Student Self-Perceptions of Design and Creative Thinking (Fundamental)

Mr. Andrew Jackson, Purdue University, West Lafayette

Andrew Jackson is currently pursuing a PhD in Technology through Purdue's Polytechnic Institute. His previous middle school teaching experience informs his role as a graduate teaching assistant for TECH 120, an introductory course in design thinking. He recently completed his Master of Science in Technology Leadership and Innovation from Purdue University with a thesis investigating middle school engineering self-efficacy beliefs. His research interests are engineering self-efficacy, creativity, and decision making.

Prof. Nathan Mentzer, Purdue University, West Lafayette

Nathan Mentzer is an assistant professor in the College of Technology with a joint appointment in the College of Education at Purdue University. Hired as a part of the strategic P12 STEM initiative, he prepares Engineering/Technology candidates for teacher licensure. Dr. Mentzer's educational efforts in pedagogical content knowledge are guided by a research theme centered in student learning of engineering design thinking on the secondary level. Nathan was a former middle and high school technology educator in Montana prior to pursuing a doctoral degree. He was a National Center for Engineering and Technology Education (NCETE) Fellow at Utah State University while pursuing a Ph.D. in Curriculum and Instruction. After graduation he completed a one year appointment with the Center as a postdoctoral researcher.

Dr. Dawn Laux

Dawn Laux is a Clinical Assistant Professor in the Department of Computer and Information Technology (CIT) at Purdue University. She has been with the University since 2007 and is responsible for teaching database fundamentals courses and introductory technology courses. Laux has 10 years of industrial experience in the information technology field, and her research area of interest includes technology readiness, the social impacts of technology, and increasing interest in the field of computing.

Dr. David Sears

David A. Sears is an assistant professor in the Department of Educational Studies at Purdue University. He holds a B.A. in Psychology from Reed College and a Ph.D. in Educational Psychology from Stanford University. His research examines instructional practices for promoting learning and transfer in individual and group contexts with a focus on the STEM disciplines.

Dr. Paul Asunda, Purdue University

Student self-perceptions of design and creative thinking

Abstract

Background: Design is an essential part of engineering for promoting critical thinking and creativity. Despite the demand for creativity, education programs have even been criticized for not focusing enough on creativity and even sometimes eroding it. Patterns of diminishing interest in engineering throughout secondary education suggest that further work needs to be done to understand the impact design activities might have on student attitudes. This is important even as young as middle school when students are forming self-perceptual beliefs and career interest.

Purpose/Hypothesis: The purpose of this correlational study was to examine middle school student design thinking and creative thinking changes following engagement in an engineering design curriculum. Student self-efficacy, "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" is a necessary prerequisite for action and persistence. We hypothesized that design thinking and creative thinking self-efficacy would be related and increase following the curriculum.

Design/Method: An online pre-test and post-test were administered to middle school students at the beginning and end of a 16-week course on technological literacy in a STEM context. The instrument included nine questions evaluating student engineering design self-efficacy and 12 questions evaluating student creative thinking self-efficacy. Pearson's correlation scores were used to describe the relationship between design thinking and creative thinking self-efficacy. Paired and independent *t* tests were used to evaluate gains in both measures.

Results: Students had highly related levels of design thinking and creative thinking self-efficacy before and after the curriculum, $r(1176) = .777$, $p < .001$ and $r(465) = .843$, $p < .001$ respectively. Analysis of paired responses demonstrated significant gains in both forms of self-efficacy, $M = 1.32$, $t(133) = 7.60$, $p < .001$ and $M = 0.79$, $t(124) = 4.19$, $p < .001$. Because a limited number of responses could be paired, subsequent independent sample *t* tests were performed which supported claims of an increase in design thinking and creative thinking self-efficacy beliefs and could utilize a greater sample size.

Conclusions: The present study provides empirical evidence for an alignment between design and creativity. Results of the study also indicate that design experiences can positively impact self-efficacy beliefs for design and creative thinking. Due to the overlap of these two constructs, strategies encouraging self-efficacy in design and creative thinking may be transferrable. The concurrent increase of creative thinking confidence following participation in a design curriculum also increases the pedagogical value of design.

Introduction

Design is an essential practice in engineering for promoting creativity and critical thinking. Bucciarelli[1] described the process as one where "different individuals, each with different ways of seeing the object of design…must work together to create, imagine, conjecture, propose, deduce, analyzed, test and develop a new product" (p. 9). By nature of the negotiation and unique lens of each individual, the design process produces many outcomes for each context [2]. Plattner, Meinel, and Leifer[3] described the goal of design challenges as producing innovations; this is certainly a goal of design in industry. Precursory to student careers, design experiences in education can be preparatory for the workplace and cultivate attitudes of innovation [4].

Despite the demand for creativity and innovation, education programs have sometimes been criticized for not focusing enough on these and sometimes even stifling student growth in creativity [5]. Patterns of diminishing interest in engineering through secondary education suggest that further work needs to be done to understand student motivations and persistence [6, 7].

This study focused on student self-efficacy beliefs, which undergird effort, motivation, and other choices and behavior [8]. Prior work has often focused on achievement in engineering and creative tasks rather than student self-perceptions or confidence with the tasks [9]. However, in order to help students, teachers must not only help students succeed in the tasks given, but also recognize their own growth; students who recognize their increasing success will "raise their perceived efficacy more than those who succeed but see their performance leveling off" [10] or who do not recognize it at all.

More specifically, our correlational study describes concurrent change in two domains of self-efficacy—engineering design self-efficacy and creative thinking self-efficacy—among middle-school technology and engineering education students. We present an argument for the importance of examining student self-efficacy beliefs and describe the methods undertaken in the study. We share our findings which include a strong relationship between engineering design self-efficacy and creative thinking self-efficacy and growth in both types of self-efficacy among students; this study provides empirical evidence for an alignment between design and creative thinking confidence.

Calls for Design and Creativity

Recent emphases by organizations in technology and engineering education have called for the development of creativity, innovation, critical thinking, and problem-solving skills in students. (Collectively these skills have been termed 21st Century Skills for their requisite nature for success in the current workplace [11].) Two such organizations are ABET and the International Technology and Engineering Educators Association (ITEEA). ABET criteria include specifications for specific areas within engineering including the incorporation of engineering design activities. The curriculum is required to cultivate critical thinking and creative skills through design activities related to student areas of study that leads these ideas to creative application that facilitates critical thinking [12]. These standards are a pattern for engineering in higher education. ITEEA provides guidance for secondary technology and engineering educators, although their influence is broader. Several standards for technological literacy (STL) provide direction on curriculum development, including ITEEA's secondary education program Education byDesign:

> STL # 9: Students will develop an understanding of engineering design.
> STL # 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.
> STL # 11: Students will develop the abilities to apply the design process. [13]

Engineering design is a process that "demands critical thinking, the application of technical knowledge, [and] creativity" ITEEA and Technology for All Americans Project, [13].

One of the stated goals of STEM education is to develop 21st Century Skills [14]. To our advantage, design represents a powerful context for supporting the development of these skills. For example, design is a "profoundly creative" process [13] and having a process to guide students through problem-solving (engineering design process) can empower students to solve even complex problems [5]. Because of uncertainty related to the types of problems engineers will need to be able to solve, the need for generalizable 21st Century Skills is even more forceful [15].

Retention in Engineering Education

"An increasing number of writers in education and the general media are beginning to comment on the need for creativity and designerly experiences in [K-12] general education curriculum" [5]. The structure of engineering design education greatly increases the likelihood of students developing critical skills. For example, Dym, Agogino, Eris, Frey, and Leifer[16] argued that design activities extend transfer knowledge which then reinforces 21st Century Competencies [11]. Unfortunately these benefits of design are often unrealized due to attrition of engineering students. Retention of undergraduate engineering students is only between 30 to 46% for female students, and 39 to 61% for male students [17] and keeping students who leave would increase the number of students graduating in the field by up to 40% [15]. This trend extends to students in high school science, technology, engineering and mathematics (STEM) programs: "Nearly 28% of high school freshman declare interest in a STEM-related field….Of these students, over 57% will lose interest in STEM by the time they graduate from high school" [6]. Miaoulis[19] argued that interest in engineering and science begins to drop off in middle school, therefore the curriculum needs to be reinforced to help students succeed in real-world problems and maintain student interest and enrollment. To address even more nascent student beliefs, Engineering is Elementary, a curriculum targeting students in middle school and even younger, has pointed to evidence that (a) people choosing careers in engineering and science gain interest as early as elementary school, (b) interest in science tends to decline after elementary school, and (c) engaging students with this material at an early age can help them consider engineering and science as a future career, which would not have happened otherwise [20].

If we are to assist students in developing 21st Century Skills through technology and engineering education, these shortcomings need to be addressed. Student beliefs in their abilities to think critically, problem solve, and be creative need to be reinforced early in education programs; many researchers have tied lack of retention to poor self-efficacy [17]. The initial junctures where students are exposed to technology and engineering content are important for fostering desire to persist in the field.

Self-Efficacy

It has been demonstrated that an individual's beliefs are important in considering their behavior, interest and motivation. Bandura[10] introduced the concept of self-efficacy as a "conviction that one can successfully execute the behavior required to produce the outcomes" (p. 193). Self-efficacy beliefs are centered in capability to carry out the actions rather than the forthcoming results of a given action; self-efficacy beliefs then, are antecedent to behavior or outcome expectations and can affect performance as well as "whether they will even try to cope with given situations" [10, 21]. Self-efficacy is necessary for entry and persistence in engineering; students transferring away have expressed poor confidence in their abilities despite any evidence supplied by their actual achievement [22]. This demonstrates that persistence can hinge on self-beliefs rather than academic success alone. While low self-efficacy can contribute to student decisions to leave engineering, self-efficacy beliefs have conversely been shown to be positively and significantly related to commitment to engineering in high school students [23]. Understanding the nature of self-perceptual beliefs can inform instructional design in order to promote student self-efficacy. We can examine sources for self-efficacy and its interplay with design education in order to augment this understanding.

Sources of self-efficacy

Bandura's [10] original presentation of self-efficacy identified four information sources that contribute to the self-efficacy beliefs of individuals: (a) enactive mastery experience, (b) vicarious experience, (c) social persuasion, and (d) physiological and affective states. Various researchers have since provided evidence that establish these sources [10, 21, 24-26]. It is important to note from these studies that information related to each source of self-efficacy may be positive or negatively influential for student self-efficacy. Mastery experience will likely instill confidence in a student attempting future tasks; however, a negative history of success will lessen expectations of being able to achieve the task. Examples with modeling by other students, verbal cues, and physiological states that would support student confidence or weaken confidence can all be imagined.

Self-efficacy and design

Many of the skills called upon during design have been empirically related to self-efficacy: problem-solving[27, 28], creativity[29, 30], critical thinking[31], and teamwork [32] are all benefitted by high self-efficacy, among others. The Committee on Defining Deeper Learning and 21st Century Skills [11] briefly described the positive benefits of focusing on student self-efficacy in curriculum: "curricula should integrate development of the intrapersonal skills of metacognition, self-efficacy, and positive attitudes toward learning that have been shown to enhance deeper learning in the cognitive domain" (p. 186). Additionally however, self-efficacy has considerable ramifications for student interest, engagement, motivation, and other behaviors. Within an educational setting these remain important goals for instruction. Self-efficacy may be a variable within the reach of instructional design that holds significant potential for changing students [10, 33]. Self-efficacy is a malleable trait that can be influenced.

Methods

Comprehending the belief that self-efficacy beliefs are dynamic, this research study sought to examine middle-school student self-efficacy related to engineering design. Based on the previously discussed sources of self-efficacy we hypothesized that exposure to an engineering design curriculum would affect student self-efficacy through providing opportunities to succeed, modeling from the instructor or other students, and encouragement in the process. "In a supportive, effective curriculum we would hope to see that students that are further along…have higher feelings of efficacy than those who are just beginning." [34].

Study participants were 7th to 9th grade students participating in the Engineering byDesign curriculum within the United States. This sample was selected because of our interest in design education programs, the pivotal nature of adolescent self-efficacy, and a gap in when engineering self-efficacy had been evaluated in previous research. Engineering byDesign reports a middle school enrollment reaching over 400 school districts nationwide [35]. The 18-week curriculum consists of approximately 10 design activities, depending on instructional modifications made by the instructor. Each activity includes a consistent design process from problem definition to testing an idea, which is representative of stages common in engineering design processes. The standards based nature of the curriculum and the consistent application of the design process support application of the information obtained from this study to other students in engineering design classes that include design activities mediated by a design process. Students enrolled in courses were surveyed at the beginning and end of the curriculum.

Variables

Two main variables were of interest in the study: engineering design self-efficacy and creative thinking self-efficacy. Self-efficacy beliefs are domain specific [36] and the questions used to evaluate self-efficacy are of great importance. The first scale used attempts to measure an individual's belief in their abilities to do engineering design [4]. The work of Carberry et al. (2009, 2010) represents initial work in the development of a self-efficacy instrument for engineering design. Design was operationalized through use of eight design process steps from the Massachusetts Department of Education [37] which align well with the Engineering byDesign design process. Both procedures include phases identifying and developing the problem, solutions, and prototypes; additionally, both conclude with redesign indicating to the engineer that the process is iterative. Although the Engineering Design Self-Efficacy Instrument was developed with a sample from higher education and professional engineers, because the content used in developing the instrument was from K-12 education it was reasonable to assume that the results would extend to a sample of middle-school students.

The proposed model to measure engineering design self-efficacy represents the linear, analytical process of design well however another important facet of design is creativity. Creativity can expand the efforts of each step of design [38]. It could be seen to build the breadth of the design process. Similarly, Lawanto and Stewardson[39] separated the two common purposes of design to include optimization problems where the analytical aspects of design are needed, and new, divergent solutions where the creative outcomes of design are emphasized. In order to capture this process of divergent thinking, the Engineering Design Self-Efficacy Instrument was paired with a measure of creative self-efficacy to identify student beliefs about their creative abilities within the design process. This combination represents a novel contribution of this study because this has not been done before, to the best knowledge of the researcher. Previous performance measures have focused on creativity within design for example, [40] but not design self-efficacy. Jobst et al.[24] described creative self-efficacy as a potential measure to explore in an attempt to assess design thinking and creative confidence; this rationale supports the decision of the researcher to include both measures.

The selected instrument for measuring creative thinking self-efficacy was developed by Abbott[41]. Creativity self-efficacy has a longer history in research than engineering self-efficacy; this instrument built off of work from Tierney and Farmer[42] and Beghetto[29] but used the same anchors as recommended for self-efficacy scale development [36]. The Creative Thinking Self-Efficacy Instrument contains 12 questions on various elements of creativity which are also replete in literature: creative fluency, flexibility, elaboration, and originality. These facets of creativity were used by Torrance[43] to explain different creative outcomes. The instrument was developed in an educational setting, which was promising for our purposes as long as the content remained viable for a middle-school sample. Following review of the questions we concluded that they were appropriate for use with middle-school students based upon their generalizability and grade level readability [44].

As a pair, the Engineering Design Self-Efficacy Instrument and Creative Thinking Self-Efficacy Instrument inform the first hypothesis of this research study:

> *Hypothesis 1: Engineering design self-efficacy and creative thinking self-efficacy are positively related.*

Engineering design is a highly creative activity full of opportunities for divergent thinking and innovation [38]. It is expected that self-efficacy perceptions on engineering design and creative thinking grow together because of the parallel nature of these processes.

Survey Development and Administration

In cooperation with expert reviewers, the self-efficacy instruments were formatted using a 0 – 10 point scale which is appropriate for use with younger students [36]. The survey was administered electronically in two parts immediately following the student pre-test and again following the post-test and design review; students accessed the survey by clicking a link included on the final page of the existing material. The EbD curriculum already included time set aside for these two activities. Both administrations included the self-efficacy instruments and a self-reported student identification number intended to pair the pre- and post-responses. The first administration of the survey included student demographics information.

Self-efficacy should be measured at significant milestones that could capture potential changes in individual beliefs [10]. Regarding repeated measures, “the findings show that people’s level of motivation, affective reactions, and performance attainments are the same regardless of whether they do or do not make prior self-efficacy judgments” [36]. This statement suggests that it was acceptable to measure self-efficacy multiple times in order to determine changes in self-efficacy. The timeline of multiple administrations relates to the second hypothesis:

> *Hypothesis 2: Engineering design self-efficacy and creative thinking self-efficacy increase following participation in the engineering design curriculum.*

Results

Prior to data analysis, we received survey export data from Engineering byDesign containing 2,699 responses to the survey. The information was screened and restructured to match student responses in the beginning of the technology and engineering curriculum to their responses at the end of the course. As much as possible we attempted to retain useful data while accurately matching responses on the instrument; first, all cases were retained whether or not they had pre- and post-test scores with the intent of simplifying the data by joining paired responses. Of those opening the survey link, 594 cases (22%) did not complete any questions and were removed for non-response. To pair up responses we used a self-reported student identification number and confirmed the accuracy of matches by using the Internet Protocol address to ensure that the responses were from the same school. Based on the date of each response, we determined which entry was the pre-test or post-test; seven pre- and post-test responses were conducted within a week of each other and were removed because this does not reflect the recommended timeframe for curriculum delivery.

Data screening was conducted based on recommendations from Tabachnick and Fidell[45] for multivariate statistics including: inspecting univariate descriptive statistics, evaluating and dealing with missing data, considering linearity and homoscedasticity, identifying and dealing with multivariate outliers, and evaluating for multicollinearity. In dealing with missing data, cases were retained for listwise completion at the subscale level because each survey was presented as its own page. This led to a greater number of students having completed the Engineering Design Self-Efficacy instrument (see Table 1) and a varying number of students being included in each statistical test. (We have taken care to report the degrees of freedom and draw conclusions accordingly.) Each variable under study was approximately normal based on inspection of the descriptive statistics, distributions, and qq plots. Several cases were removed as multivariate outliers. As a result of the restructuring and screening procedures, 1,713 cases were retained for later analysis. A depiction of this process is shown in Figure 1.

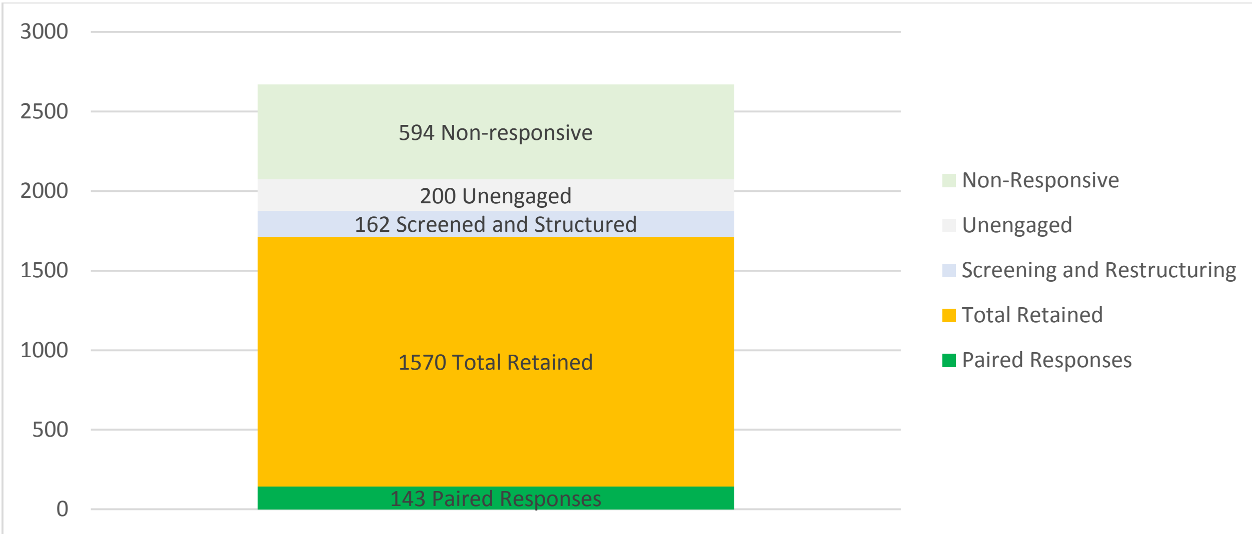

Figure 1. Data reduction through screening and restructuring procedures.

After data screening, the internal consistency and reliabilities of each survey were considered because we applied them in a new context. Pre- and post-curriculum administrations of the survey were considered separately. The Engineering Design Self-Efficacy and Creative Thinking Self-Efficacy Instruments seemed to be sound as administered to middle-school students. The mean was near the middle of each scale, the item-total correlations were good, and the internal consistency as measured by Cronbach's α was also good. "In general…a good measure should have a Cronbach's alpha of at least .60 and preferably closer to .90" [46]. Our results had internal consistencies of α > .95 (see Table 1).

Table 1. *Subscale Reliabilities and Totals*

Subscale Name	*n*	*M*	*SD*	Item-total correlations	No. of Items	Cronbach's α
Engineering Design Self-Efficacy						
Pre-Test	1322	5.89	2.37	.76 – .84	9	.95
Post-Test	510	6.53	2.43	.79 – .88	9	.96
Creative Thinking Self-Efficacy						
Pre-Test	1199	5.81	2.23	.70 – .84	12	.96
Post-Test	471	6.34	2.36	.77 – .91	12	.98

In anticipation of the statistical analyses planned (correlation and *t* tests) these data screening procedures helped ensure that statistical assumptions were met and conclusions drawn might be accurate. Ensuing hypotheses were tested using a significance level of α = 0.05 and are reported with effect sizes (Cohen's *d*).

Relationship Between Engineering Design Self-Efficacy and Creative Thinking Self-Efficacy

As previously stated, we hypothesized that design self-efficacy and creative thinking self-efficacy would be related; because of the resemblance between design and creative processes, we expected student attitudes to be similar [47]. To assess the relationship between these two measures, the scale mean was obtained for each student. Both scales used a scale from 0 to 10, with higher values indicating greater confidence in ability to complete the task. Also, correlation analysis only included cases where engineering design self-efficacy and creative thinking self-efficacy were reported at the same time point. However, initially we used responses from both the pre- and post-test. Results showed that the two domains of self-efficacy are significantly related, $r(1541) = .783$, $p < .001$. Follow-up analysis separated by time of survey response confirmed that the perception of similarity between design and creative thinking self-efficacy existed prior to and throughout the curriculum: $r_{pre}(1176) = .776$, $p < .001$ and $r_{post}(465) = .843$, $p < .001$.

Growth in Engineering Design Self-Efficacy and Creative Thinking Self-Efficacy

The next hypotheses were related to any change in student self-efficacy following participation in the technology and engineering curriculum. We hypothesized that positive experiences with design throughout the curriculum would help enhance student self-perceptions of design and creative thinking ability. Among survey responses received, only 143 were successfully paired with a pre- and post-test score on engineering design self-efficacy or creative thinking self-efficacy. Dependent (paired) *t* tests were conducted for each type of self-efficacy with both having a significant increase following the curriculum. Student engineering design self-efficacy had a positive increase: $M_{edse} = 1.32$, 95% CI [0.98, 1.67], $t(133) = 7.60$, $p < .001$. Fewer students had completed both times of the creative thinking-self-efficacy measures but a significant effect was still observed: $M_{diff} = 0.79$, 95% CI [0.42, 1.16], $t(124) = 4.19$, $p < .001$. The two tests had a medium effect size, $d = 0.66$ and $d = 0.38$, indicating a practical difference in self-efficacy beliefs before and after the curriculum. The growth in these two types of self-efficacy is depicted in *Figure 2*.

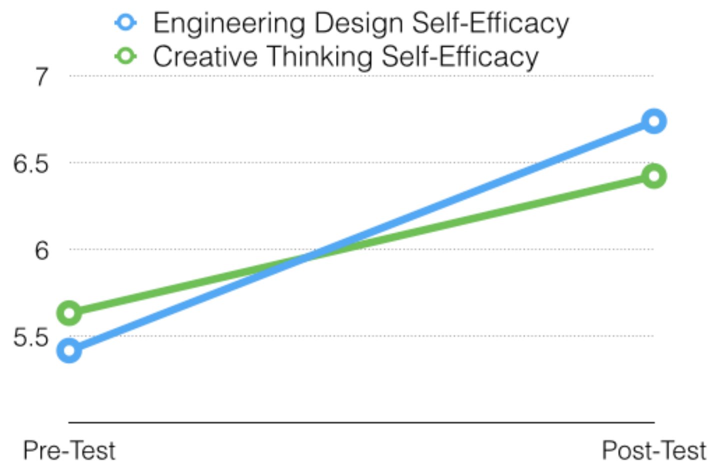

Figure 2. Line chart for mean self-efficacy before and after the curriculum on paired responses, n = 134 for engineering design self-efficacy and n = 125 for creative thinking self-efficacy.

The paired *t* test is advantageous for taking into account within individual differences by utilizing the difference score when calculating the *t* statistic, and the sample size for both tests approaches the recommended value of 156 for adequate power [46]. However, we recognize that the number of subjects utilized by these tests is much less than the information obtained in our overall sample. Because the survey responses with matched scores were limited, a follow-up independent means *t* test was conducted for differences in engineering design self-efficacy and creative thinking self-efficacy over time. Levene's test for equality of variances found that for the engineering design self-efficacy total the pre- and post-curriculum score variance could be assumed equal ($F = 1.459$, $p > .05$). Student responses indicated a higher engineering design self-efficacy score when taking the survey after the curriculum, $M_{diff} = 0.65$, $t(1830) = 5.22$, $p < .001$. The creative thinking self-efficacy scores violated the assumption of equal variance however ($F = 5.72$, $p = .017$) requiring an adjustment on degrees of freedom from 1668 to 817 for the test statistic. The results still indicated a significantly higher creative thinking self-efficacy score following the curriculum, $M_{diff} = .52$, $t(817) = 4.15$, $p < .05$.

Equity of Design Impacts on Self-Efficacy

Following hypothesis testing we conducted post-hoc analysis to examine possible gender and ethnic differences on engineering design self-efficacy and creative thinking self-efficacy growth. Because demographics questions were asked on the pre-test, a large number of responses did not contain identifying information that was useful for these analyses; these represent nascent exploratory results and should be interpreted carefully. Because it pertains to growth in self-efficacy these analyses were limited to those with paired scores, although we compare the demographic distribution to the overall sample obtained. A two-way ANOVA for time and gender was conducted first. There were 60 (56.1%) male and 47 (43.9%) female students as self-reported. This is close to the overall distribution of young men and young women for all responses (52.2% and 47.6% respectively). The outcomes replicated previously reported results by showing that there was significant growth in engineering design self-efficacy over time, $F(1,210) = 21.12$, $p < .001$, and creative thinking self-efficacy over time, $F(1,210) = 11.24$, $p = .001$, but there was not a gender difference for either self-efficacy outcome, $F(1,210) = 1.63$, $p = .203$ and $F(1,210) = 0.30$, $p = .58$ in order.

Two-way ANOVA for time and ethnicity included 106 students. Uneven distributions for ethnicity makes interpretation difficult: most students were White (71.7%), some were Black (9.3%) and fewer were Asian (2.5%), Pacific Islander (2.5%), Native American (0.8%) or another ethnicity (2.5%). The between-subjects effect for ethnicity on engineering design self-efficacy was not significant, $F(5,200) = 1.98$, $p = .08$. Nor was the effect for ethnicity on creative thinking self-efficacy, $F(5,200) = 1.27$, $p = .28$.

These concluding findings, taken as a whole, suggest that the impacts of a design curriculum on self-efficacy for students is equitable. Scores between gender and ethnic groups remained fairly similar while demonstrating an overall increase by time. The sample sizes for these tests were limited and represent an opportunity for further investigation. The negligible differences by gender and ethnicity may also be explained by the middle-school classroom setting: perhaps stereotypes that have traditionally affected STEM self-efficacy are not yet emphasized. Previous research has shown that these attributes are related to self-efficacy differences [48-50].

Discussion and Implications

The present study extended research on engineering self-efficacy by exploring adolescent engineering design self-efficacy through participation in a middle-school engineering curriculum, Engineering byDesign. It further extended previous work by coupling analysis of engineering design self-efficacy with analysis of creative thinking self-efficacy; this granted empirical comparison of the two domains of self-belief and led to instructional implications related to both domains, which follow. Utilizing a pre- and post-test surrounding the curriculum content, this correlational study was able to detect student growth in engineering design self-efficacy and creative thinking self-efficacy following the curriculum.

Preliminary conclusions relate to the usefulness of the Engineering Design Self-Efficacy Instrument and Creative Thinking Self-Efficacy Inventory for middle school students. Previous work conducted during the development of these tools showed reliability and validity among undergraduate populations [4, 9, 41]. Review by educational researchers, textual readability analysis, and the appropriate range of responses and internal consistency for these instruments provides nascent support for their use among younger students. Also, for the purposes of measuring self-perceptions and progression over time, the scales performed as expected. Multiple forms of statistical analysis and repeated trials on the scales showed consistent results (see Table 1).

Engineering Design and Creative Thinking Are Concurrent Thought Processes

Engineering design and creativity go together [39]. Several findings from this research indicate that these processes hold similar perception in student eyes and are changed correspondingly. First, a high correlation among the total scores for students before and after the curriculum indicates that engineering design self-efficacy and creative thinking self-efficacy are perceived similarly. Students who are confident in one are likely to possess high confidence in the other. Next, analysis of student growth in self-efficacy revealed similar increases for engineering design self-efficacy and creative thinking self-efficacy following the design curriculum.

These findings lead to a considerable implication for technology and engineering practitioners: because engineering design and creativity work together, classroom strategies encouraging self-efficacy in these domains may be transferrable. Experienced designers have been considered "creative experts" [51] and design solutions are valued for their creativity [52]. These overlaps illustrate the similarities between the two constructs; this said, a shift in how engineering design self-efficacy or creative thinking self-efficacy is framed in curriculum development may open divergent possibilities for instruction. Technology and engineering educators are encouraged to use design thinking strategies as scaffolds for creative thinking in other domains. For example, the strategy of using design heuristics has evolved from research on expert designers and innovative products [53]. These strategies (such as "allow user to customize") can be used to widen the design space while generating ideas and promote creative thinking in the field of engineering design. Ongoing work to develop these strategies involves identifying transferrable domains where these design strategies can be leveraged to promote creative thinking in a new way [54]. Atman et al.[55] likened creative writing experts to engineering design experts; the application of design heuristics—a design thinking strategy—to support creative thinking in writing scenarios is feasible. The transferability of engineering design strategies to promote a desirable 21st Century Skill increases the value of pedagogical knowledge for design.

Technology and engineering educators are also encouraged to be aware of student beliefs on creativity and facilitate student creative self-efficacy prior to, and during, engineering activities. Instructors can bridge best practices for promoting creative thinking to engineering design when directing open-ended design activities. These practices, which may already be used, include offering choice [56], associating design tasks to be personally relevant and interesting [57], using collaborative activities, and carefully structuring assessment to support creativity [38]. Students should understand how creativity will relate to their grade which can mitigate the fear of taking creative risks [58].

Limitations

There are positive findings related to potential growth in self-efficacy. In retrospect, a great challenge to the research was an inability to accurately match many student pre- and post-responses when analyzing the data. Students were required to click a link from the existing curriculum activity to connect to the research surveys. Next, in the survey, they self-reported their student identification number which was intended for use in pairing student responses. These several stages created fallibility in the process. Because of this less than 10% of the responses received at the time of analysis were used for paired sample testing that accounted for individual differences (although a majority were used for independent *t*-tests which substantiated the findings).

There is also no way to be certain (in this correlational design) that there are not effects due to the pre-test. It is possible that administering the survey on self-efficacy beliefs draws student attention to these experiences and makes them especially attentive to information sources that would modify their beliefs throughout the curriculum. Conversely, it is possible that there should be effects measured, such as calibration with the instrument, that were not because of the pre- and post-test design. It is possible that students had a self-response bias and the initial scores were inflated. Controlling for an initially overconfident score would produce greater effects than those realized here.

Future Opportunities for Research in Adolescent Design Self-Efficacy

This study found positive gains in engineering design self-efficacy and creative thinking self-efficacy following participation in design curriculum by comparing measurement at the beginning and end of the curriculum. This description identifies several avenues for future research by way of a closer examination:

- What facets of engineering design self-efficacy are most benefitted?
- What facets of creative thinking self-efficacy are most benefitted?
- And what does a more granular trajectory for self-efficacy growth look like?

Although the self-efficacy beliefs collectively increased for students in the sample, more discrete analysis may reveal differing effects inside each form of self-efficacy. Longitudinal analysis of student growth through a series of design experiences would also provide interesting insight into student perspectives over time and at significant milestones [59]. The addition of time points in the study may highlight a type of calibration as students progress in the curriculum and recognize what they don't know [60].

As instructors we have the opportunity to help students utilize a variety of information sources well to build self-efficacy; we can also be the source of positive information. Self-efficacy as a precursor to motivation, action, persistence, and effort, represents one entry point into examining psychological factors that interplay with engineering design and creativity. While others are notable, self-efficacy can be seen as a determining factor that opens up future pathways and opportunities for students. These findings are helpful for teachers because they provide points for change that may already exist in the curriculum but which can be better capitalized on. Acting on these findings can catalyze student growth in their confidence to do engineering, leading to a significant change.

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