows his way ‘round government, and so it was quite important and he’s quite well-connected as well. (SH interview, March 23, 2012)

Emphasizing the necessity for “getting the right people on board,” one staff member characterized the campaign chair as a “gate-opener” who could “literally be able to pick up the phone and speak effectively to Number 10 Downing Street’s personal office to get through to David Cameron [Prime Minister].” This individual explained,

...*that* is how you work things. It is about those who know, and those who can influence and those who can press the right buttons for advocacy. So, you know, you can’t in this country just ring up and say, “I want to speak to the Prime Minister!” (LV interview, January 29, 2015).

Sir Kevin’s connections in government and industry created opportunities for the campaign group to present its views to politicians. Some people believed “getting that business voice was absolutely essential” because “the government would not have listened to teachers” (LV interview, January 29, 2013). According to Michel Callon (1986), key actors (or groups) control a network through the displacement or suppression of dissenting voices. If a group successfully transforms itself, “only voices speaking in unison will be heard” (Callon, p. 223). The reasons for deploying a business line of reasoning are described next.

**Making a Case for D&T**

Projecting a rational and compelling argument was the case-making strategy recommended by Weber Shandwick’s PR chair.

So we, for example, in the case of Design and Technology, needed to make a case which linked it to the manufacturing economy, ...and to demonstrate that in fact when you look to the school curriculum, the only thing which really related strongly to manufacturing and engineering was Design and Technology as a subject and therefore to remove it when manufacturing and engineering was regarded at a top level as such a key part of our economy was just completely nonsensical! . . . . But by far and away the major card was the connection to industry, ...people were desperately concerned about the economy and indeed were thinking that, you know, should we really have an economy which is so dominated by the financial services sector, for example, which was freefalling into disrepute at the time. (KN interview, February 18, 2015)

The PR professional’s comment about the disreputable state of the financial services sector in 2011 is another reminder that conditions of possibility are never given (Mol, 1999); sets of relations are only temporary, and power-effects depend on the particular networks in and through which they are generated. Legitimating D&T in economic terms was not the only argument presented during the campaign, but it was the dominant one. Underpinned by an instrumental logic, D&T was narrowly framed as the only connecting pathway to engineering and manufacturing. Linking it to higher education presupposes particular kinds of knowledge, skills, and technologies for students. While many would welcome this configuration, other displacements and disconnections were incurred. When I asked how this came to be the predominant argument, my interviewee acknowledged that teachers “want to feel that their
subjects have got intrinsic merit from an educational perspective” however the “prevailing conservatism in education policy” was “quite potent politically.” He explained,

We just had to argue that it is a key purpose of education to create, for example, skilled and gifted engineers who are able to support our manufacturing economy, and by removing it as a statutory subject, it would get crowded out by the statutory subjects, which have to be taught and therefore we kill off our supply chain of young talent going into industry. (KN, February 18, 2015)

Successful and Not?
Stabilizing and securing D&T’s place as a foundation subject in the National Curriculum is an important accomplishment. By forming a coalition with other more stable and extensive networks, D&TA achieved legitimacy and status for the school subject. Similar to ANT studies of parent advocacy groups (Nespor, 2002; Nespor & Hicks, 2010), finding allies was critical to this campaign’s success. Examples of school subject advocacy shown in this paper entail efforts to claim worth and tentatively support Nespor’s (2002) assertion that reform processes are contingent effects of interactions and transactions “in which groups try to define themselves and their interests by linking up with other relatively durable and extensive networks” (p. 366). The taken-for-granted logic of the instrumental argument used to bolster D&T’s legitimacy effectively associates classroom activities with “top level” engineering practices in wealth-producing worlds of work. However, such an association implies a school-to-industry trajectory that essentially translates children into skilled workers and precludes other equally important considerations of why technology should be taught in schools.

Concluding Remarks
Initial findings suggest that school subject reform is better understood as a process, a consequence, a precarious effect (Law, 1992). Ongoing analysis will require close scrutiny of the particular ways in which associations among people, devices, technical knowledges, institutions, interests, and ideas are brought into play in practices that have traceable political effects. Because ANT does not subscribe to notions that social and material relations are structurally frozen and forever reproduced, it offers an analytical framework for investigating the methods and materials different organizations deploy to realize a particular version of D&T. This new way of engaging with policy advocacy processes also challenges us to consider how things “could be and often should be otherwise” (Law, p. 390). By promoting a “new vision” for a “modern” curriculum, the D&T Association, I submit, emerged as a policy actor that both resisted and sustained narrow exclusionary definitions of D&T in schools. This case will provide a useful illustration of the conundrum, contradictions, and paradox experienced by members of a subject association working toward a vision of their subject area as a vital part of liberal and general education.

References


Does LEGO Robotics and the Universal System Model Provide a Useful Tool for Understanding Brain Processing?

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Abstract
The Universal Systems Model is a way to conceptualize the components of a system needed to complete a task. The model has four components: input, processing, output and feedback. This is an essential concept in technology education.

Natural phenomena such as homeostasis can also be described using the language of the Universal Systems Model. It requires input from a sensor to detect changes in the environment, processing of the information to determine the appropriate response (output) and contains a feedback mechanism to monitor the effect of the changes. Brain function can be described using this language. In the last decade, using new technology such as fMRI made it possible to study information processing in the brain. However, for the average student it is still an abstract topic. In addition, few if any labs exist to illustrate the concept.

The purpose of this research was to determine whether LEGO Robotics could be used as a model to study brain processing. LEGO robots have sensors that provide input, programming that visualizes processing steps and motors to see the response to changes, essentially visualizing brain processing using the Universal Systems Model.

Students enrolled in an Anatomy and Physiology course were asked to participate this study. Data was collected from 2012-2014 using the following tools: reflections and observations by students and the professor, surveys, and the robot design and programming. The results showed that students could model the responses to incoming information from sensors, the sequencing of processes in the brain and the subsequent result on the behavior of the robots. As an added benefit, this project created a way to incorporate an engineering design challenge within a science course environment.

Approaches such as this may support technology education teachers in addressing design world standards related to agriculture, biotechnology and medicine.

Keywords: LEGO Robotics, Universal Systems Model: input, processing, output & feedback, Designed World Standards, Brain processing.
Introduction
At first glance there may not be a close relationship between teaching technology and teaching anatomy and physiology. However, one of the essential approaches in technology education is the use of the Universal Systems Model. This is used as an approach to conceptualize technology as a human made system to complete a specific task (Wright, 1996) and the design process as a systematic process (International Technology Education Association, 2000). The model has four components: input, processing, output and feedback (Wright, 1996).

The Universal System Model shows conceptual similarities used to describe natural phenomena such as homeostasis. Maintaining homeostasis requires input from a sensor to detect changes in the environment, processing of the information to determine the appropriate response (output) and a feedback mechanism to monitor the effect of the changes. Similarly, brain function can be described using the same language. For the average student, homeostasis and brain processing are abstract topics. In the last decade, using new technology such as functional Magnetic Resonance Imaging (fMRI) has made is possible to study information processing in the brain but few if any labs exist to illustrate the concept clearly for students in a basic anatomy and physiology course.

Good labs use hands-on, inquiry-based or design-based learning because they are student-centered methods instead of teacher-centered (Emery & Paprocki, 2009; Titterton, Lewis & Clancy, 2010). Students are encouraged to ask questions and develop their own solutions but not necessarily the “correct” solution. Making mistakes is part of the process (DiPasquale, Mason & Kolhorst, 2003). Students are building and constructing their own knowledge. Providing students with a good model is an essential part of the process (Papert, 1980).

LEGO Robotics was first released in 1998 after research at MIT and the LEGO Corporation was combined with research at Tuffs University. The goal was to develop easy access micro-technology devices and programming environments for children and adults (Chambers & Carbonaro, 2006). LEGO Robotics has become a powerful tool in learning (Mosley & Kline, 2006; Barker & Ansorge, 2007; Whittier & Robinson, 2007). It combines the power of design and inquiry in an easily accessible form of technology. It puts students in charge of their own learning and has, therefore, the ability to engage students. It has the potential to create a variety of “models” that may make understanding complex phenomena easier (Papert, 1980).

The purpose of this research was to determine whether utilizing a model (Universal Systems Model) and technology (LEGO Robotics) used extensively in Technology Education could be adapted to provide a model to teach scientific phenomena. The LEGO robots have sensors that provide input, programming that visualizes processing steps and motors to see the response to changes, essentially visualizing the brain processing steps.

Methods
Students enrolled in a college level spring Anatomy and Physiology course (2012-2014) participated in this study. Enrollment was 38, 29, 33 students, respectively, in mixed majors (health science, biology, psychology and athletic training), with mixed levels (sophomores through seniors) and ages (traditional and older-than-average students).
During the first 8 weeks of the anatomy and physiology course, the nervous system was discussed extensively. LEGO Mindstorms Robotics kits were utilized in the lab as a model to show brain processing. Students were asked to build the standard robot as described in the LEGO kit (week 1). Subsequently, students were taught basic programming (week 2). A square (room) was laid out on the floor (approximately 4’ across) with tape. Obstacles, in the form of small boxes, were placed in the square. Students were asked to maneuver the robot around the “room” circumventing the obstacles using the sensors and programming. The students were free to select their sensors. In the third week, students were required to abandon the most used sensor and repeat the assignment with a different sensor.

A mixture of qualitative and quantitative data sources was used for this study. A survey, using a modified Likert scale, provided data on how students experienced their own learning and their level of engagement, creativity and problem solving skills. Written reflections were used to solicit students’ perspectives about their experiences with the LEGO Mindstorms Robotics. Reflection questions were provided to guide the students’ responses. Observations were used to supply the perspective of the teacher about student engagement and student involvement. Students were required to submit their final Mindstorms programming for evaluation. This provided valuable data about the design and problem solving strategies students employed in the project.

The study was approved through the VCSU IRB approval process. This study was in the exempt category because all students are older than 18 and not part of a protected group. In addition, no deception was involved and students were asked to give their consent for participation.

**Survey results**

Students were asked to complete a survey after they finished the LEGO project. In addition, the students were asked the same survey questions after a “cookbook” style lab (a lab where students follow instructions, followed by questions but without input of students on design of the lab). A modified Likert scale was used to quantify the results. The Likert scale was subdivided in 7 categories: **strongly disagree** (1), **disagree** (2), **mildly disagree** (3), **mildly agree** (4), **agree** (5), **strongly agree** (6) or **no opinion** (7). This scale was selected so the no-opinion answer (null value) would not skew the data calculations but would count towards the number of responses. Therefore, the average was not influenced by no-opinion choice.

**Table 1: Survey statements part 1**

<table>
<thead>
<tr>
<th></th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>I was engaged during this laboratory exercise</td>
</tr>
<tr>
<td>B</td>
<td>I used creativity in this laboratory exercise</td>
</tr>
<tr>
<td>C</td>
<td>I used problem-solving skills in this laboratory exercise</td>
</tr>
<tr>
<td>D</td>
<td>I was aware that I formulated a solution to a problem, tested the solution and evaluated the results</td>
</tr>
</tbody>
</table>

In part 1 of the survey, the students were asked to rank 4 statements. Results indicated (figure 1) that students felt they were engaged (A), that they used creativity (B) and used problem-solving
skills (C). In each of the categories, the average was above 5.0 meaning most students selected Agree and Highly agree. Students also recognized they used the problem-solving process (D). Little variation was found from year-to-year meaning students consistently ranked the activity highly (results not shown). Results for the cookbook style lab activity (cranial lab) were slightly lower than the LEGO™ lab but no significant difference was found for Statements A through C. A statistical difference (Student Ttest, p< 0.05) was found in Statement D asking about recognizing utilizing problem-solving skills (figure 1). This result supports that the LEGO lab illustrated the problem-solving process better than “cookbook” labs.

![Figure 1: Survey results of cookbook lab (cranial lab) versus the LEGO lab (average of three years)](image)

In the second part of the survey, students responded to statements about their understanding of brain signaling and brain processing (for LEGO lab only)

<table>
<thead>
<tr>
<th>F</th>
<th>LEGO™ robotics helped me understand integration of signals in the brain</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>LEGO™ robotics helped me understand the sequencing of signals and effects</td>
</tr>
<tr>
<td>H</td>
<td>LEGO™ robotics helped me understand the effect of brain processes on behavior</td>
</tr>
<tr>
<td>I</td>
<td>LEGO™ robotics provided a useful model for visualizing processes happening in the brain</td>
</tr>
<tr>
<td>J</td>
<td>LEGO™ robotics helped me understand the material in lecture better</td>
</tr>
</tbody>
</table>

The survey results (figure 2) indicated that students felt the LEGO lab helped their understanding about brain processing. The average for Statements F through I was just above 5 meaning most
students selected *Agree* and *Highly agree*. However, students did not necessarily link the information from the lab with the information in the lecture (Statement J). Statement J scored below 5 showing the students selected *Mildly agree*. Interestingly, the last statement also showed the greatest variation from year-to-year. These results and observations by the teacher support the idea that the information provided by a teacher influences the connections the students make during lab.

![Figure 2: Students believe LEGO robotics helped understanding brain processing.](image)

At the end of the survey, students were asked a final open-ended question: “*What was the most surprising about this laboratory exercise?*”. Each student answered this question differently, but review of the answers revealed several themes (Figure 3).

![Figure 3: Open-ended survey question revealed 6 themes](image)
Three main themes emerged: comments related to precision required to make the robot work and the effect of a simple change (cause and effect), comparison with the brain (compare to the brain) and the complexity of the process with the need to pay attention to detail (complexity). A lesser theme was the number of things the robot could do (variation). Several students commented that they felt they were engineering or designing something they did not know they could (engineering). Several students commented that they really liked the lab (experience).

**Programming results**

Students were asked to submit their final programming for review. Each program was reviewed on the following criteria: the number of steps used in the programming, the type of basic blocks (move, switch, loops, wait blocks) and the type of sensors (light, ultrasound, sound, touch).

Table 2 shows the number of steps students used to program the robot to navigate a space.

**Table 2: results of the programming: number of steps used**

<table>
<thead>
<tr>
<th></th>
<th>Number of Steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>All years</td>
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<tr>
<td>average</td>
<td>6.07</td>
</tr>
<tr>
<td>max</td>
<td>22</td>
</tr>
<tr>
<td>min</td>
<td>2</td>
</tr>
<tr>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>5.37</td>
</tr>
<tr>
<td>max</td>
<td>10</td>
</tr>
<tr>
<td>min</td>
<td>2</td>
</tr>
<tr>
<td>2013</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>5.55</td>
</tr>
<tr>
<td>max</td>
<td>10</td>
</tr>
<tr>
<td>min</td>
<td>2</td>
</tr>
<tr>
<td>2014</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>7.57</td>
</tr>
<tr>
<td>max</td>
<td>22</td>
</tr>
<tr>
<td>min</td>
<td>3</td>
</tr>
</tbody>
</table>
This data showed how students approached the assignment. Several students used a linear approach and sequencing each step leading to an increased number of blocks being used. The use of switch and loop blocks lowered the number of steps required to reach the goal. There was a significant variation in the number of steps, showing the variety in the approach by the students.

Table 3 shows the types of block the students used. All the students used the move block. Around 80% of the students used a loop block representing that movements can be repetitive. Around 60% of the students used a switch block, which makes it possible to program the robot to make a dichotomous choice based on two different settings, for example: distinguish between light and dark or close and distant objects.

Table 3: Results of the programming: Types of block students used

<table>
<thead>
<tr>
<th></th>
<th>Loops</th>
<th>Switches</th>
<th>Move Blocks</th>
<th>Wait blocks</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All years</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>87</td>
<td>66</td>
<td>106</td>
<td>37</td>
<td>15</td>
</tr>
<tr>
<td>percentage</td>
<td>83.7</td>
<td>63.5</td>
<td>100.0</td>
<td>35.6</td>
<td>14.4</td>
</tr>
<tr>
<td><strong>2012</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>35</td>
<td>21</td>
<td>47</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>percentage</td>
<td>77.8</td>
<td>46.7</td>
<td>100.0</td>
<td>55.6</td>
<td>17.8</td>
</tr>
<tr>
<td><strong>2013</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>27</td>
<td>25</td>
<td>29</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>percentage</td>
<td>93.1</td>
<td>86.2</td>
<td>100.0</td>
<td>13.8</td>
<td>6.9</td>
</tr>
<tr>
<td><strong>2014</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>25</td>
<td>20</td>
<td>30</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>percentage</td>
<td>83.3</td>
<td>66.7</td>
<td>100.0</td>
<td>26.7</td>
<td>16.7</td>
</tr>
</tbody>
</table>

The data showed that when students used loops and switch blocks the use of wait blocks and other types of blocks went down (figure 4). This shows the effectiveness of the loop and switch blocks. Interestingly, not all students used the switch or loop block, showing that not all students connected switch and loop blocks with efficiency within programming.
Figure 4: Relationship between the types of blocks students used in the programming

Table 4 shows the use of the various sensor blocks. The robot kit includes 4 types of sensors: light, sound, touch and ultrasound.

Table 4: Results of all programming: usage of sensors in the LEGO programming reflecting both assignments

<table>
<thead>
<tr>
<th></th>
<th>Light</th>
<th>Ultrasound</th>
<th>Sound</th>
<th>Touch 1</th>
<th>Touch 2</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>All years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>57</td>
<td>51</td>
<td>17</td>
<td>17</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>percentage</td>
<td>54.8</td>
<td>49.0</td>
<td>16.3</td>
<td>16.3</td>
<td>1.0</td>
<td>2.9</td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>17</td>
<td>20</td>
<td>12</td>
<td>6</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>percentage</td>
<td>37.8</td>
<td>44.4</td>
<td>26.7</td>
<td>13.3</td>
<td>2.2</td>
<td>0.0</td>
</tr>
<tr>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>15</td>
<td>14</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>percentage</td>
<td>51.7</td>
<td>48.3</td>
<td>17.2</td>
<td>13.8</td>
<td>0.0</td>
<td>3.4</td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>25</td>
<td>17</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>percentage</td>
<td>83.3</td>
<td>56.7</td>
<td>0.0</td>
<td>23.3</td>
<td>0.0</td>
<td>6.7</td>
</tr>
</tbody>
</table>
Most students started programming using the light and ultrasound sensors. These sensors are introduced first to the students and the easiest to understand and program. Several students tried the sound sensor but found it was hard to adjust due to surrounding classroom sound and abandoned the effort. In 2014, several groups used the touch sensor first, which was different from other years. This result indicated that students communicated with and learned from each other.

**Discussion**

The major purpose for use of LEGO robotics was to provide students with a model for brain processing—to provide a picture of the inner workings of the brain. During the project, students were presented with very little information about how to approach the programming. This was done on purpose to see what connections students would make independently. Most students started programming the robots in a linear fashion: every move as a single step. They did not think to use switches or loops. In lecture reflex arcs and neural loops (a set of nerves linked to accomplish a specific task) were identified as building blocks for brain processing but students did not link switches and loops as representations for neural loops and reflex arcs on their own. Observation and the results of Statement I from the survey (figure 2) supported the conclusion that students did not automatically connect and apply what they learned in lecture about neural pathways with the programming in lab. Comments by the students in the reflection support this statement.

However, when students were made aware that their programming would no longer work if the boxes were moved students realized that the brain is more flexible than what they programmed. After learning about the function of loop and switch blocks within the programming, most students choose to incorporate switch and loop blocks (table 3). They realized that the programming became more efficient because they needed less steps to accomplish the task (observations and personal communications with students). This conclusion was supported by the comments in the students’ reflections. One student commented that the robot provided a great model to show input and processing instead of just output (as is the case when reflexes are tested). Students recognized that the programming required them to think about each step involved in the behavior of the robot. They had to make sure that every step was present. Several students mentioned that the LEGO robotics visualized the mistakes they made.

Most students recognized the brain does jobs fast and with precision. Several students mentioned they were glad they did not have to consciously think about everything that the brain does. Several students also mentioned they now understand the complexity of the processes. One student commented: “It also made the point on how intricate our CNS (central nervous system) and PNS (peripheral nervous system) are. A second student mentioned the project helped understand the way the brain is “wired” to do the job controlling the body. A third student commented: “the brain combines a bunch of simple concepts to create the complex function that it carries out”.

Another interesting observation happened during the third lab period. Students were required to discontinue the use of one sensor and replace it with another sensor. This part was added to show that the brain can adapt—for example, using braille to read when blind and using sign language to communicate when deaf. Once students understood the power of the switch and loop
blocks, they could adapt the programming quickly with minimal changes (personal observations). They realized that it did not matter where the input came from, it was the processing that mattered. This was supported by comments made in the reflections. Several students recognized the brain can adapt by using a different pathway or sensors to fulfill a specific task. Most students linked the sensors of the robot with special senses in the human body. A few students made the connections with reflex arcs. One student felt the robot illustrated the types of disabilities a human could encounter; another commented: “even when a sense is lost we can make adaption and compensate”.

In conclusion, this project intimated that LEGO robotics not only provide students with a programming experience but can be used to illustrate and provide a model to study biological phenomena, in this case brain processing. This conclusion is also supported by the work published by Whittier & Robinson (2007). The Universal Systems Model provided the bridge between programming and biology.

This research shows that models and technology used in technology education can serve as models in science education providing important cross-over between the two disciplines. Therefore, utilizing models from technology education can support technology teachers addressing design world standards considered more science based such as standard related to agriculture, biotechnology and medicine (International Technology Education Association, 2000) and illustrate the connection for students between science and technology.

References


The Collaborative Activities of Learning Design: “Inserting” Partnerships in Engineering and Technology Teaching with Novice Teachers

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Abstract

During the second year of their Education Master’s, French novice teachers in Engineering or Design and Technology have to learn how to design tasks and activities to develop pupils’ skills, capabilities, and knowledge. To achieve their tasks, they must follow the curricular requirements and train with their fellow students, along with their own teachers and tutors. In such a situation, do the novices assimilate collaborative learning practices when designing? What if they have to insert partnerships in their ‘project-based learning’ design? How do they react and what do they do?

In order to answer these questions, research was conducted based on activity analyses of two classes of novice teachers (using questionnaires; interviews; activity tracks of artifacts and action research). The groups were observed in 2014–2015 and 2015–2016. The students were in multidisciplinary teams. Each team had to design a multi-technological project, to draw up specifications, and to adapt the project to include multidisciplinary pedagogical content for their own students. Each stage led to communication of the completed work.

The outcomes highlighted struggles within teams during the time that the novice teachers had to make up teams, carry out the project, and shape the pedagogical content. Team members also found a way to work together and to organize their activities. If the apprentices did not see the goal of the learning situation, they found it senseless and disputed the exercise. Those teams who tried to tamper with the required tasks needed the strongest guidance. Team members felt the need to link the projects to their actual learning and teaching field. Finally, participants achieved their goals of fostering PBL situations and fostering design partnerships.
Keywords: Collaborative learning design, Project-based learning, Design skills or abilities, Teamwork activity

Context of the Study: Training of Teachers in the Fields of Technology and Engineering Education

This paper examines in particular the training of French teachers in the STEM area (Strimel & Grubbs, 2016; Hacker et al., 2010) and more specifically in technology & engineering education. During the second year of their Education Master’s degree, novice teachers in the fields of industrial engineering, design and technology, learn to design tasks and activities to develop skills, abilities, and knowledge (Bødker, 2012; Ginestié, 2008; Sambu & Simiyu, 2016). To develop these tasks and activities, they have to follow curriculum requirements and to train with their fellow novice teachers, as well as their own teachers and tutors (Long & Carlo, 2013; Svinicki & Schallert, 2016). In this regard, the training involves collaboration where novice teachers from several educational fields learn to cooperate in a project-based learning (PBL) environment.

Theoretical Framework: Collaborative Design Activities

Within PBL, students learn how to complete necessary planning tasks to gain results and realize their actions (Lawanto, 2013). Several researchers (De los Rios, Cazorla, Dias-Puente, & Yague., 2010; David, 2008) highlight the impact of projects on learning. Helle, Tynjälä, and Olkinuora. (2006) underline that PBL is especially based on knowledge linked to different fields that can support designing and building of mental models. Knowledge also allows the understanding of a concept's complexity. PBL involves a multidisciplinary approach (Proulx, 2004) and potential partnerships (Aasland, 2010). It makes sense to collaborate in learning situations (Loperfido et al., 2011; Castéra, Sarapuu, & Clément, 2013).
In a literature review, several studies investigate the activity theory linking task and activity (Vygotsky, 1962; Leontiev, 1978; Engeström, 2005). This is a perspective that allows observation of what a teacher wants students to make, the tasks he/she suggests, what students actually make, and the activities they undertake.
To better understand the teaching-learning process in the field of technological education (Hérold & Ginestié, 2009), there are some issues to discuss related to PBL. Do novices assimilate collaborative learning pedagogy into their practice? What if they have to "insert" partnerships into their PBL activities? How do they react and what do they do?

Study Methodology

To address these questions, this study is based on activity analyses of two classes of novice teachers and on an action research project. The groups were observed in 2014-2015 (teams from T1A to T8A) and 2015-2016 (teams from T1B to T8B). All the students were mixed in multidisciplinary teams (Table 1).
During the 2014-2015 year, they were more different design specialists and engineering specialists; the teams were set up by the teachers within the rules of multidisciplinary links (mixed disciplines to avoid a group with only one subject matter). During the 2015-2016 year, we observed a scattering of specialties, like mechanical works and an elimination of technology or arts and crafts. The teams were set up by the students themselves after an oral introduction of each student, and while the students discussed their teaching specialty they collectively organized the teams’ distribution on a white board.

During the first two semesters, each team had to design a multi-technological project (bioclimatic housing) to draw up specifications. The second two semesters were devoted to the transformation of the previous project into a fictitious adaptation including a focus on multidisciplinary pedagogical content. Each stage led to a presentation and to communication of the results of the completed work (Table 2).

### Table 1: The teams’ features

<table>
<thead>
<tr>
<th>Team members</th>
<th>T1A</th>
<th>T2A</th>
<th>T3A</th>
<th>T4A</th>
<th>T5A</th>
<th>T6A</th>
<th>T7A</th>
<th>T8A</th>
<th>T1B</th>
<th>T2B</th>
<th>T3B</th>
<th>T4B</th>
<th>T5B</th>
<th>T6B</th>
<th>T7B</th>
<th>T8B</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014-2015 (31 students)</td>
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<td>4</td>
<td>4</td>
<td>4</td>
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<td>3</td>
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</tr>
<tr>
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<td>●</td>
<td>●</td>
<td>●</td>
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<td>●</td>
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<td>Graphic design</td>
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<td>●</td>
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### 2015-2016 (32 students) | 4   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 5   |

During the 2014-2015 year, they were more different design specialists and engineering specialists; the teams were set up by the teachers within the rules of multidisciplinary links (mixed disciplines to avoid a group with only one subject matter). During the 2015-2016 year, we observed a scattering of specialties, like mechanical works and an elimination of technology or arts and crafts. The teams were set up by the students themselves after an oral introduction of each student, and while the students discussed their teaching specialty they collectively organized the teams’ distribution on a white board.

During the first two semesters, each team had to design a multi-technological project (bioclimatic housing) to draw up specifications. The second two semesters were devoted to the transformation of the previous project into a fictitious adaptation including a focus on multidisciplinary pedagogical content. Each stage led to a presentation and to communication of the results of the completed work (Table 2).
Table 2: The multidisciplinary project and the different stages of the research

The teachers documented their activities (using questionnaires; interviews; artifacts; slideshows; oral presentations; etc.) which illustrated several stages of the project’s progress.
This approach followed The Buck Institute for Education (2012) recommendations that the realization of an individual report as well as a team report of the work progress be compiled. This report can take various forms: logbook, portfolio, etc., allowing a highlighting of the differences between the requirements and the actual and realized tasks (Tables 3a and 3b).

Table 3a: Topics of the 14-15 teams, tools, and representations

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<th>Stud.</th>
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<td>S1-1a</td>
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</table>

All the collected tracks cannot be exhibited in this paper (16 teams, 18 stages and several tracking versions that teams left on the university digital environment that have been downloaded). Some samples are displayed in Tables 3a and 3b.
Table 3b: Topics of the 15-16 teams, tools, and representations

<table>
<thead>
<tr>
<th>Stud.</th>
<th>Specialties</th>
<th>Topics</th>
<th>Representations’ tools</th>
<th>Final slideshows tools (sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1b</td>
<td>Mechanical engineering</td>
<td>‘Hab-borie’ (French play on words with ‘Hab’ instead of habitat and ‘Borie’, a local farmhouse made with dry stones)</td>
<td>Internet, Pictures, Schemes, Maps, Diagram, Mind maps</td>
<td>‘Exploring all-around’</td>
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<td></td>
<td>Boiler work</td>
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<td>Interior design</td>
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<td>Metal work</td>
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<tr>
<td>T2b</td>
<td>Graphic design</td>
<td>ECOLOGIS – Bio Habitat Optimum Wooden House for Tourism (BIOWHT) [in English]</td>
<td>Google image, ‘SketchUp’ among several 3D CAD on line, Handmade sketches, Schemes, 2D maps</td>
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<td>Stonework</td>
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<td>Automotive maintain.</td>
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<td>T3b</td>
<td>Product design</td>
<td>Design study of a bioclimatic rotating house with atypical shape</td>
<td>SketchUp, ‘Illustrator’, Excel, Handmade sketches, Maps, Pictures</td>
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<td>Energy engineering</td>
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<td>Lorry driver</td>
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<td>T4b</td>
<td>Graphic design</td>
<td>Beyond the hills</td>
<td>‘Board of trend’ InDesign, Mind maps, 3D sketches and illustrations, Schemes, Pictures</td>
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<td>3 Energy engineering</td>
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<td>T5b</td>
<td>Product design</td>
<td>Development of a bioclimatic housing environment on the foundations of the Phocaean city</td>
<td>Drawings, Schemes, Mind map, Systemic drawings: GANTT &amp; PERT charts, InDesign, Illustrator</td>
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<td>Energy engineering</td>
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<td>T6b</td>
<td>Graphic design</td>
<td>Corsican individual bioclimatic housing</td>
<td>Drawings (Illustrator), Schemes, Pictures, Mind maps</td>
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<td>T7b</td>
<td>Graphic design</td>
<td>‘Biohousing’ panorama</td>
<td>Documents on paper 2012 Thermal regulations InDesign, PDF vs. PowerPoint, Schemes with Word or Illustrator, Handmade sketches’</td>
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<tr>
<td>T8b</td>
<td>Civil engineering</td>
<td>Bioclimatic mobile home</td>
<td>Handmade sketches, Schemes, Mind map</td>
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<td>2 Electronic engineering</td>
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In addition to the above information, interviews (at the end of the first semesters) are analyzed to understand the differences between projects teams carried out and what they thought about inconsistencies between requirements and actual activities. Students are quoted using anonymous codes: for instance, the members of T1A are called S1-1a, S1-2a, S1-3a, and S1-4a. All members are quoted using their anonymous code and the number of their intervention during interviews (see Tables 4 to 7).
Outcomes

PBL as a Fight …

- … Against Several ‘Barriers’ …

Teams struggled with several problems (outlined in Table 4). This fight led T5A to itemize some issues (S5-3a called it “barriers”, S5-4a, “discrepancies”, and S5-1a, “peculiar sensitivity” or “falling apart”). First, they competed against the time allotted and finally found a way to buy time. For instance, T5B was competing with time to respect constraints, to be practical, pragmatic, “simple at most” (S5-4b). T2B members felt they wasted time agreeing or compromising, debating, attempting to impose every point of view; they also found “things don’t occur naturally”. T1B put it this way: (01. S1-1b) “We got to know each other well.” And (02. S1-1b): “We needed a long time to get to know each other.”

- … Against “Clichés” …

T5A necessarily carried out the project despite “experiences,” “preconceptions or preconceived notions,” “orientations.” or “guidelines.” It required team members to re-examine themselves, to take a new look at themselves. T1B found prior knowledge to be a “burden,” trying to break the deadlock. T4A (04. S4-1a) strongly “mourned” the ambition of the first intentions or agendas.

- … and Against “Other Subjects”

Finally, teams struggled with other learners or teachers. T6A blamed the “non-significance” of the teachers: they were not “of some use”. Furthermore, T6A & T7B challenged stakeholders, sponsors or backers because they seemed to be “off the project”. Consequently, T2B suggested the appointment of a project leader, who must:
- take responsibility (someone uses to be responsible);
- channel tasks and energy;
- save time;
- centralize action and information;
- “clear the air” with team workers;
- help to choose wisely (making choices);
- build bridges (bonds, etc.);
- get what it takes to be a leader.
### Table 4: PBL generates fighting behavior

<table>
<thead>
<tr>
<th>PBL main features</th>
<th>Detailed PBL features</th>
<th>Teams’ statements or characteristics, quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finding a way to work together, committing to the teamwork</td>
<td>Struggling behavior: competing with time or wasting energy</td>
<td>T1B called it a race against the clock; however, team members were aware that this race was a means for developing skills (13. S1-1b to 15. S1-2b)</td>
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<td>T2A: the deadline especially during teamwork (worried S2-4a: 05, 06 &amp; 07. S2-4a).</td>
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<td>T2B: wasting time seeking a project leader and expecting teachers would choose one on their behalf.</td>
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<td>T4B. S4-1b &amp; S4-3b. They regret the uncertain length of the assigned tasks: “Long or short time per tasks” (S4-1b); “In the beginning of the year, it was holidays and last week we had to work harsh”, “Last week, we really believed that we were going to lose hair…” (S4-3b).</td>
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<td>T7B. 02. S7-3b: tough to find the way to “create”, to “enhance creativity”, to “overstep the representation stages” and the problem solving.</td>
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<td>T7B. 13. S7-1b: fighting the noise during teamwork, seeking isolation to focus on the project and to product.</td>
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<td>Struggling behavior with “clichés”</td>
<td>T2B wanted to make the project anyway, but other team members gave up.</td>
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<td>T2B. S2-3b: “It’s hard to lead a project.”</td>
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<td>T3B. S3-4b and S3-3b had former representations and skills that prevented them from understanding the project and its design. Dialog with team mates aided. They especially opened their mind. They got out of the rut in which their former ideas blocked them. (To be reproduced in “fostering design”.)</td>
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<td>T4A: designing is shaping before introducing technical considerations.</td>
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<td>T5B. 14. S5-2b: “It sure got stuck in the head”.</td>
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<td>Struggling behavior with others (teachers, other students or stakeholders)</td>
<td>T1B: how to unveil the way T1B carried out the project getting teamwork under control.</td>
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<td>T1B. 02. S1-3b: “I don’t know exactly what to do but we don’t care until it’s of use to us!”</td>
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<td>T1B. 30. S1-1b: “We asked ourselves whether it was on purpose or whether it was an observation stage.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T1B: fighting against unsettled stakeholders while acknowledging as novice teachers they behave identically with their own students.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T2B. Applied arts teacher fought against technical aspects that the engineering part of the team enhanced. Inside T2B team, things did not naturally occur.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T7A. 16. S7-1a: “Me too, this is an ethic point. If that isn’t good enough, I’m off the project.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T7B. 13. S7-2b: stakeholders did not know the real requirements…</td>
</tr>
</tbody>
</table>

**Working Together with a Clear or an Unclear Goal**

Lack of Visibility

Despite unclear requirements—called by several teams: “lack of visibility” or “senseless”—students found a way to work together (Table 5 for other details). T3B had no understanding, asking: “What is the goal?” T3B needed more visibility to understand how to progress and how the project would be assessed. T1B stated (04. S1-1b): “So, where did we put the slider? […] it was the point that took up most of our time.”

**Rumors but Agreement**

T4B noticed fake information, rumors, gossip, and whispers, instead of strong guidelines, and specifically added: “It was a grapevine” (15. S4-1b). On the same point, T1B decided the issue: “After a while, we stopped to look at the others” (01. S1-3b). T6A must have considered several team adjustments, synchronizing and upgrading each other step by step. It allowed them to face
differences in skills with an open mind and to say they “got enough to realize something beautiful and innovative” (01. S6-5a). While the make-up of the team was messy, its asset was “human contact” (02. S6-1a). This kind of relationship was based on consensual motivations (02. S6-3a).

-Tampering with Tasks

They faulted tasks they found senseless or contradictory. T4A disputed a prerequisite when stakeholders questioned it too and tried to negotiate and reconsider the project. T7B fought against exercise (02. S7-2b), enhancing skills’ affinities rather than real skills and mixing up knowledge, skill, and capability.

-Requesting Stronger Guidance While Being (Novice) Teachers

T2B regretted the lack of accurate guidance and therefore demanded the appointment of a project leader (S2-1b & S2-3b). Another student claimed: “I appreciate when someone tells me ‘you do that’ or ‘you do this’ need a frame, guidelines” (15. S3-3b). From the same team: “We don’t know where to move, sometimes” (15. S3-2b), or: “But, we’ll do it, anyway (laughs)” (16. S3-3b). T7A did not understand the differences between the knowledge the topic required and the written requirements. They found it paradoxical and felt abandoned and a little bit lost. T7B questioned what they have to do exactly. They raised a contradiction between concise constraints and unclear goals. They also did not understand the interest of skills’ presentation by all students, thinking this was a “random setting up”.

To conclude, T4B found it tough to work without strong guidance or without omnipresent teachers. The team also recognized that it is a ridiculous situation to be managed like pupils while they are student-teachers.
Table 5: PBL encourages collaboration

<table>
<thead>
<tr>
<th>PBL main features</th>
<th>Detailed PBL features</th>
<th>Teams’ statements or characteristics, quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working together (within and between the teams)</td>
<td>Finding it senseless</td>
<td>T2A. 02. S2-2a.: “We couldn’t determine our skills because we didn’t know what the use was. At least it helped us a little. And we also used our representations.”</td>
</tr>
<tr>
<td></td>
<td>Working with or without</td>
<td>T5A was remade because of the arrival of a new member: it improved teamwork while they fought against constraints they added themselves. According to T7B, all teams had difficulties to “solve the problem” in the prescribed time (or within the allotted time).</td>
</tr>
<tr>
<td></td>
<td>Tampering with required tasks (solutions before specification)</td>
<td>T1B. 08. S1-2b. Team members worked outside regular hours although requirements said teams must work during class. T2B. 12. S2-2b. Filling the daily form to bring the content into line with the teachers’ idea and not to the students’ design; however, they got the goal and achieve the task. According to media and other clichés, T5B initially thought of a hidden country cottage without environmental impact. But it decided to design a townhouse and team members found it a pleasure and a challenge.</td>
</tr>
<tr>
<td></td>
<td>Demanding stronger guidance (to know what exactly the requirements are, or to appoint a project leader)</td>
<td>T1B compared the understanding of teachers’ requirements with other teams. It seemed they did not get same information. They tried to gather some hints. T2A. Because of renewed requirements, T2A found it tough to seek direction, anticipate solutions, and so on. T2A. Without disputing requirements, T2A describes the efficiency of learning situation contributing to focus on the real problem. T2B. Lack of guidance was perceived as a deliberate decision to compel team members to step back.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T4A. According to S4-2a, some stakeholders did not introduce themselves and caused confusion. With a clear understanding of the stakeholders’ role, students may have been able to question more precisely.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12. S4-1b: “Teachers can’t be everywhere, but sometimes, it’s difficult to wait […] if we have a claim.” 13. S4-2b: “Eight or twenty-two slides? Everybody gets desperate…” 14. S4-2b: “It looks a little academic and it seems ridiculous to manage people who are novice teachers but, nevertheless, I think it’s just as well, sometimes, to write guidelines on the blackboard…”</td>
</tr>
</tbody>
</table>

How to use Teaching Matters or Former Expertise

Relying on what Novices Already Know

Teams mainly asked to bind the projects to their actual learning and teaching field (Table 6). T4B made self-presentations to determine or identify their own skills. T2A stated it so: “we have different ideas because we’re working more in terms of representations” (26. S2-1a); “that’s the work method you can find in an industry engineering department, for instance” (15. S2-4a). T5B highlighted and managed former representations’ methods like: drawings – Gantt chart – Excel Tables, etc. T2B involved everyone, seeking compromise on the project illustrated by a T5A quote: “Nobody forces anybody” (13. S5-3a). T4A emphasized a debate with other specialists that allowed for a reappraisal.
Managing Discovered Skills

T5B managed skills to synthesize, to summarize, to simplify, to be consistent. T5A thought teaching is a way to engage in collaborative work such as in the voluntary sector or collective organizations or club management. A T2B member may have planned a multidisciplinary project in high school (24 & 26. S2-3b): it seemed easier because every committed teacher knew what to do. S2-3b expected a learning project, one that it called an “instructional sequence” that involved a training progression.

Shaping Pedagogical Contexts

T1B imagined a learning situation to provide practice (26. S1-1b). T3B requested the same learning situation they organized with their own students. T5B showed pupils’ ways of designing (31. S5-2b): diagnostics development; assignments; specification; skills sharing; etc.

Table 6: PBL enhances dialog and collaborative work

<table>
<thead>
<tr>
<th>PBL main features</th>
<th>Detailed PBL features</th>
<th>Teams’ statements or characteristics, quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binding projects to the teaching fields and jobs</td>
<td>Acquiring knowledge linked to different fields</td>
<td>T1B. 20. S1-3b: struggling with internal stakeholders and their unclear specifications, like in his/her teaching job.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T5A. Sharing languages to communicate easily with a common language; sharing objectives after long debates; learning to communicate and to understand interpretations of each expert making up the team.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T6A. 07. S6-5a learned during an industry internship that specifications could have been reshaped.</td>
</tr>
<tr>
<td>Managing former collaborative skills</td>
<td>T2B made an internal agreement to distribute the different tasks according to inner skills.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T2B. 01. S2-3b: “Everyone contributed.”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T2B added members’ skills and did not balance.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T7A first defined an “acting location” to set up its project.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T7B. 07. S7-1b: “We got different tools, so we had to explain things to be understood.”</td>
<td></td>
</tr>
<tr>
<td>Managing discovered collaborative skills</td>
<td>T4A. Managing collaborative work and skills without taking the risk: how to follow the rules for fear of losing themselves. A kind of discovering of new collaborative abilities.</td>
<td></td>
</tr>
<tr>
<td>Shaping pedagogical contents</td>
<td>T1B. Avoiding technical things (standards, charts, “stuff”) to communicate to a diverse, heterogeneous audience (06. S1-3b).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T3B. S3-3b thought of an instructional project with models and mockups, while S3-2B asked how to transpose their teamwork in a real learning situation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T4B. S4-2b suggested a transposition in a learning situation requiring a focus on teamwork skills and not on the topic.</td>
<td></td>
</tr>
</tbody>
</table>

Fostering PBL Situations

Organizing Activities to Achieve Project and Learning Design

This dialog between three T1B members illustrates the idea (Table 7). T4A itemized carrying out the mission: visualizing the project; finding technical situations; seeking environmental information; asking some other experts. T5B (S5-1b) had a precise definition of the learning situation, looking at how to:
- React in a team in which members deliberately came from different fields.
Look at how people could previously project in an unexpected way. Look at how balances could be carried out. T5B also precisely reported a concerns and affordances related to collaborative design activity:
- issues with illegible, unreadable handmade drawings (sketches, drafts with erasures, deletions);
- back-talks and corrections;
- use of vector drawings’ applications (Illustrator and InDesign);
- debates about efficient use of paper or PC (easier to practice with four learners around paper than in front of a screen);
- sketches as efficient starters, fast enablers of exchanges, dialog;
- “go and return” between handmade drawings and digital design (iterative process);
- enhancing of communication (empowering channels).

Planning Tasks and Activities

T5B resolved several unexpected skills or irrelevant abilities to answer the questions teachers asked. They harmonized each member’s commitment or willingness to build something. T5B “completed and achieved by focusing and re-focusing on the project” (03. S5-1b). They “coped with it, anyway” (05. S5-1b).

Fostering Partnership and Design

S3-4b and S3-3b (T3B) had prior conceptions and skills that prevented them from understanding the project and its design. Dialog with teammates aided. This group in particular, especially opened their minds. They got out of the rut in which their former ideas blocked them. A team member said: “Every time someone gets a job done, everybody gives the opinion on it too”. T3B got the other teams to palliate shortcomings or misunderstandings and to bring new solutions. Moreover, requirements were distinctly understood from team to team. It needed dialog away from teachers in order to unveil the actual requirements. Together they chose a “pleasant” and “unusual” or “non-typical” path to carry out a project.

Knowledge of Designing and Building Mental Models

T2B mixed the technological fields to understand that they were “missing something”. T4A members re-examined or challenged themselves, reassessed their ways, and “broke away” from former representations or opinions as said in this dialog:
- 03. S4-4a: “So, abstracting the issue, so, opening ...”
- 06. S4-1a. Sharing a picture all the team members got and so, opening it to let other people go inside.
To conclude, T5B members admitted:
- 03. S5-2b: “Forging an assignment.”
- 15. S5-4b: “We showed what was fit to be seen.”
Table 7: PBL fosters partnership

<table>
<thead>
<tr>
<th>PBL main features</th>
<th>Detailed PBL features</th>
<th>Teams’ statements or characteristics, quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrying out the project within a PBL situation</td>
<td>Organizing activities to achieve project and learning design</td>
<td>T1B: they isolate themselves from their peers to focus on their work of making a video projection to gather data and share the tasks they identify.</td>
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<tr>
<td></td>
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<td>- 22. S1-3b: “We were lost.”</td>
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<td>- 13. S1-4b: “We made our own decisions and we figured it was time to decide and to make it this way.”</td>
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<td></td>
<td></td>
<td>- 06. S1-1b: “Finally, there are different sensibilities. Everyone learns from each other. […] Thus, I learned to create better lessons for the other specialties.”</td>
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<td>T2B. 02. S2-1b: “In a way, we tried to get the best qualities of each other to achieve the goal we were assigned.”</td>
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<td>Despite the lack of project leader and time, T2B carried out the project, outlining representations as tools to be understood by a large audience. T2B also gathered all its members.</td>
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<tr>
<td></td>
<td></td>
<td>T7A had a moment of hesitation (an “awkward moment”) and, so, kept its work about basic specification to be available to design.</td>
</tr>
<tr>
<td>Planning tasks and activities</td>
<td>T3B. S3-1b: “choosing without time to design”.</td>
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<td></td>
<td>T5B. Discussions about the project to compare vocational or specific views on specifications. All members evolved and changed their definition of specifications.</td>
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<tr>
<td></td>
<td></td>
<td>T7B dispatched the tasks according to each skill set.</td>
</tr>
<tr>
<td>Fostering partnership and design</td>
<td>T4A. S4-1a needed a specialist on project management.</td>
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<tr>
<td></td>
<td>T7B. 01. S7-2b explained the discussing and brainstorming the team conducted in order to choose the “good idea”, to scaffold and underpin it, to “unfortunately” make compromises.</td>
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<td>T7B. 06. S7-3b admitted all issues were “creativity engines”. It looked like a dynamic process.</td>
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</tr>
<tr>
<td>Knowledge to designing and to building mental models</td>
<td>T2B. 14. S2-1b: “On my own behalf, I felt a little bit dumped because it’s not my job. So, finally, I succeed to follow suit, quickly. And I think we completed some interesting things with each other.”</td>
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<td></td>
<td>T2B. A learning situation; teachers moved toward deep thought and things’ shaping.</td>
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<td></td>
<td>T6A. 12. S6-1a learned what design is even though he already worked in an industry engineering department. All team members experienced collaborative work.</td>
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</table>

Discussion

From one year to the next, student teams did not react similarly, although the requirements and the sequence chronology were similar (with a few improvements and shifts). In 2014-2015, novice teachers, in addition to other designers, re-examined themselves. Most of them experimented with collaborative work during their studies or in a former job, internship, or teaching. They projected less pedagogical content than the following year. In 2015-2016, team members were stressed by the requirements. Consequently, they demanded stronger guidance, continuously looked at the work of the other teams, compared the methods they chose, and checked interpretations of the specification. However, “after a while”, they “stopped to look at the others” (T1b), and made their “own sweet way without asking [themselves] too many questions”. Gathering all the products the teams designed, this ongoing action research highlights the necessity of a common world in which dialog between several experts needs time because teamwork helps to develop a constructive work dimension (discussions about barriers to cross, building teams, etc.) rather than a productive dimension (e.g., no time to produce).
Conclusion

This paper presented a first step into analyzed data of a PBL situation with 16 teams of students’ teachers in engineering, design, and technology fields. At this stage, first outcomes allow an understanding of the generation process. Meanwhile, teams of novice teachers do not look like engineers’ teams or designers’ teams, but they worked like them, especially when they sought to overcome the “discrepancies” with diverse strategies they could not quickly or easily find (how to share the same goal). In this way, novice teachers demanded more supervision. Following on this process, they produced pedagogical content that will be analyzed in a further paper.

References


Mitcham Score - A Method to Assess and Quantify Students’ Descriptions of Technology

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Abstract

Studies have shown that students often describe technology strictly as different kind of objects. More specifically, modern electrical objects. For American adults’ similar results have been reported. With a philosophical approach, Carl Mitcham describes technology in a broad spectrum, where technology is conceptualized as Knowledge and Volition within the human being and Activities and Objects as a result of the first two. With the meaning, that a technical activity requires a technical knowledge.

The purpose of this study is to analyze students’ descriptions of technology, using Mitcham’s typology as an analytical tool. What aspects of Mitcham’s typology are covered in student descriptions of technology and how reliable is the assessment among several raters? An assessment template has been developed for this study, that can be used by researchers and by teachers, to quantify students’ descriptions. In this study 164 students (ages 12-15) descriptions of technology and technology education are assessed and quantified within Mitcham’s typology. The student descriptions are compared to the Mitcham typology and students score a point for every one of the four aspects of technology they describe, this is named Mitcham Score. Three researchers assessed a sample of 15 technology descriptions to control inter-rater reliability using Krippendorff’s alpha calculations and percent agreement.

This study shows that students, in general, do not see knowledge as a part of technology. They mostly focus on describing technology as objects and activities. It also shows that the aspects Volition and Objects are more difficult to agree on among the raters. Measurements within this philosophical framework can provide a tool to study both student knowledge about technology and which factors might affect this.

Keywords: Technology education, assessment, Technological literacy, Mitcham score
Introduction
In our technological intense world, we must find it important that our knowledge about technology is broad and in need of critical aspects. Many countries aim to find their future engineers and workforce in technology related jobs through compulsory technology education. On the other hand, people who do not want to work in technology intense jobs still have to be able to participate as a democratic citizen. To do this, it is important that schools provide possibilities for students to gather knowledge in and about technology, (of course, this is relevant to other subjects than technology). Several countries highlight aims in their technology syllabus that is pointing toward the importance of a technological literate citizen.

In the New Zealand technology syllabus, we can read that; “The aim is for students to develop a broad technological literacy that will equip them to participate in society as informed citizens and give them access to technology-related careers.” (Ministry of Education, 2007, p. 32) In Sweden: “Teaching in technology should aim at helping the pupils to develop their technical expertise and technical awareness so that they can orient themselves and act in a technologically intensive world.” (The Swedish National Agency for Education, 2011, p. 254) And the International Technology and Engineering Educators Association (ITEEA) describes that: “The goal is to produce students with a more conceptual understanding of technology and its place in society, who can thus grasp and evaluate new bits of technology that they might never have seen before.” (ITEEA, 2007, p. 4)

Despite these important aims we are not quite there yet. A technological literate citizen would, in some meaning, have to see technology in a broader sense. Several studies have presented, that students often see technology strictly as technical objects and more specifically modern electrical objects (de Vries, 2006; Köycü & de Vries, 2015; Garmire & Pearson, 2006; Burns, 1992; DiGironimo, 2011). This, even though much of the technology we meet on daily basis is part of something greater, like technological systems etc. which in some meaning is invisible, as long as they are functioning as intended. For American adults, similar results have been reported (ITEA, 2004). This is, of course, interpretations of the majority’s view of technology and a great variation among people might be observable. One might say that the majority of people do not seem to be technological literate in a broad sense. Especially if compared with an analytic philosophical approach, like Mitcham’s (1994) description of technology, where technology is conceptualized as technological Knowledge, Volition, Activities, and Objects. Together the four parts of the typology can be expressed as knowledge about technology along with the human will to create and improve leads to developing, manufacturing and use of new technical objects. Mitcham’s typology has previously been used by Nia and de Vries (2016) to analyze the Standards for Technological Literacy (ITEEA, 2007). The analysis by Nia and de Vries (2016) using the typology shows the usefulness of using this broad framework.

The purpose of this study is to analyze students’ descriptions of technology, using Mitcham’s typology as an analytical tool. The research questions for this paper are What aspects of Mitcham’s typology are covered in student descriptions of technology? And How reliable is the assessment within the typology, when comparing researchers?

Method
For this study, we elaborated two questions to lure students to write more extended descriptions of technology. These two open-ended questions were added at the beginning of the PATT-SQ-survey (by Ardies, De Maeyer, & Gijbels, 2013. using the adapted Swedish version by Svenningsson, Hultén, & Hallström, 2016) to let the students describe their views on technology before getting possible inspiration from the rest of the survey. The questions were:
Describe what you consider to be technology (not the school subject technology)? and If you were to describe the school subject technology for anyone who has not studied it in school themselves, how would you describe it?

These two questions together form data to assess students' descriptions of technology. Most students have at least some experience in technology education, the second question does not exclude students who do not feel that they know what technology is. To analyze the answers concerning students' descriptions of technology, we intend to use Mitcham’s (1994) four ways of describing technology (objects-activities-knowledge-volition). The description analysis makes it possible to quantify students’ qualitative descriptions. This typology is not intended to evaluate or assess students’ descriptions of technology. Hence, it provides a general description of technology that corresponds well with the aims in the technology syllabus in e.g. New Zealand and Sweden.

Data collection
Four schools were visited to gather data for the study. The schools were selected based on a convenience sample, with the intention to get a variation among school types. The sample schools include one suburb school, one small town school and two private schools from different areas and different profiles. The total number of participating students were 173 (ages 12-15).

The assessment
The respondent's descriptions of technology and/or technology education are assessed and score 0-1 points on each of the four ways of describing technology (total score 0-4 points and we choose to call this “Mitcham score”). The assessments are made using the template in appendix 1. There is no hierarchy between the different descriptions, only the broader the description is, the more likely to score higher points. Unlike the intention of Mitcham’s typology, we accept student descriptions that for instance describe technological activities as possible without mentioning that it requires technical knowledge. To score in the object category the respondent has to write that technology has to do with man-made objects. In the activities category, the respondent has to mention the process of making or using technological objects. To score in the knowledge category the respondent need to use technology as an example that requires knowledge, “how to/know how”. The final category, volition, includes respondents who express technology as a human will to improve or control technology consciously or express consequences of technology. Typical examples for Mitcham score are:

1 point - “Computers, Cellphones and Tablets” placed in the category Objects
2 (1+1) points - “I'm thinking of electronics and to build things” placed in the categories Objects and Activities"
3 (1+1+1) points - “How things work and how to fix them” placed in the categories Objects, Activities, and Knowledge
4 (1+1+1+1) points - “It is knowledge about electricity, technical gadgets, how they are made, how they can become more environmentally friendly, the evolution of technology, how things are built etc.”

Reliability
To explore this method for assessment, three researchers (referred to as researcher 1, 2 and 3) in technology education were given a random sample of 15 (9%) student descriptions of technology and technology education. They were asked to follow the instructions in appendix 1 to assess which of the different parts of the Mitcham’s typology were reached in each student description. To measure inter-rater reliability Krippendorff’s alpha was used, between the three researchers’ ratings, on every part of the typology. Krippendorff’s alpha was calculated in IBM
Statistical Package for the Social Science (SPSS) using Hayes and Krippendorff's macro (2007). This statistical method simultaneously measures several raters to find out the assessment method’s reproducibility. The aim in these type of studies is an alpha value above .667 (Krippendorff, 2004). Interrater agreement calculations are sensitive to rare findings, meaning that a low alpha, does not have to mean low agreement (Viera & Garrett, 2005). Since all three researchers are well trained within the used philosophical framework, percent agreement can serve as a good benchmark (McHugh, 2012). Therefore, the percent agreement between the three researchers will be calculated as well. A fourth rater (referred to as researcher 4) completed the assessment twice, two weeks apart. That researcher’s assessments will be used to control intra-rater reliability Cohen’s Kappa between this one researcher’s ratings will be calculated. A Kappa above .21 is considered as a fair agreement, .41 and above as a moderate agreement, above .61 a substantial agreement and above .81 is considered as an almost perfect agreement (Viera & Garrett, 2005).

**Results**

Firstly, the results of the assessment within the four aspects of technology are presented, both as distribution in the different categories and the distribution of the students’ Mitcham score. Nine of the 173 students were excluded because they had no written response at all, to any of the open questions, in total, there are 164 students in the analysis. Since this study also intends to try this method among other researchers, the assessments are followed by the results of inter-rater agreement results.

**Descriptions of technology**

Results from the students’ descriptions of technology within Mitcham’s typology are shown in table 1 and table 2. The assessments have been made by researcher 1, on the 164 valid respondents.

Table 1.
<table>
<thead>
<tr>
<th>%</th>
<th>Object</th>
<th>Knowledge</th>
<th>Activities</th>
<th>Volition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>79.9</td>
<td>44.5</td>
<td>49.4</td>
<td>4.9</td>
</tr>
<tr>
<td>Girl</td>
<td>82.1</td>
<td>50</td>
<td>52.4</td>
<td>6</td>
</tr>
<tr>
<td>Boy</td>
<td>79.2</td>
<td>40.3</td>
<td>46.8</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Table 2.
<table>
<thead>
<tr>
<th>Mitcham score</th>
<th>Frequency</th>
<th>Valid Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>24</td>
<td>14.6</td>
</tr>
<tr>
<td>1</td>
<td>32</td>
<td>19.5</td>
</tr>
<tr>
<td>2</td>
<td>69</td>
<td>42.1</td>
</tr>
<tr>
<td>3</td>
<td>33</td>
<td>20.1</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>3.7</td>
</tr>
<tr>
<td>Total</td>
<td>164</td>
<td>100</td>
</tr>
</tbody>
</table>

Of the 164 students, 14.6% of them describes technology as something else that does not fit the model of Mitcham’s four ways of describing technology. Examples of those answers are “Don’t know”, “Technology is technology” and “Not fun. Love soccer” The most common description of technology is technology as an object. The most common combination is object-activities, 2 of 39
respondents that score 2 points including activities relate this to knowledge. Of the 164 participating students, 44.5% of them describe technology as something that has to do with or requires knowledge. Generally, girls in this study provide a more detailed description of technology than boys do. Especially, girls are more common to include technical knowledge as a part of their descriptions (table 1).

**Assessment reliability**
Assessments of the 15 randomly selected student descriptions were examined, firstly how well the rater that completed the assessment on two separate occasions. In the Cross-tabulation (table 4), it is shown that researcher 4 had different interpretations of the student descriptions four times of the possible 75 times (percent agreement .947). This results in a Kappa value of .893 (table 3) where a Kappa above .8 is considered as an almost perfect agreement (Viera & Garrett, 2005).

### Table 3
Cohen’s Kappa, intra-rater agreement for Researcher 4 between 1st and 2nd assessment

<table>
<thead>
<tr>
<th>Measure of Agreement</th>
<th>Value</th>
<th>Approximate Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kappa</td>
<td>.893</td>
<td>.000</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>75</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4
Researcher4 1st * Researcher4 2nd Crosstabulation of rater between 1st and 2nd assessment

<table>
<thead>
<tr>
<th>Researcher4 1st</th>
<th>Researcher4 2nd</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>NO</td>
<td>39</td>
<td>0</td>
</tr>
<tr>
<td>% within Rater</td>
<td>90.7%</td>
<td>0.0%</td>
</tr>
<tr>
<td>YES</td>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>% within Rater</td>
<td>9.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Total</td>
<td>43</td>
<td>32</td>
</tr>
<tr>
<td>% within Researcher 2nd</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Our next step is to compare the three raters when using the template in appendix 1. As presented in table 1, one can assume that problems regarding a high alpha reliability will be harder to achieve in the categories volition (rare that it is included in student descriptions) and objects (rare that it is not included in student descriptions). Therefore, we present the percent agreement as well. The results are presented in table 5.
Table 5
Krippendorff's alpha inter-rater reliability for researcher 1, 2 and 3 and percent agreement all three researchers

<table>
<thead>
<tr>
<th></th>
<th>No definition</th>
<th>Objects</th>
<th>Activities</th>
<th>Knowledge</th>
<th>Volition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>.560</td>
<td>.294</td>
<td>.819</td>
<td>.778</td>
<td>.060</td>
</tr>
<tr>
<td>Observed agreement</td>
<td>.87</td>
<td>.60</td>
<td>.87</td>
<td>.87</td>
<td>.67</td>
</tr>
</tbody>
</table>

The Krippendorff’s alpha, in this case, is below the recommended .667 (Krippendorff, 2004), in objects and volition in the typology and above in the two aspects knowledge and activities. The observed percent agreement is relatively high. Student descriptions where all three researchers totally agree in the assessment varies from 60% to 87% (or 9/15, to 13/15).

Discussion
The purpose of this study was, first of all, to analyze students’ descriptions of technology using Mitcham’s typology. This typology, seem to be suitable for assessing student descriptions, it is rather easy to use and the Mitcham score is almost normally distributed, with an exclusion of 4 points which create a skewness. It is important to acknowledge the fact that there are students, in ages 12-15, that can describe technology using Mitcham’s four aspects of technology. The model is suited both to analyze how broad students’ descriptions of technology are and what aspects of technology they find relevant. The results tell us that technology among these Swedish students commonly is described as technical objects. More than 60% of the students also expressed that technology is more than just objects, either it has to do with knowledge and or activities as well. It is troubling though that few students see that the activities as something that requires knowledge. This might be because the students’ perceptions of that technology education have to do with making and creating objects, but the process is rarely reflected upon. This used typology and scoring are, as mentioned, only to assess the students’ knowledge about technology. However, this is important knowledge, that should be taken into account, when trying to achieve the syllabus aims in, for example, New Zealand and Sweden.

An important issue for Mitcham score is that it is easy to use and is in some way reliable. The results of the intra-rater agreement calculations show that this method sustainable from time to time, at least for researcher 4, Kappa .893. And we are confident that it will be, even for others. We consider this result very good, especially when considering that every student description has 16 different possible ratings (by chance). A more difficult judgment occurs when there are several raters (in this case 3). Cohen’s Kappa is not suitable when using multiple raters, so Krippendorff’s alpha was used to measure the level of agreement between all raters simultaneously, with consideration to chance. Problems occur in the categories technology as object and volition, which both can be considered as rare findings (Viera & Garrett, 2005). While the aspects activities and knowledge are present in half of the student descriptions receive a high alpha value .819 and .778. The effect of rare findings can be exemplified by comparing the alpha values in activities and knowledge to the no definition category .560. It is notable that the percent agreement is the same for all these categories (87%) with the only difference that the no definition category is more rarely expected. Taking both the Krippendorff’s alpha and the percent agreement into account we consider No definition, Knowledge, and Activities as reliably. A conclusion though is that it is more difficult to assess and agree in the categories volition and objects. Especially volition is in need for a clearer description. The assessment template (appendix 1) might need some clarifications or a deeper discussion among the raters prior the assessment.

As a conclusion, the method is relatively reliable and it is not very time-consuming. The results can give important information about a school’s level of understanding and knowledge about
technology. The method is not intended to be used to analyze individual students. Instead, teachers can use the template to assess a whole class. Thereby get an indication of what might be missing to reach a broader understanding of technology. Since this method quantifies qualitative data, it is possible to perform correlation studies between different factors and to compare schools or use it when performing attitude surveys. As further research, it would be interesting to analyze the technology syllabus using the same framework, to see if the curricula “creates” students' unawareness of, for example, technical knowledge.

References


The aim of this survey is to investigate how similar researchers assess student descriptions of technology and technology education within four predetermined categories. A random sample of 15 out of 164 student descriptions is used in this survey.

Your task is to place every student description within one, several or none of the following categories:

Technology as: **Object**\(^1\) - **Knowledge**\(^2\) - **Activities**\(^3\) - **Volition**\(^4\)

The assessment is based on this definition of technology: **Knowledge about technology**\(^2\) **along with the human will to create and improve**\(^4\) leads to **developing, manufacturing and use**\(^3\) of new **technical objects**\(^1\).

There is no hierarchy between the different categories. All students can be placed in 0 up to 4 of these categories by analyzing their descriptions.

In the next page, you can read some student descriptions and how they are assessed. To ease your assessment, trigger-words for the categories are color-coordinated and bolded as in the description above.

Firstly the answer on ”a= technology is” is used. but if ”b= technology education is” cover more or other categories this answer is used as well.
APPENDIX 1

Five student descriptions with an example of assessment

1
a "Technology is technology"

b "boring"

Does not fit into any of the predefined categories. By mentioning technology alone does not make the answer fit into any of the categories.

2
a “Computers, Smartphones and tablets”

b "Don’t know"

Fit into the category Technical objects

3
a “Inventions”

b "To build and invent things"

Fit into the category Technical objects and in Activities when including answers to both a and b.

4
a “How things work and how to fix them”

b "It’s fun and you get to learn a lot”

Fit into the category Technical objects, Activities and Knowledge.

5
a "Facts about electricity. Technical gadgets. How they are manufactured. How they can be made more environmentally friendly. The evolution of technology. How things are built etc."

b "As above"

Fit into the category Technical objects, Activities, Knowledge and Volition

You may print this page and use as a template when analyzing student answers.
Does Authentic Learning Work? Evaluating an Innovation Project in Upper Secondary Technology Education in Sweden

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Abstract
Creativity is widely viewed as a key component of human development. Creativity is part of the “21st century skills” movement as well as a cornerstone of the technology subject in the Swedish school system. Could authentic learning, as described by Herrington, Reeves and Oliver, be one way to promote creativity? In a pilot study conducted in 2016, 13 groups of upper secondary students participated in a five-week authentic innovation project where they cooperated in the design of solutions for real-world problems. This approach mirrors Brown, Collins and Duguid’s statement that in order to learn a subject, students need more than abilities that focus on acquiring abstract concepts; they need to use and apply conceptual tools while performing authentic activities. The outcome of the innovation project was displayed and presented at an exhibition where professional inventors provided feedback on students’ created solutions. This paper presents results from the pilot study as well as preliminary findings from a main study, involving 25 groups, currently underway. Data from the pilot study was collected through questionnaires after each lesson, following the five-week module, and at the end of the entire course, as well as through semi-structured interviews with nine students. The results from the pilot study indicate that the students perceived the project as being authentic, and departed the course with an increased sense of comprehension and understanding. Future studies will explore learning activity within groups, and differences between students' and teachers' understanding of authenticity.
**Keywords:** Technology education, Upper secondary school, Authentic learning, Innovation

**Introduction**

Innovation is closely related to creativity and novelty. The Organisation for Economic Co-operation and Development provides the following definition: “An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations” (The Organisation for Economic Co-operation and Development [OECD], 2005, p. 46). Creativity is also one of the “four Cs” in the 21st century skills movement comprising Creativity, Critical thinking, Cooperation and Communication (Partnership for 21st century learning, n.d.), and flagged as a necessity in a reformed curriculum (National Education Association [NEA], 2012; Council of the European Community [EU], 2008). In 2008, the EU stated that schools need to foster creativity as well as a spirit of innovation and enterprise in their pupils. In the Innovation Project described in this paper, the demand for creativity and novelty was pitched at a “non-Googleable” standard. Here, the aim is to approach the definition of creativity as suggested by Plucker, Beghetto and Dow (2004, p. 90), who state that, “Creativity is the interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context”. The latter points to the fact that a creative act must be viewed within the context it is deployed, such as an upper secondary school.

The Swedish National Agency for Education defines Technology as a subject in upper secondary school that is interdisciplinary, aiming to fulfil human needs and preferences by transforming the physical resources of nature or immaterial assets in products, processes, facilities or systems (Skolverket, n.d.). The Innovation Project is thus not only interdisciplinary in nature but also student-centred and authentic, in line with Rotherham and Willingham’s (2010) claim that “advocates of 21st-century skills favour student-centred methods—for example, problem-based learning and project-based learning—that allow students to collaborate, work on authentic problems and engage with the community” (p. 19).

**Authentic Learning**

Authentic learning is described extensively in the literature, but with a major caveat; there is no universal and clear-cut definition for what elements actually constitute authentic learning *per se*. Eddy and Lawrence (2013) point to the Greek origin of “authentic” as being “auto” and “-hentes”, meaning “self-doer”, and state that “what lies at the foundation of ‘authenticity’ in learning is the notion that the individual is not only the learner, but also the doer” (p. 265). Such an insight connects strongly with Plucker et al.’s (2004) earlier assertion regarding the social context of creativity.

Authentic learning, as described by Herrington and Oliver (2000) in the form of key elements is built upon a situated learning paradigm previously described by Brown *et al.* (1989). In 2010, Herrington *et al.* defined nine key elements of authenticity comprising of Authentic context, 
Authentic task, Presence of expert performances, Multiple perspectives, Collaboration, Reflection, Articulation, Metacognitive support and Authentic assessment. At the same time, they described the role of Authentic learning in an academic setting. This definition constitutes the basis for interpreting the meaning of authentic learning in the Innovation Project in this study.

The Innovation Project

Louis Pasteur once said that “chance favours the prepared mind” (Harnad, 2004), and school students are in no more a privileged position 150 years later. Therefore, prior to engaging in the Innovation Project (IP), basic knowledge and skills will have to be obtained. These include problem-solving skills, using “Six thinking hats” (De Bono, 1987), basic insights in material properties and processing, as well as fundamental drawing techniques, including the use of CAD.

Brown et al. (1989) have suggested that, “...students need much more than abstract concepts and self-contained examples. They need to be exposed to the use of a domain's conceptual tools in authentic activities – to teachers acting as practitioners and using these tools in wrestling with problems of the world” (p. 34). It is in this spirit that the Innovation Project was formulated, enabling the students to plan their own work, adopt their acquired skills and knowledge, and test their abilities in an authentic real-life project, in line with the nine elements of authenticity (Herrington et al., 2010; Herrington, n.d.).

The IP was implemented for the entire first year of upper secondary school technology at the first author’s school. This consisted of a 5-week period when the students spent about 20 hours of the total allocated teaching time working collaboratively in small groups of three to four students, solving a problem of their choice. The students are urged to tackle problems pertinent to their everyday life, and anything that does not have a trivial solution will certainly serve as a starting point for the IP. During these weeks, the students are aware of the fact that they are attending their own classes, not the teacher’s class. The students plan and carry out their own projects, including searching for necessary information, appropriate materials and manufacturing techniques, analysing the potential market (including market research when appropriate), and calculating the financial aspects of the project. The project’s main period ends with an exhibition where the students exhibit their results, mostly as models but also sometimes as operational prototypes. At the exhibition, the students are required to explain to fellow peers, interested viewers as well as invited professional inventors, how their product or service functions (Svärd, Schönborn & Hallström, 2016).

Methods

In the current study, 25 projects (groups of students) within the IP module were evaluated by the students themselves as well as by their teachers. The assessment was performed using a four-point Likert scale questionnaire, which enabled a possibility to both compare the results of the study by Bozalek et al. (2013) that used a three-point Likert scale, and Ciolan and Ciolan (2014), using all four points. Each student’s evaluation was performed immediately after the exhibition at the end of the IP module. The questions about the IP module were designed in
such a way that students’ opinions about the nine elements of authenticity could be obtained. The teachers used Herrington et al.’s (2010) guidelines to evaluate the group performances in a similar way.

Bozalek et al. (2013) used a three-point Likert scale to evaluate 21 university student projects in South Africa for signs of authenticity as described by Herrington et al. (2010). Scores of 0 (no evidence), 1 (weak evidence) and 2 (strong evidence) were assigned to each of the nine elements of authentic learning. The evaluation was made by five members of the research team and a mean value was used. The results were presented as a percentage of the maximum scores as assessed by the researchers. Apart from the percentage of each of the elements, a median score of authenticity was calculated for each of the projects, as well as for the entire study.

In the current study, when calculating the degree of authenticity of each of the elements, the four points were assigned the following scores; 1 (0 – no evidence), 2 and 3 (1 – weak evidence) and 4 (2 – strong evidence). A mean value was then calculated for each group. In this study we only have one teacher to evaluate the group, compared with having a mean value of five researchers per group in the South African study, resulting in an imprecise presentation. We therefore chose to use all four points instead, resulting in the following percentages of authenticity; 0%, 33%, 67% and 100%.

Ciolan and Ciolan (2014) have shown great discrepancies between the teacher’s point of view and the student’s. We therefore compared the views of the student groups with those of the teachers. Using a four-point Likert scale made it possible to compare data from our study with the results of Ciolan and Ciolan (2014).

The findings of our 2016 and 2017 studies are presented together with the results of Bozalek et al.’s (2013) results to place the data into perspective.

Results

Findings from Bozalek et al. (2013) on the levels of authenticity in 21 university projects are presented in Figure 1, which also yielded a mean authenticity rate of 65%. The results from our respective 2016 pilot study and 2017 main study are presented in Figure 2, together with Bozalek et al.’s (2013) original South African study for comparison. The data in Figure 2 is also presented as a Radar chart in Figure 3. Interestingly, the mean authenticity rates for both the current 2016 and 2017 study were found to be 65%, which is similar to Bozalek et al. (2013).
Figure 1. Students’ perceived level of authenticity for each respective element of authentic learning found by Bozalek et al. (2013, p. 634).

Figure 2. Level of authenticity per authentic learning element generated in the current 2016 and 2017 studies, and also compared with Bozalek et al.’s (2013) results.
Figure 3. Radar chart representation of level of authenticity per authentic learning element in the 2016 and 2017 studies, and compared with the data from Bozalek et al. (2013).

The radar chart method was also used to explore the variance of results in the pilot study. In the 2016 pilot study, we found that the average authenticity levels of the groups ranged between 52% and 76%, with the average of all the 13 groups found to be 65% (Figure 4).

In the 2017 study, the dimension of more than one teacher being involved in the project was added. The data from the participating groups emerged with approximately similar values as in the pilot study, with a maximum value of mean perceived authenticity of 76%, minimum of 47%
and an average value for the 25 groups in 2017 at 65%. The maximum value was accomplished by two individual groups (Figure 5).

Figure 5. Data representing the most authentic groups (Max 1 and Max 2), the least authentic (Min), and average authenticity, as evaluated by the students themselves in the 2017 study.

The 2017 study also involved two teachers, which allowed for comparisons between different groups under different conditions. In line with Ciolan and Ciolan’s (2014) findings regarding discrepancies in how authentic a task is perceived, we compared the views of different student groups with the teachers. Using a four-point Likert scale made it possible to compare data from these studies with the results of Ciolan and Ciolan (2014). As described in the methods, the teacher’s evaluations were presented using all four points, instead of three as in the case of the students. The mean discrepancy between using a three or four-point scale was only 0.7%, but resulted in graphs that better represented teachers’ views of the projects.

In Ciolan and Ciolan’s (2014) work, the teacher evaluated the project as being more authentic than the students thought it was. This finding was replicated in the current study. On average, the teacher graded the projects as 12% more authentic than the students did with a range between –14% and +37% (Figures 6, 7 and 8).
Figure 6. A typical result from the 2017 study for student group 1. The teacher evaluates the task as 85% authentic, and the students as 71% authentic.

Figure 7. Authenticity of student group 11 as evaluated by the students and the teacher. This group, and three other groups, were identified as being 100% authentic by the teacher.
Figure 8. Five out of 25 student groups evaluated themselves as being more authentic than the teacher evaluated them as. Only two had a discrepancy of more than 10%. In this case, students evaluated the project as being 47% authentic and the teacher as 33%, respectively.

There is also a discrepancy between the two teachers in this study. Teacher 1, who was part of the 2016 pilot study, displayed a better conformity with the students’ evaluations than Teacher 2, who joined the project a year later. This could possibly be due to previous experiences in evaluation according to Herrington et al.’s (2010) guidelines for authentic learning. Other differences are most likely due to different groups of students (see Figures 9 and 10).

Figure 9. Authenticity as evaluated by Teacher 1 and corresponding students.
Figure 10. Authenticity as evaluated by Teacher 2 and corresponding students.

**Discussion and Implications**

The similarities between our 2016 and 2017 studies in Sweden, and the South African research context is an interesting platform from which to move the research agenda forward, at least when looking at the average evaluation of authenticity in which all studies scored approximately 65%. The fact that this score was obtained in all three studies is interesting bearing in mind that the evaluation was carried out very differently in the Swedish and South African studies respectively (students and teachers versus researchers). The contexts of the studies are also very different. While the Swedish studies were carried out in upper secondary schools, the South African study was conducted at university level. Further inspection of the results also reveals clear differences between the elements **Authentic task** and **Articulation**, for example. In this regard, authentic task received the highest score in Bozalek *et al.* (2013) while in our studies it was assigned the lowest scores. Regarding Articulation, in the Swedish context it emerged the other way around; a very high score in the Swedish studies but the lowest in the South African study. It is conceivable that the high score on Authentic task in the South African study was due to students being enrolled in higher education programmes in teacher education and health care where one can easily conceive an authentic link, whereas this was more difficult to achieve in the Swedish secondary school context. Conversely, the low score on Articulation in the South African study was probably due to traditional restrictions on presentation and assessment of student results, while in our studies we promoted a wide array of articulation techniques and authentic assessment. Also, the higher grades for **Collaboration** and **Reflection** in Bozalek *et al.* (2013) could be expected due to differences in age between upper secondary- and university students (also see Svärd *et al.*, 2016).
The perceived authenticity of the IP module varied among the different groups of students, and it also varied among the teachers. However, on average, the teachers perceived the IP module as being more authentic than the students did. Concerning the differences in scores between the teachers and the students, our studies support the pattern of previous studies (e.g. Ciolan & Ciolan, 2014). At this stage in the research programme, we can only speculate about the reasons for this discrepancy. It is possible that the teachers, who initiated the IP module, were more positive at the start of the implementation. They also invested more time and energy in the project, and therefore they may have sought a positive outcome. In a few cases, the students evaluated their efforts as more authentic than the teachers did. One possible reason could be anxiety over receiving low grades by the teacher, even though students were assured that the study itself was not part of the grading process. This finding might call for group interviews with those groups that differed most from the teacher evaluation.

At the end of the study, after having analysed the various questionnaires and conducted interviews with some students, we hope to move closer to probing questions such as:

Does engagement during the IP module affect the outcome of the project? Do the students perceive a higher degree of satisfaction with the outcome? Is there any relationship between perceived authenticity and grades in Technology? Has the course changed students' ideas about their future prospects? And, do students see themselves as engineers or designers?

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A Critical Examination of Engineering Design Processes and Procedures

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Abstract

The authors conducted a content analysis of P-16 curricula, educational standards, industry-driven accreditation/certification requirements, and design cognition research to (a) identify the engineering design processes used in P-16 curricula and design practices used in industry, (b) determine the similarities and differences between these engineering design procedures and practices, and (c) examine the relationship of engineering design cognition research and the processes highlighted in P-16 technology and engineering education curriculum. This investigation was enacted to help further guide educators and instructional designers in creating effective learning experiences that utilize engineering design activities and to provide a foundation for future research and development endeavors to better teach the fundamentals of engineering design.

Keywords: Technology, Engineering, Design, Cognition
Introduction

Creativity, problem solving, collaboration, critical thinking, and communication are consistently referred to as the skills necessary for students to succeed in the 21st century workforce as well as in post-secondary education (Partnership for 21st Century Skills, 2011). Consequently, technology and engineering education (TEE) programs attempt to prepare students to be successful contributors to society (Pavlova, 2006) by providing them the opportunity to integrate these skill sets by designing solutions to complex and complicated issues (Leahy & Phelan, 2014). Globally, designing is considered a fundamental component of P-12 TEE (Banks & Williams, 2013; Barlex, 2006). Subsequently, a number of engineering design process models and procedures have been endorsed and are currently implemented in classroom learning environments. Though many of these design process models have similarities, components represented in one model, may be excluded in another. Additionally, some may follow a traditional technological design approach, while others follow a more contemporary, analytical engineering design process. Yet, in terms of educational and cognitive outcomes, a chosen design process model may elicit varying results.

Accordingly, the authors conducted a content analysis of P-16 curricula, educational standards, industry-driven accreditation/certification requirements, and design cognition research to (a) identify the engineering design processes used in P-16 curricula and design practices used in industry, (b) determine the similarities and differences between these engineering design procedures and practices, and (c) examine the relationship of engineering design cognition research and the processes highlighted in P-16 TEE curriculum. The cognitive lens is necessary to consider in the interest of teaching, learning, and performance in completing an engineering design problem-solving task as student performance can be influenced by fundamental cognitive procedures and limitations while solving multifaceted problems (Schunn & Silk, 2011). Therefore, the findings of this analysis can help further guide educators and instructional designers in creating effective learning experiences through engineering design activity while developing students’ 21st century cognitive competencies.

Engineering Design in Technology Education

Today, immersing students in the practices of engineering design is often seen as a means to engage them in the integrated, self-directed learning of disciplinary content through authentic contexts (Grubbs & Strimel, 2015). As a result, STEM education initiatives continue to emphasize teaching through the application of engineering design. However, a major problem has been a lack of a clear and consistent definition of engineering design (NGSS Lead States, 2013) and the development of fundamental learning progressions of design and the methods best to teach such foundational design practices (Kelley, 2017). Instead, STEM curriculum programs oftentimes provide an
engineering design process model to serve as a series of steps for students to follow as they attempt to solve a design challenge. As Dym, Little, and Orwin (2014) state, these engineering design process models are either prescriptive or descriptive in nature. A descriptive model simply explains what designers typically do when solving a problem and a prescriptive model stipulates what should be done during the design process (Reeve, 2016). However, these models are regularly generated based on the opinion of experts and frequently do not take into account the cognitive development of students at various age levels (Strimel, 2014). Consequently, teachers of these curricula may deliver the design process models without the proper introduction to and scaffolding of the design skills/practices that enable students to achieve the authentic and rigorous practice of engineering design. In doing so, students may never experience the appropriate application of design, mathematical, and scientific principles to generate multiple solution ideas and narrow down the ideas through the engineering practices of predictive analysis and optimization (Harris & Jacobs, 1995; Merrill, Custer, Daugherty, Westrick, & Zeng, 2009).

Nonetheless, curriculum providers continue to forego the development of design abilities and promote the idea that providing students with engineering design tasks and a prescriptive engineering design process model will enable them to self-learn the required disciplinary-specific content of the subject in which it is employed (Antony, 1996). Yet, research has indicated that design experiences can potentially distract students from learning difficult to understand discipline-specific concepts and reduce their abilities to transfer knowledge to other settings or problem scenarios (Goldstone & Sakamoto, 2003; Kaminski, Sloutsky, & Heckler, 2009; NAE & NRC, 2014). Therefore, it becomes vital to understand engineering design and engineering design-based pedagogies in an effort to provide students with a deeper dive into the related practices and concepts that will enable them to employ rigorous approaches to resolving problems. As Flowers (2010) indicates, the affinity toward procedure-based instruction has led to the association of “steps” in teaching design becoming too strong—resulting in a dogmatic approach to technology education. Supporting this claim, Lewis (2005) stated:

> The problem for the field of technology education in the United States and elsewhere is that the overt description of the stages of the design process, observable when engineers do their work, has become the normative design pedagogy. This stage approach runs the risk of overly simplifying what underneath is a complex process. (p. 44)

**Design Cognition Research**

As engineering design-based pedagogical practices continue to expand across primary and secondary education (Strimel & Grubbs, 2016), it is imperative to better understand the ways in which pupils of all levels cognitively process design tasks, to provide effective instruction, adequate scaffolding, and suitable feedback (Grubbs, 2016). Design cognition research may prove to serve in the role of developing an improved
comprehension of engineering design practices and effective pedagogies for cultivating students’ design abilities and scaffolding the learning of engineering design. The increased understanding of student cognition during engineering design tasks can also help to identify shortcomings and endorse potential interventions for enhancing a student’s designerly abilities (Bransford & Vye, 1989; Strimel, 2014). Fittingly, the study of design cognition has been conducted across multiple disciplines for several decades (Grubbs & Strimel, 2016; Lammi & Gero, 2011)—primarily examining the cognitive processes of practicing professionals such as engineers, architects, or post-secondary students as they complete a design task (Cross, 2001; Lammi & Becker, 2013). The objectives of this type of research is typically to establish enriched techniques for preparing prospective designers (Adams, Turns, & Atman, 2003). More recently, research examining design cognition at the P-12 level has been on the rise, with the purpose of refining students thinking capability and the integration of STEM content and process knowledge. But, as Dixon (2016) concluded in his analysis of studies involving engineering design, researchers have not yet investigated the merit of one design process model over another and whether students are using engineering design to effectively learn disciplinary specific STEM concepts. For these reasons, the researchers undertook this investigation to construct a foundation for future research and development endeavors aimed at improving the teaching of engineering design fundamentals.

Problem Statement

Literature repeatedly suggests that engaging students in engineering design activities at all levels of education promotes critical and creative thinking, engages students in the resolution of authentic problems, integrates concepts from science and mathematics, and generally results in a “good” educational experience. As a result, a variety of engineering design process models are used in primary to post-secondary studies and consequently, students are often taught to use an idealistic engineering design process to solve problems. However, while a number of engineering design process models have been endorsed through curriculum programs, a gap in empirical research exists examining the merit of one model over another (Dixon, 2016). Furthermore, Kelley (2017) states there is limited attention paid to teaching design fundamentals at the K-12 level. Therefore, this study was conducted to set the foundation for future endeavors investigating the impacts of various engineering design process models and provide an understanding of design practices for examining how students cognitively progress through engineering design activities.

Research Objectives

The research objectives that guided this study included:

RO1: Identify the engineering design processes used in P-12 curricula and design practices driven by industry
RO₂: Determine the similarities and differences between engineering design procedures and practices

RO₃: Examine the relationship of design cognition research and the processes highlighted in P-16 technology and engineering curriculum

Methodology

This study employed a content analysis method to examine P-12 TEE curriculum and standards, industry-driven standards/examinations for post-secondary engineering programs, and empirical design cognition research to achieve the designated research objectives. The Journal of Engineering Education, the International Journal of Engineering Education, the Journal of Technology Education, the Journal of Pre-college Engineering Education, the Journal of STEM Teacher Education, the Journal of Technology and Design Education, and the Journal of Technology Studies were selected to purposively search for empirical studies that have investigated design cognition at P-12 level. These journal searches resulted in the inclusion of 16 studies that examined P-12 students’ cognitive process while engaged in a design challenge using a design process related coding scheme. The researchers then analyzed the foundation of each design process coding scheme by locating and investigating their origins.

Findings

Research Objective 1. To achieve research objective one, the researchers first reviewed the US standards documents or curricular frameworks for the school subjects of science, technology and engineering, mathematics, English/language arts, and computer science. This examination revealed the Standards for Technological Literacy (STL) (2000/2002/2007), Next Generation Science Standards (NGSS) (2013), and K-12 Computer Science Framework (2016) specifically emphasize engineering design or a design process. The STL includes four standards directly related to design and includes a prescriptive model of steps for solving design problems. The NGSS provide a descriptive model of engineering design that includes defining a problem, developing solutions, and optimizing designs and includes Engineering, Technology, and the Applications of Science as one of the core disciplinary ideas, which contains engineering design as a standard at each grade level. In addition, the foundational document for the NGSS titled A Framework for Science Education (2012) details a set of engineering practices employed during the process of defining and solving problems. Lastly, the K-12 Computer Science Framework (2016) discusses design in terms of the creation of computational artifacts which is focused on user-end design. Table 1 provides the engineering design processes and practices provided in these standards/framework documents.

Table 1
Next, the researchers examined popular TEE curriculum providers to identify the different engineering design process models promoted across primary and secondary education. The researchers identified *Engineering byDesign* (2017), *Project Lead the Way* (2017), and *Engineering is Elementary* (2017) as widespread national TEE providers. Each program provides an engineering design process model geared for students at different age levels with each model expanding to a greater number of “steps” in the design process as the curriculum advances across grades. In addition, three other national curriculum providers (NASA, 2017; PBS Kids, 2017; Teach Engineering, 2017) that deliver a general engineering design process model were identified. These programs use the same model across all of the grade levels they intend to reach. Table 2 provides the “steps” included in each of the design process models included in the identified TEE curriculum.

To determine how engineering design is modeled in industry, the researchers examined the program standards of the Accrediting Board for Engineering and Technology (ABET) (Engineering Accreditation Commission, 2017) and the certifying exams of the National Council of Examiners for Engineering and Surveying (NCEES) (2017). The ABET works to provide confidence that post-secondary engineering programs meet quality standards to produce graduates that are prepared for the engineering workforce and the NCEES is an organization dedicated to advancing professional licensure for engineers. Therefore, it would be hopeful that their depiction of engineering design would be an accurate reflection of industry.
For a post-secondary engineering program to be accredited, ABET requires documented evidence the program prepares graduates to enter the professional practice of engineering by meeting 7 established student outcomes (provided in Table 3). These outcomes all address practices involved with engineering design with one outcome explicitly attending to the application of “the engineering design process.”

NCEES administers the examinations used for engineering licensure in the United States. The first exam in the process towards becoming a professionally licensed engineer is the Fundamentals of Engineering (FE) exam. The FE exam is offered for seven different engineering disciplines and commonly covers fundamental knowledge of mathematics, probability and statistics, computational tools, engineering economics, and ethics and professional practice across the different engineering disciplines. The common elements of these FE exams are provided in Table 4.
### Table 2

**Engineering Design Processes Models in P-12 Curriculum**

<table>
<thead>
<tr>
<th>Engineering by Design (K-2)</th>
<th>Engineering by Design (3-5)</th>
<th>Project Lead the Way (K-5)</th>
<th>Project Lead the Way (6-8)</th>
<th>Engineering by Design (9-12)</th>
<th>Project Lead the Way (9-12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• <strong>State the Problem</strong></td>
<td>• <strong>Define Problem</strong></td>
<td>• <strong>Ask</strong></td>
<td>• <strong>Define Problem</strong></td>
<td>• <strong>Define &amp; Justify a Problem</strong></td>
<td></td>
</tr>
<tr>
<td>• <strong>Look for Ideas</strong></td>
<td>• <strong>Generate Ideas</strong></td>
<td>• <strong>Explore Model</strong></td>
<td>• <strong>Brainstorm Possible Problems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• <strong>Develop Solutions</strong></td>
<td>• <strong>Select Solutions</strong></td>
<td>• <strong>Evaluate</strong></td>
<td>• <strong>Can the Problem be Justified?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• <strong>Share Solutions</strong></td>
<td>• <strong>Test Solutions</strong></td>
<td>• <strong>Define Problem</strong></td>
<td>• <strong>Has the Solution Been Attempted?</strong></td>
<td></td>
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<tr>
<td></td>
<td>• <strong>Make Item</strong></td>
<td>• <strong>Brainstorm Possible Solutions</strong></td>
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<tr>
<td></td>
<td>• <strong>Evaluate Item</strong></td>
<td>• <strong>Generate Concepts</strong></td>
<td>• <strong>Why Have Prior Solution Attempts Failed?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• <strong>Present Results</strong></td>
<td>• <strong>Needed Technology</strong></td>
<td>• <strong>Critical Solution Design Requirements</strong></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>• <strong>Exists</strong></td>
<td>• <strong>Analysis of Prior Solution Attempts</strong></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>• <strong>Scientific</strong></td>
<td>• <strong>Problem Statement</strong></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Research Needed</strong></td>
<td>• <strong>Project Proposal</strong></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Develop a Solution</strong></td>
<td>• <strong>Generate and Defend Solution Concepts</strong></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Is Solution Valid?</strong></td>
<td>• <strong>Identify Design Goals/Design Requirements</strong></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Construct &amp; Test Prototype</strong></td>
<td>• <strong>Identify Application of STEM Principles</strong></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Is Prototype Valid?</strong></td>
<td>• <strong>Select Final Solution Path Decision Matrix</strong></td>
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<td></td>
<td></td>
<td>• <strong>Evaluate Solution</strong></td>
<td>• <strong>Develop A Testable Solution</strong></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Solution Solves Problem?</strong></td>
<td>• <strong>Generate Drawings/Schematic Process Chart</strong></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Present Solution</strong></td>
<td>• <strong>Identify Materials/Tools/Resources</strong></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Product Innovation</strong></td>
<td>• <strong>Preliminary Design Review</strong></td>
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<td></td>
<td></td>
<td></td>
<td>• <strong>Construct Prototype and Develop Testing Plan</strong></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• <strong>Develop Qualitative and Quantitative Testing Procedures</strong></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• <strong>Build</strong></td>
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<td></td>
<td></td>
<td></td>
<td>• <strong>Reflect On/Evaluate Solution Reflect on/Evaluate Design Process</strong></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• <strong>Stakeholder Feedback</strong></td>
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<td></td>
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<td></td>
<td>• <strong>Finalize Documentation</strong></td>
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<td></td>
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<td></td>
<td>• <strong>Next Steps/Modifications/Reflection</strong></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• <strong>Presentation of Findings/Defense of Project Steps</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**General Engineering Design Processes**

- **Teach Engineering**
  - Find the need
  - Define the problem
  - Brainstorm to come up with ideas
  - Select the most promising design
  - Plan and manage the project
  - Build-test-refine the design

- **PBS Design Squad**
  - Identify Problem
  - Brainstorm
  - Design
  - Build
  - Test/Evaluate
  - Redesign
  - Share Solution

- **NASA**
  - Ask a question first about the goal
  - Imagine a possible solution
  - Plan out a design and draw your ideas
  - Create and construct a working model
  - Experiment and test that model
  - Improve and try to revise that model
Table 3

Accrediting Board for Engineering and Technology (ABET) Engineering Design Criteria

<table>
<thead>
<tr>
<th>Student Outcomes</th>
<th>Process of Engineering Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics</td>
<td>• Identify opportunities</td>
</tr>
<tr>
<td>2. An ability to apply the engineering design process to produce solutions that meet specified needs with consideration for public health and safety, and global, cultural, social, environmental, economic, and other factors as appropriate to the discipline</td>
<td>• Perform analysis and synthesis</td>
</tr>
<tr>
<td>3. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions</td>
<td>• Generate multiple solutions</td>
</tr>
<tr>
<td>4. An ability to communicate effectively with a range of audiences</td>
<td>• Evaluate those solutions against requirements</td>
</tr>
<tr>
<td>5. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts</td>
<td>• Consider risks</td>
</tr>
<tr>
<td>6. An ability to recognize the ongoing need to acquire new knowledge, to choose appropriate learning strategies, and to apply this knowledge</td>
<td>• Make trade-offs to identify a high quality solution under the given circumstances</td>
</tr>
<tr>
<td>7. An ability to function effectively as a member or leader of a team that establishes goals, plans tasks, meets deadlines, and creates a collaborative and inclusive environment</td>
<td></td>
</tr>
</tbody>
</table>

Table 4


<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td>Analytic geometry; Calculus; Roots of equations; Vector analysis; Algebra and trigonometry; Complex numbers; Discrete mathematics; Differential equations; Linear algebra</td>
</tr>
<tr>
<td>Probability and Statistics</td>
<td>Measures of central tendencies and dispersions; Estimation for a single mean; Regression and curve fitting; Expected value in decision making; Hypothesis testing; Regression; Design of experiments</td>
</tr>
<tr>
<td>Ethics and Professional Practice</td>
<td>Codes of ethics; Professional liability; Licensure; Sustainability and sustainable design; Professional skills; Contracts and contract law</td>
</tr>
<tr>
<td>Computational Tools</td>
<td>Spreadsheet computations; Structured programming; Numerical methods and concepts; Simulators</td>
</tr>
<tr>
<td>Engineering Economics</td>
<td>Discounted cash flow; Cost analysis and estimation; Analyses; Uncertainty; Time value of money; Accounting; Depreciation and taxes; Capital budgeting; Project selection</td>
</tr>
</tbody>
</table>

**Research Objective 2.** The identified engineering design process models range from having as little as four steps to having as many as 24 steps and sub-steps. However, on average these identified models have between 6 and 7 steps. When examining the various process models, three different themes emerged in regards to their depiction or illustration. Models were illustrated as either a cyclical process, a flowchart of operations, or as a cloud of practices without providing an idealistic progression from one practice to the next. See Figure 1.
Figure 1. Styles of engineering design process models.

The most common depiction of the engineering design process was as a cyclical model with the providing entity describing the process as iterative and non-linear. However, upon reviewing the design portfolio templates provided in the curriculum, it seems as though the process may be implemented as a step-by-step linear procedure during instruction. Essentially, students are tasked with completing each “step” in sequence and therefore, potentially transforming the process from cyclical to linear as seen in Figure 2.

Figure 2. Implementation of cyclical design process.

The P-12 models share a lot of commonalities in regards to the “steps” provided. Essentially, the engineering design process models include defining a problem, generating ideas, gathering information, creating a solution, testing the solution, and refining the solution. However, one of the major differences between TEE and the engineering profession seems to be the emphasis on quantitative analysis, computation, and optimization. Wicklein (2006) and Wicklein and Thompson (2008) highlighted this difference when they compared the STL and post-secondary engineering practices to note a major difference between technology education design and engineering design in the practices of optimization, engineering analysis, and mathematical prediction. Therefore, the TEE engineering design process models are sometimes viewed as a trial-and-error design approach whereas students develop an idea, produce a prototype to test, and “fix” the prototype until a level of satisfaction is achieved (Grubbs & Strimel, 2015). Conversely, the engineering profession focuses on developing computational
models to make predictions of the effectiveness of a design prior to physically producing a prototype (Merrill et al., 2009).

**Research Objective 3.** Design cognition is typically studied using a concurrent think aloud protocol procedure. This procedure is used to collect a person’s behaviors and commentary on their own thoughts as they occur during a design activity (Kelley, Capobianco, & Kaluf, 2014). The resulting verbal commentary is then analyzed using verbal protocol analysis which applies a previously derived coding scheme consisting of a series of cognitive processes or design practices over a transcription of the verbal commentary or video of the participant performing the task (Purcell, Gero, Edwards, & McNeill, 1996). This coding procedure is used to determine quantities of time dedicated to the various processes or practices in an effort to describe how a participant thinks when completing a design activity. The authors have identified 16 different design cognition research studies targeting P-12 students between 1995 and 2016. Of these 16 studies, 8 different coding schemes were used to examine the participants’ design cognition. See Table 5. These coding schemes may provide another view of the practices of engineering design specifically with a cognitive science lens. Upon review of the origin of each coding scheme, the researchers have determined 3 different foundations for the processes/practices in each. The coding schemes were either derived from general models of a design process developed for curriculum, design process steps identified by studying practitioners’ work in design or practitioner oriented textbooks, or cognitive processes determined through cognitive science research. A thematic analysis of these schemes may be one approach to determining a more valid series of engineering design practices.

Out of the 16 design cognition studies, only one purposely focused on the development of an engineering design process model. Strimel (2014) studied students as they completed an engineering design task that included designing, making, and evaluating a physical solution to the given challenge. While the students completed the task, Strimel recorded students as they thought aloud and then later mapped out the different mental processes using Halfin’s (1973) coding scheme to determine the procedure that each student took to solve the challenge. From there, he compared each students’ procedure to the performance of their solution to determine certain practices that may aid in the development of a successful solution. These practices included planning/project management, detailed documentation, design analysis, proper tool/equipment selection, attending to quality, material experimentation, optimization, scientific investigations, and mathematical examination. In 2017, Strimel enacted the same study with post-secondary engineering students and identified three different procedures that students employed to solve the task. One approach is what he called an inquiry-based method where students did not design, they only tested currently available solutions to determine which one best solved the given problem. Another approach was a technological trial-and-error approach—students created a solution design and iteratively refined and tested it until they were satisfied or decided to give up. The last approach was what he viewed as
engineering design as it was a combination of both. The students created a design, set up a series of experiments to determine what materials or ideas worked best for their design, then revised their design before ever creating it.
Table 5

Design Cognition Research Coding Schemes

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Reading the Design Brief</td>
<td>Identify Need or Problem</td>
<td>Analyzing</td>
<td>Problem</td>
</tr>
<tr>
<td>Discussing Performance Criteria</td>
<td>Research Need or Problem</td>
<td>Communicating</td>
<td>Definition</td>
</tr>
<tr>
<td>Discussing Constrains</td>
<td>Develop Possible Solution</td>
<td>Creating</td>
<td>Generation</td>
</tr>
<tr>
<td>Generating Possible Solution</td>
<td>Possible Solution(s)</td>
<td>Defining</td>
<td>Generation</td>
</tr>
<tr>
<td>Sketching / Drawing a Possible Solution</td>
<td>Select Best Possible Solution(s)</td>
<td>Designing</td>
<td>Generating Ideas</td>
</tr>
<tr>
<td>Planning the Making of a Mock-up</td>
<td>Construct a Prototype</td>
<td>Experimenting</td>
<td>Modeling</td>
</tr>
<tr>
<td>Manipulating Materials</td>
<td>Test and Evaluate Solution(s)</td>
<td>Interpreting Data</td>
<td>Feasibility</td>
</tr>
<tr>
<td>Making a Mock-up</td>
<td>Communicate the Solution(s)</td>
<td>Managing</td>
<td>Analysis</td>
</tr>
<tr>
<td>Refining a Mock-up</td>
<td>Redesign</td>
<td>Measuring</td>
<td>Evaluation</td>
</tr>
<tr>
<td>Copying a Mock-up</td>
<td>Completion (leaves the cycle)</td>
<td>Predicting</td>
<td>Decision</td>
</tr>
<tr>
<td>Checking Available Resources and Materials</td>
<td></td>
<td>Visualizing</td>
<td>Communication</td>
</tr>
<tr>
<td>Abandon Current Solution Plan Making</td>
<td></td>
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<tr>
<td>Making a Prototype</td>
<td>Identifying a Problem with a Prototype</td>
<td></td>
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<tr>
<td>Modifying the Prototype</td>
<td>Evaluation of a Possible Solution</td>
<td></td>
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<tr>
<td>Evaluating of a Sketch or Drawing</td>
<td>Testing a Mock-up</td>
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<tr>
<td>Testing a Prototype</td>
<td>Evaluating a Mock-up</td>
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<tr>
<td>Evaluating Prototype</td>
<td>Recording Results from a Mock-up</td>
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<tr>
<td>Recording Results from a Prototype</td>
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</tbody>
</table>

Design | Formulation
Function | Synthesis
Analysis |
Behavior | Evaluation
Documentation |
Structure | Behavior |
Description | Refinement |
Type 1 | Refinement |
Type 2 | Refinement |
Type 3 | Refinement |
Discussion & Conclusion

This investigation was enacted to help further guide educators in creating effective learning experiences through engineering design activity and to provide a foundation for future research and development endeavors to better teach the fundamentals of engineering design. The findings should spark several questions in regards to teaching engineering design and the ways in which design cognition is studied. In today’s world, engineering design is an important feature in STEM education and as such, engineering design process models continue to be developed and used in classrooms. However, the models are often employed as a step-by-step procedure with little attention to the actual practices that support “good” design. Instead, the engineering design process models may serve as nothing more than a general problem solving process. The question is then whether or not students are provided with the abilities to perform a rigorous approach to design that includes analysis and optimization. Also, are the instructional models enhancing a student’s ability to design and be innovative or just maintaining a status quo. Therefore, it is recommended that an emphasis not be placed on developing the best engineering design process model but on diving deeper into the practices of design and engineering such as problem-scoping, brainstorming techniques, sketching, decision making, optimization, computational thinking, and mathematical prediction. These practices could then best serve students as tools in their engineering design toolbox rather than a step-by-step procedure to follow. Then, it would be recommended that secondary students are provided an open design portfolio rather than a prescriptive one to document their on-going process where they can later go back and highlight what best demonstrates their design competencies. Lastly, research should question how to best bridge design cognition research with TEE practice by exploring opportunities to examine the merit of instructional design models and to identify patterns in design thinking behavior that are outside of the norm. This research can then help to develop instructional strategies that push students beyond general problem solving.

References


Reeve, E. M. (2016). Are the engineering design processes used in engineering and technology education classrooms an accurate reflection of the practices used in industry and other technical fields?. Paper presented at the 103rd Annual Mississippi Valley Technology Teacher Education Conference, Rosemont, IL.


Talking with Avatars: The Potential and Impact of Design Dialogue with an On-Screen Avatar on the Development of Learner’s Design and Technology Project Work

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Abstract

This paper builds on research presented at the PATT 2016 conference that reported on the development of a dialogic framework that structured an on-screen conversation between a learner and a digital avatar acting as a surrogate mentor. The paper continues the story of the research, reporting on the findings of a major trial of the system, drawing on two data sets. The first is from the analysis of 732 on-screen conversations between learners and avatars, focusing on the ways in which learners responded to questions, including those that encouraged learners to speculate about the development of their design ideas. The second draws from an evaluation survey conducted with 118 learners after using the avatar application. Results reported include their choice of avatar, reactions to using it and the value it had for their design project work. The survey explored the ways in which the avatar helped learners reflect on their work, think about next steps and speculate on alternative approaches. Analysis of the on-screen conversations illustrate the impact on both design projects and the learners themselves including insights into ways that dialogic question frameworks can influence learners’ speculative, descriptive and reflective abilities, indicating potential for digital applications to support learning and teaching in this respect.

Keywords: dialogic question frameworks, onscreen avatars, project based learning,

Introduction

This paper reports on research that has supported the development of FormativeAssess – an Application (App) that can be used to assist project based learning. The data drawn from the use of the App in design and technology projects in 10 English secondary schools. The central
role of the App is to provide onscreen avatars that act as surrogate mentors providing a sounding board when the teacher is not available. The avatar engages in an onscreen, typed, dialogue, posing questions that encourage learners to review the current position in their project and nudge them to think about issues and ideas that will move their work forward. The first phase of the research, (Stables, Kimbell, Wheeler & Derrick, 2016) focused on the development of a pedagogic question framework to underpin the onscreen dialogue. This paper reports on the impact of the dialogue on the learners and their projects in a development trial.

The theories and practices underpinning the development of the pedagogic aspects are reported in Stables et al. (2016). In summary, the development is based on theories of the relationship between language and thought, for example Vygotsky (1962) who articulated the link between external language (speech) and internal language (thought), and Langer who expanded this theory, describing language as “our prime instrument of conceptual expression” (Langer, 1962, p.17) through which we express our thinking to the outside world and to ourselves. Putting these ideas into the context of designing draws on our own research through the Assessment of Performance in Design and Technology project that articulated the iterative relationship between thought and action when designing (Kimbell, Stables, Wheeler, Wozniak & Kelly al 1991), and Hamilton (2007) who highlighted the power of using hypothesis, powerful questioning and speculative language in dialogue. The approach to developing a ‘mentor’ avatar draws on research on design dialogue, for example through project tutorials (Goldschmidt, Hochman & Dafni, 2010; Ward, 2010) and the roles teachers take in such dialogue – questions that allow them to understand what a learner is doing and thinking (mindreading), that allow them to support development (mentoring and coaching) and that allow them to support students in planning next steps (managing) (Lawler, McTaminey, de Brett & Lord, 2012).

Data sources drawn on

This paper reports on insights gained from two sources – transcriptions of on-screen conversations (732 conversations) and an evaluation survey undertaken by a proportion of the participants after using the App (118 surveys). Both the survey and the conversations were conducted using devices that were available/ standard in each of the pilot schools. This was mainly workshop-based PCs or class sets of tablets, with occasional use of computer suites. The research project approach was developmental and ‘agile’ – both pedagogic and technological aspects influencing development whilst the research was underway.

The conversation transcripts followed a standard pattern, based on the question framework, reported in Stables et al., (2016). This framework was structured by a sequence of questions that asked learners to describe what they were designing, to give an evaluation of their progress to date, to speculate on how their project could be improved and to comment on their plans for next steps. The questions followed one of three branches: one focusing on making, one focussed on users and one focused on aesthetics. The questions were customised to the stage the learners identified their project to be: near the beginning, in the middle, close to the end. The framework also included what we refer to as ‘left field’ or ‘blue touchpaper’ questions that aim to unsettle learners and encourage them to think differently. Table 1 shows examples of questions from the three branches.
Table 1 Examples of question sequence.

The evaluation survey collected data on demographics, choice of avatar, reactions to using it, the value for their project work and potential for future uses.

**Relationship with avatar**

Early research used a rubber duck (initially real, then virtual) as the dialogue avatar but feedback indicated that learners would welcome a range to choose from. This resulted in the creation of four distinctly different avatars: a rubber duck, a person, a ‘Lego’ brick and a robot (Figure 1).
From both datasets, the rubber duck proved most popular overall. However, the actual use (in the transcripts) showed a gender difference, with boys putting the robot first, girls preferring the duck, with a noticeable split in the choice of the person (Chart 1).

**Figure 1 Avatars available**

**Chart 1: Choice of avatar, by gender**

Whichever avatar was chosen, we were keen to know if the conversation had a sense of reality – did the avatar respond well to questions, did it understand what the learner was designing? The response to both of these was positive (Charts 2&3) indicating that the avatar was a credible 'sounding board' for the majority.
**Impact on projects**

Having a believable avatar is one thing – but having a productive conversation was core to the research. As outlined above and illustrated in Table 1 the questions were structured to address how designs would ‘work’ (technical/making issues), how users’ needs and wants were being addressed and how people responded to a design's looks and feel – what emotions it provoked. From the evaluation survey, we found a relatively balanced picture with an overall positive message about the value of encouragement to think more about aspects of designing, with “making me think more about how my design would work” as the aspect providing the most support, (Chart 4).

**Chart 2: “Avatar understood what I was designing and making”**

**Chart 3: “Avatar responded well to my answers”**

**Chart 4 Support from the avatar for designing and making**
Transcripts of conversations allowed more detailed insight into this. One question that was asked both in the survey and at the end of the avatar conversation was whether using the App had changed their design. The evaluation survey indicated that the majority (70%) had not changed their idea. Linking this to the evidence shown in Chart 4 indicates that the dialogue was developmental, not disruptive. The transcripts showed that exactly 50% said that their idea had changed in some way. They also showed variations in relation to gender, the question route followed and the stage they were at with their project (Charts 5, 6 & 7).

**Chart 5: Gender difference in the App changing ideas**

**Chart 6: Question route differences in the App changing ideas**
Chart 7: Project stage differences in the App changing ideas

This further detail indicates that girls, those following the ‘user’ route and, somewhat surprisingly, learners near the end of their project were most likely to change. Further investigation into this latter group showed changes varying from active decisions on specific improvements

*The shape and the thickness of the screen and I will improve these things* (Transcript 022)

to more reflective comments on overall approach

*It has made me reflect more and realise that even though I know what I did wrong, I need to focus more on getting things right again, planning my mindset before I approach a project.* (Transcript 565)

Detailed analysis showed that the question itself was interpreted differently. The wording of the question “Has answering these questions changed your ideas and, if so, how?” resulted in some learners, seeing change as relating to their overall project focus, some seeing it as being a change in their way of working or thinking and some interpreting it more literally as a physical change in their design.
Chart 8: The nature of changes in ideas

The most common reason given was that the avatar had made them think more deeply about their designing:

*These questions have made me think more about how to present and design my idea. They have also helped me think about researching it. They did this by asking important questions* (Transcript 339)

*It has made me question myself about my product and it has given me more to think about which has given me more ideas.* (Transcript 931)

This was followed by those who could see ways of changing or improving their idea.

*Yes because it has made me realise just how much I can improve my work* (Transcript 495)

*I feel as if answering these questions have slightly changed my opinion that I have upon my product. All these questions have really made me think if my product is up to the best of my ability, and if it is not, what I could possibly do to improve my product further.* (Transcript 839)

Next were those who said the conversation had provoked new, more innovative or more imaginative ideas or ways of working.
Yes as it opened my eyes to see the innovative way of designing. (Transcript 309)

yes, its make me think outside the box and about the possible things I could design (Transcript 093)

I think answering questions myself about my own product, has allowed me to understand the issues with my product, my ideas are to improve the factors of my torch that need it, however I have come up with new ways to solve problems with my torch, such as the circular LED placement etc. (Transcript 726)

I didn’t think of scratch and sniff before (Transcript 735)

There were also those who said their ideas hadn’t changed, but the App had been constructive, helping them to reflect on their work.

These questions have not changed my ideas for my design, however, they have made me consider the processes I will perform more, so I can make them as efficient as possible. (Transcript 897)

They haven’t changed my ideas but they have made me think about my choices (Transcript 208)

Some responses were unexpected, such as learners who found the process helped them see their ideas more clearly, including visualising their ideas more clearly in their heads.

Yes because it makes me rethink about my product and whether it would be possible to make the finished product the way I am imagining the finished product in my head (Transcript 528)

Answering these questions has helped me to think out how and what I am going to do with product to improve and it has allowed me to visualize it more in my mind (Transcript 343)

This latter example comes from a transcript where the growth of the idea through the dialogue is tangible. In response to the initial “what are your designing” question the response is “I am modifying a garlic crusher”. When the question “how will your ideas please people” the learner adds in that the handle will be more comfortable. When pushed further with “how can you make your ideas more attractive and enjoyable” the learner shifts to using sustainable materials as people are becoming more aware of the environment. Following the 1-4 Sensational to Lukewarm question, the learner turns to advertising the product in a sensational way to make users happy to buy the garlic crusher. Asked what will be unique or special, the idea has expanded again to include a self-cleaning system to get rid of the garlic residue. What is evident is that the learner has been designing in her head whilst responding to the avatar’s questions.
The use of language for mind reading, mentoring and managing

Early stages of the research (Stables et al., 2016) indicated the value of using question language that encourages learners to be descriptive (e.g. questions starting with ‘What is …’ or ‘Why do …’) and language that encourages learners to be speculative (e.g. ‘What might be …’ or ‘What could you …’). This development sprang from us exploring different roles that teachers take in conversation (Lawler et al., 2012) such as mind reading to understand what learners are doing, mentoring to encourage creative thinking and managing to help plan next steps. Descriptive language is useful for mind reading and managing, whilst speculative language is useful for mentoring. As a surrogate mentor, the avatar needed to use these different forms. In the very early phases, we realised that the language we were building into the question framework was almost exclusively descriptive and consequently the conversations were less successful in moving learners forward. The framework used in the trial reported here made more explicit and strategic use of both descriptive and speculative language. This resulted in relatively clear snapshots of the nature of learners’ projects through the initial questions and descriptive responses towards the end as they outlined their plans for next steps. In the mid section three specific strategies were used to encourage learners to think more creatively about their project.

The first strategy was using speculative language. Learners often picked up on the word in the question stem, such as

**Question:** How could redesign to reduce the number of parts and processes?

**Answer:** I could change the materials used to be cheaper to make and maybe more elegant. Also I could merge the parts into one bit to make the design process easier and faster.

The 1-4 valuing questions were followed by a speculative question which frequently helped learners move forward. In the following example learner is designing a bedside table, which she rates as ‘3’ on a lukewarm – sensational continuum.

**Question:** What could you do to make people feel more delighted about your ideas?

**Answer:** I could make it look cooler and more personal to the user.

**Question:** Is there anything you now need to know or find out about?

**Answer:** I need to do more research on my materials and what the user might want it to look like

**Question:** What’s going to be unique or special about interacting with your ideas?

**Answer:** Its more personal for the user as I have taken colours and materials they like into consideration in my designs so that my end product will suit the aesthetics of the room

**Question:** Has answering these questions changed your ideas and if so, how?
Answer: It has helped me think about my designs more, more about different features sizes and materials. (Transcript 756)

The riskiest strategy was the use of ‘left field’ questions. For example, one question asked “What if it was made from custard?” receiving mixed responses, for example

a laser can’t print custard the custard is a liquid so it cannot be cut
.........!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!! (Transcript 861)

If it was made from custard the product would fail as the custard would seep into the electronics of the speaker and break it. (Transcript 481)

The custard would have to be poured into a mould and solidified in one piece for it to work, but it could be possible I guess. (Transcript 198)

In this latter example, the response to the follow up question ‘Is there anything you need to know or find out about?’ was “Whether custard can solidify and be strong, and if other materials will work/be popular for a desk tidy” and in response to the question about anything having changed “It has made me consider what other materials would work for my design, and what I could to strengthen some.”

A more developed response came to the question “What would Vivienne Westwood or Philippe Starck do with your ideas?” The learner was designing a casing for speakers, linked thematically to a favourite show. At the outset of the questions she describes it as aesthetically pleasing, without providing more detail. When pushed by the question ‘Which senses and emotions will your ideas stimulate?’ she suggests they should create a scary atmosphere. The avatar then asks “What would Vivienne Westwood or Philippe Starck do with your ideas?”. The conversation continues as follows

Answer: She would maybe tell me to consider using different fabrics and materials because her work consists of unusual out of the box ideas with a mixture of textiles incorporated together.

Question: What could you do to make people feel more delighted about your ideas?

Answer: I could explain the thoughts behind my idea and show why its unique. I can explain how the texture, materials and even the colours I use are different to normal speaker casings.

Question: Is there anything you now need to know or find out more about?

Answer: Yes, I think I might want to look more into the different materials I could use to improve my design. This can completely change the textures and colours. I hope this can make it more unique like how Vivienne’s designs are.

Question: Other than the Internet, where could you go to get this information?
Answer: I could go to museums, fashion shows, game stores or look in books to find different ideas.

Question: What are you planning to do by the end of this lesson?

Answer: Research different aspects that I can improve my design with. This is mostly on using different colours, materials, structures and textiles.

Question: What's going to be unique or special about interacting with your ideas?

Answer: It is more personalised and innovative to what you would find in a store. It is more unique in terms of the theme of the casing.

Question: Has answering these questions changed your ideas and if so how?

Answer: Yes, it has made me think more about what I can do to make the design more pleasing to the buyer. It has made me consider more than just how it looks, but how it feels and what feelings it stimulates. It has also made clear that my design may require some more research to get it to the best it can be. (Transcript 512)

Next steps for the avatars

Analysis is still underway, but evidence suggests that having a private conversation with an onscreen avatar can be useful in a range of ways. While a small number of learners used the avatar on several occasions, the majority used it just once, when prompted by their teacher. This allowed for both technological and pedagogic development and has provided considerable insight into how dialogic question frameworks can be constructed and the potential of these being screen based. But questions still remain about longer term pedagogic value. What would be the outcomes of using the App throughout a design project? Would learners build a relationship with their avatar? Would they tire of the questions asked? Could it become a stimulus for reflection and speculation that would translate into metacognitive development of design capability in learners? The next step for the research will involve reviewing and developing the questions and using the App in case studies of full projects. Watch this space.

References


Abstract
The type of assessment implemented within an educational course has profound effects on the nature and depth of learning that students engage in. Typically there are two core types discussed within the pertinent literature. These are criterion and norm referenced assessment. The nature and impact of these modes of assessment have been explored within a variety of learning contexts. However, another and often overlooked form of assessment is ipsative enquiry. This refers to the comparison, by the student, of current performance to previous performance within a course of learning.

Ipsative assessment has been shown to increase motivational effects among students and promotes inclusivity in the learning process. Despite the potential benefits, its role in technology education contexts is under researched. This paper gives an overview of an ipsative approach to assessment that serves two functions. Firstly, to facilitate an opportunity for each student to develop a personal construct of what it means to be capable and secondly to provide a capacity to track their level of competence based gain both normatively and ipsatively.

The study tracks the performance of a cohort of student teachers (N = 128) in a core graphics module during a year three semester of an Initial Technology Teacher Education (ITTE) programme. Four consecutive graphical design tasks, focusing on the application of graphical principles, were designed to elicit core graphical skills and knowledge. An adaptive comparative judgment method (see Pollitt (2012) and Kimbell (2012)) was employed by the students to rank the responses to each task.

The paper highlights the potential of this approach in developing students’ epistemological understanding of graphical and technological education, while tracking competence based gain through ipsative enquiry within the collective performance of their peers. Significantly, this approach demonstrates the capacity to track performance over time. The paper concludes with a discussion around the benefits of utilising ipsative assessment in design and technology education.

Keywords: Ipsative assessment, Personal constructs, Design education.
Introduction
This paper looks specifically at the need to synthesise perspectives on assessment as learning that enhance the depth of comprehension and development of Initial Technology Teacher Education (ITTE) students with respect to their discipline expertise. With the focus on discipline competency, there is a rationale and justification for enhancing feedback as defined by Nicol (2007) and its relationship with the expectations of higher education students as postulated by Sadler (2009).

The work of Nicol (2007) supports the view of actively engaging students in the assessment process through engagement with feedback. Nicol (2007) outlines the importance of active participation that supports engaging with diverse views on evidence of learning and the benefit of evaluating and rehearsing internalised knowledge and understandings when reviewing and preparing feedback. The responsibility is placed on the learner to comprehend the qualities and standards associated with expected performance. This enables a self-regulatory capacity that is critical to developing teacher expertise. Together with the benefits of engaging with feedback and formative assessment, students must become inducted into the assessment practices (Sadler, 2009). Sadler (2009) argues that the development of a conceptualisation of quality is critical to consistency in high achievement. Building on the work of Sadler (2009), this study was cognisant that the prescribed task design was meaningful and pre-planned to support students in evaluating the quality of evidence created, building appraisal skills, relating directly to learning experiences, and learning how to make judgments about the quality of emerging and finished works holistically rather than analytically.

Assessment as Learning
Without oversimplifying views on learning as either passive or constructed, what is important is that there is a shared view between the learner and the teacher. Agreeing to view learning as being constructed affirms not only the importance of the nature of feedback but also the way that it is received. Hughes (2011) highlights that teaching staff claim to give good feedback and yet students disagree. Involving the learner in creating feedback as much as they engage in constructing knowledge can satisfy the alignment of this action. Nicol and Macfarlane-Dick’s (2006) seven principles of effective feedback support this participatory view of learner involvement. The function of assessment is multi-faceted and as such the discourse around defining the functions of assessment in response to a targeted agenda become critical. Assessment as a diagnostic tool supports direct and meaningful feedback in a way that is a pedagogical feed-forward. Within the scope of this paper, a macro view of assessment is adopted in an attempt to push the boundaries of implementations and interpretations so as to actively include the learner in the process of assessment (Sadler, 2009; Black & William, 1998; Yorke, 2003; Orsmond et al. 2000). This focus is critical within design and technology as the disposition of enquiry is central to developing capability. The value of assessment ‘as’ learning is not argued but there is a challenge in implementing an engaging and sustainable model that encourages self and peer appraisal as a self-regulatory act.

Adaptive Comparative Judgement (ACJ)
Boud and Falchikov (2007) identify a fundamental problem with the dominant discourse in assessment being the positioning of the learners as passive subjects to be measured or classified by the assessment acts of others. Seeing the learner as a ‘passive subject’ does not subscribe to the philosophy of design education. Within the context of design and technology education a participatory notion aligns well with a discipline area governed by
the synthesis of critical and speculative characteristics.

Kimbell et al. (1991) believe that due to the complex and integrated nature of design based activities, a model of holistic assessment that takes account of learning processes and interactions is the most effective in assessing the overall capability of students. Holistic assessment (as made possible by the ACJ pairs engine - see Kimbell 2012, Pollitt, 2012) is the judgement of value of ‘the whole’ rather than the sum of a set of individual components of a task or assessment. The system has three elements; a set of portfolios of work from the students that is a response to the assessment task, a community of judges, and a ‘pairs engine’ – a software solution that dynamically selects pairs of portfolios and presents them to judges for adjudication on the quality of the work. As judges make decisions on pieces of evidence, the process begins with a rough sorting mechanism to establish broad categories of quality and evolves into an adaptive system that refines the position of the work on a rank order of capability as collectively determined by the group of judges.

The binary decision required when making pairwise comparison allows judgements to be made on an unarticulated recognition of qualities. This is an important feature of this study. It is the immediate and unqualified appraisal that requires the students to internalise their position, with direct reference to their submitted work and its comparison to the work of peers.

The flexibility in the ACJ approach requires that the judge call on a hazy, yet emerging ‘construct of capability’ to make a value judgement rather than being bound by fixed and predetermined criteria (Hager & Butler, 1996). For a novice (learner), the judging process forces the learner to build a conception of what it means to be capable and this can be achieved (at least in part) by exposure to exemplars and the breadth of interpretations and submissions. These qualities must be internally processed by the judge, based on personally set (externally influenced) criteria and standards.

The comparative judgment approach (ACJ) presents a mechanism to support the tracking of a learners performance gain over a series of tasks/activities and has a number of significant advantages when considered within a series of learning tasks:

- It allows the tracking of performance over time
- Can directly compare performance to the norm (for reference)
- Requires active participation
- Supports the development of appraisal skills
- Links appraisal to defining capability
- Directly links feedback with learning task

While ACJ has been applied in several contexts and empirical benefits have included enhanced participation among students, it has not been applied to observe an individual’s personal gain over time. As such, there is a need to explore its implementation within education from a perspective of Ipsative enquiry.

**Ipsative Development**

The important characteristic of ipsative assessment is that it focuses on a learner’s performance relative to a previous individual performance. This concept of reference to the self makes explicit the learners progress. This form of feedback qualifies the development over time in response to a target or goal. In practice, the learners’ performance in an initial
task is then compared to a subsequent task in a sequential process of feedback and action. Developmental tasks can be intermediate and also examined through an Ipsative perspective. The benefits of an ipsative approach are multifaceted. From a learner perspective there is a motivational value in clearly seeing progress and development relative to a previous achievement or understanding (Hughes, 2011). From a teacher’s perspective, it illustrates a macro view of performance over time and allows a diagnostic scheme to structure learning with defined expectations and/or pathways for individual learners.

By its nature, ipsative assessment supports a cumulative understanding of performance developed over sequential tasks and activities. Tasks that support ipsative assessment tend to be designed to reflect governing principles and a macro view of capability, therefore allowing the learner to compare performances, while honing associated attitudes, skills and knowledge. Ultimately the approach supports a formative agenda that is largely self-regulated (Hughes et al., 2014). The constructivist view of learning further supports an ipsative approach that facilitates the unmediated feedback that compares performance to previous performance utilising a “feed-up” lens on the part of the students (Hughes, 2011). Here students are facilitated in reflecting on their own personal goals in reference to their cumulative performance to date.

Ipsative assessment also facilitates an effective synthesis of feedback and feedforward processes (Hughes, 2011). It increases the likelihood of the learner acting on feedback, as it is personally relevant and benchmarked with previous performance. However, the capacity of the individual to unpack performance deficits may be outside the capacity of a novice learner, especially if there is no reference to expected progress either absolute or normative. Therefore, the ipsative agenda must be critically managed and articulated. As outlined by Hughes (2011) one of the challenges with ipsative assessment is in operationalising it. The requirement to design and implement a sequence of learning tasks or activities can be difficult within a modularised and semester based system, usually constrained by 13 weeks of teaching. Additionally, providing feedback that is timely, relevant and bespoke to each learner on all tasks is impractical and further inhibits its implementation.

Method
Approach
The method was designed to explore students’ development over time by synthesising feedback and appraisal through an Ipsative model for assessment as learning. The study employed four tasks over a 12 week semester, all equispaced to observe students’ gain over time. Students responded to similar design tasks and then using the ACJ method produced a rank order of performance and generated peer feedback on the quality of the work observed. Although there is significant qualitative data that supports the value of an ipsative approach, the focus of this paper was to initially explore a quantifiable variance (if one existed) in performance, as a precursor to exploring the evidence from a qualitative perspective.

Participants
The study engaged Year 3 ITTE students (N = 136). Natural attrition accounted for 8 students and therefore the final study cohort consisted of 128 students. The cohort was divided into quartiles (n = 32) based on performance on the first task to support the statistical analysis of the data by providing an initial baseline of performance for which subsequent tasks can be compared to from an ipsative perspective.
Design
The four design tasks were governed by core graphical design principles (graphical communication, innovation, stages of design, and functions of design), common to all tasks and the conceptual design agenda mirrored the nature of the tasks used for the national assessment in the participants subject discipline of Design and Communication Graphics (DES, 2007). This allowed for comparison with respect to overarching skills and competencies.

Implementation
Following instruction on core descriptive geometry, students were given a design task and two weeks to complete. The design task was an opportunity to apply the newly acquired knowledge to resolve a design problem. Following submission, students used the ACJ engine to complete a pair-wise comparison of peer submissions. This immediately exposed students to the work of their peers and as such saw a breadth of interpretation and solutions. On average, students made 17 comparisons of work during the ACJ assessment activity. This activity was immediately followed by the next design task and this approach was repeated for the final tasks. For all assignments the rank to grade conversion was validated by the module leaders as an independent task to ensure validity of performance.

Findings
The peer assessment of each of the four assignments recorded interrater reliability scores of 0.974, 0.973, 0.965 and 0.971 respectively. This demonstrated that there was a shared understanding of what was of value when appraising the evidence from each of the tasks.

The mean score for Assignment 1 (54.93%) compared to Assignment 4 (76.56%) illustrate an increase in performance over the course of study. Although this is welcome, it is important to consider how this incremental improvement manifested with varying ability levels. To explore the relationship between the performances in each of the four tasks across the quartiles, a multivariable analysis of variance (MANOVA) was employed using the assignment as independent variables and the quartiles as dependant variables. The results indicated a statistically significant difference in assignment scores based on quartiles, F (12, 320.427) = 21.362, p < .000; Wilk’s \( \lambda \) = .211, partial \( \eta^2 \) = .405. To determine how the dependant variables (quartiles) differ for the independent variable (assignment performance), Tukey’s Post Hoc test was used. Figure 1 illustrates the consistent statically significant difference that existed between assignments 1 and 2 (with the exception of quartile 3) and between 3 and 4, with no difference in performance between assignment 2 and 3 recorded for all baseline quartiles. Although the design of the assignments in principle and the associated transposition of the rank to grade were constant, task design could account for the differences between assignments. However, the pattern was reflected in all quartiles.
Figure 1. Tukey's HSD post hoc test results
The tracked improvement for the quartile 1 group shows a gain of 40% between assignment 1 and 4. While quartile 4 decreased by 1% over the same tasks. It is important to note that for quartile 4, the initial mean score of 81.14% meant there was limited capacity to increase relative to the other quartiles. From Figure 1 the comparison within groups (Horizontal) demonstrates an ultimate gain for quartiles one, two and three. While quartile 4 saw a decrease in mean score, it is posited that this may still represent development as relative to Assignment 1, Assignment 4 would have had inherently higher expectations. The comparison between groups (Vertical) also suggests that the gain for all performance levels was also relatively constant.

From an ipsative perspective, what is interesting is that from the baseline definition of quartiles, how much variance occurred by definition of quartiles as the module progressed – i.e. did students move in to other quartiles? To examine this, the quartiles determine from Assignment 1 were compared with quartiles derived from the results of Assignment 4. The results of this are presented in Table 1. Further analysis is required to examine the statistical significance of the movement however it is interesting from the overview to see the scope of the movement. Of particular interest is Q1 which saw substantial movement to Q2 and Q3 however only one student ultimately moved to Q4. A similar trend is seen in reverse for Q4 whereby most movement is into Q2 and Q3 with only three students ending in Q1.

Table 1. Student movement between quartiles

<table>
<thead>
<tr>
<th>Initial Quartile</th>
<th>Q1</th>
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<td>Q4</td>
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Discussion

Reflecting much of the literature on ACJ (Kimbell, 2012; Seery & Canty, 2017; Seery et al., 2012) the data here once again demonstrated the value of the ACJ strategy as a powerful means of establishing what is of value as determined by a community. In this study, the high level of consensus consistently across the four tasks demonstrated the capacity of the community to agree on qualities and standards in an unarticulated way. The alignment of the high interrater reliability scores with the increasing performance across the tasks also highlights the incremental development of the students as a cohort on the sequence of assignments.

Synthesising the creation of evidence with its appraisal engaged students in a double looped system of reflection in action. Not only were students critiquing their own work relative to the breadth of work presented by their peers, they were also engaged in the ‘first principles’ critique that considered the purpose of the design task with respect to core competency development. The identification of qualities that aligned with capability could be observed during the judging process. As students were engaged with the recurring evidence as presented by their peers, it is posited that they developed a better capacity to discriminate standards. This hypothesis is supported by the increase in performance between Assignment 1 and Assignment 4 for the entire cohort. This engagement is often only visible
to a grader at a summative stage of the process.

Two significant elements of this approach are noteworthy. Firstly, students by virtue of their ranked position got a normative indication of their performance relative to the entire cohort. Additionally, there was an immediate context for this performance as students appraised a number of their peers work. The immediate feedback was therefore both situational and contextual. Secondly, the focus on appraisal (which possibly also became more sophisticated over the four tasks) engaged students in determining the critical aspects of capability and formed a dialogic creation of individual constructs of capability. This discussion with self was mediated by authentic evidence that exemplified varying qualities and standards. The exposure to peer work was immediate and unqualified, requiring that each student critiqued evidence as the basis of constructing or refining his or her own construct of capability. In essence this unmediated feedback acted as an explicit feed-forward.

Interestingly, the impact of the process was variable across the cohort. Students who initially performed poorly (bottom quartile) showed a significant gain over the course of the four assignments. This is also evident by their movement into higher quartiles by the end of the semester. The middle quartiles (Q2 and Q3) had a more general dispersal however still saw an overall increase in performance. Q4, while initially the top quartile, was the only group to see a ultimate decrease in performance. Many students also ended up in lower quartiles. It is posited that this is a result of having less capacity for improvement and therefore this group may have required a different education experience which offered more of a challenge than the other groups.

Conclusion
The study presents evidence of a performance gain that was both ipsative and normative. The unmediated feedback formed by the exposure and appraisal of peers work supported a reference for ipsative development. The identification of qualities and standards provided explicit exemplars as targets. The capacity to interpret unmediated evidence of capability and discriminate between qualities and standards although beneficial may have proven more difficult for the less able students and as a resulted limited their capacity to perform in the upper quadrants of performance. Although, beyond the scope of this paper further research is required to explore the individual level ipsative gain and unpack the associated qualitative data.

References


