Employ a modern technology education approach with G-W titles written by authors with significant classroom and industry experience. These comprehensive textbooks are packed with a collection of valuable features from learning objectives and key vocabulary terms to STEM Applications, Engineering Design Challenges, and TSA Modular Activities. For nearly 100 years, G-W has focused exclusively on providing affordable, high-quality instructional resources for Career and Technical Education. Let’s work together to build careers!
2020 Registration NOW OPEN!

Sign up for ITEEA’s REACH Challenge! REACH Challenge is an innovative design-thinking project for middle, high school, and college STEM programs. Teachers and their students use their STEM skills to REACH a member of their community who has a challenge to overcome, and design a viable adaptive or assistive technological solution to their problem. When teachers sign up, they get an Educators Toolkit with everything they need for the project, including slides, worksheets, case study topics, videos and activities on:

- Adaptive & Assistive Technology
- User-Centered Design
- Empathy
- Listening Techniques for Gathering Qualitative & Quantitative Data
- Safety Considerations
- Prototyping Tips & Tricks
- Intellectual Property 101

Then, once the projects are complete, they can be submitted to ITEEA for an opportunity to earn awards and funding for their STEM program! Change someone’s life - take the ITEEA REACH Challenge!

For more information and to register: www.ReachChallenge.org
features

THE ANATOMY OF A DESIGN BRIEF P.8
Promotes the discussion about design briefs and provides one perspective of the anatomy of a design brief.
Todd R. Kelley, DTE

INCREASING FEMALE ENROLLMENT IN TECHNOLOGY AND ENGINEERING CLASSES: AN ALL-FEMALE CLASS P.13
The results of a middle school teacher's "experiment" teaching an all-female Technology and Engineering class.
Thomas Walsh and Geoffrey A. Wright, DTE

MAKING CENTS OF THE NATURE OF ENGINEERING P.20
Describes an activity in which middle school students are asked to create a product to help a fictional bank sort coins.
Sarah Voss, Hannah Klinker, and Jerrid Kruse

departments

ON THE ITEEA WEBSITE P.5
SAFETY SPOTLIGHT P.26

STEM EDUCATION CALENDAR P.6
CLASSROOM CHALLENGE P.30

STEM EDUCATION NEWS P.7
SOCIALLY RELEVANT CONTEXTS P.32

TETe SUSTAINABLE DEVELOPMENT AND ELEMENTARY STEM IN JAPAN AND THE UNITED STATES
The purpose of this article is to introduce sustainable development education and provide guidance to elementary STEM teachers on ways to implement lesson plans in different countries.
Thomas Loveland, DTE, Hidetoshi Miyakawa, DTE, and Zulay Joa
www.iteea.org/TETApr20TETe.aspx

On the cover: DKJA High School Engineering Teacher Stephen Obaido and his students Yakov Wahnich and Noah Rubin were among the award winners in ITEEA's 2019 REACH Challenge. They used their STEM skills to change lives by designing an assistive technology device to help adults with special needs in their Boca Raton, Florida community gain employment. Registration is now open for ITEEA's 2020 REACH Challenge! Find out more at www.ReachChallenge.org.
STEL Feedback Requested

Recently ITEEA released the third draft of the new Standards for Technological and Engineering Literacy (STEL) document for public review. It can be viewed at iteea.org/stel_review.aspx. Below the draft is a link to a survey to make providing feedback to the leadership team easy. Your comments on the draft STEL will be carefully considered. Reviewers may choose to be listed on the STEL Appendix D Acknowledgements page.

Included on the ITEEA STEL page are other resources including a STEL Benchmark Crosswalk to NGSS, CCSS Math, and CCSS ELA; an updated Frequently Asked Questions, the Executive Summary; and an informational STEL PowerPoint presentation. Additional resources will be added as they become available, including an interactive Standards feature for teachers.

2020 REACH Challenge

ITEEA’s REACH Challenge registration is now open! The registration fee includes instant access to the REACH Challenge Toolkit, a valuable set of activities, lesson plans, and slide presentations that are designed to teach students about User-Centered Design, Adaptive and Assistive Technology, Empathy, Prototyping, Intellectual Property, and more. Teams will also have help finding a User-Expert, as well as the ability to submit the team’s project for awards from ITEEA. Each team can have up to 10 students, and a teacher can be the TEAM LEAD over multiple teams. Learn more/register today at https://www.iteea.org/REACH.aspx

Denver Application to Present

The Application to Present for ITEEA’s 83rd Annual Conference, March 24-27, 2021 is now open. The 2021 conference theme is “Where Technology and Engineering Education Come to Life!” Applications must be received by June 30, 2020. Apply today at: https://forms.gle/uMEhfnbfn2Ud82q27

International Technology and Engineering Educators Association
All professional articles in REFEREE POLICY the ITEEA Headquarters staff.

official policy or the opinion of the association, its officers, or expressions of the authors and do not necessarily reflect the Materials appearing in the journal, including advertising, are solely to the development and improvement of technology and engineering education.

As the only national and international association dedicated to the development and improvement of technology and engineering education, ITEEA seeks to provide an open forum for nonmembers, plus shipping and handling.

$110 outside the U.S. Single copies are $10 for members; $11

TERNOLOGY AND ENGINEERING TEACHER.

ISSN: 2158-0502, is published eight times a year (September through June, with combined December/January and May/June issues) by the International Technology and Engineering Educators Association, 1914 Association Drive, Suite 201, Reston, VA 20191. Subscriptions are included in member dues. U.S. Library and nonmember subscriptions are $90; $110 outside the U.S. Single copies are $10 for members; $11 for nonmembers, plus shipping and handling.

Technology and Engineering Teacher is listed in the Educational Index and the Current Index to Journal in Education.

Volumes are available on Microfiche from University Microfilm, P.O. Box 1346, Ann Arbor, MI 48106.

EDUCATIONAL POLICY

As the only national and international association dedicated solely to the development and improvement of technology and engineering education, ITEEA seeks to provide an open forum for the free exchange of relevant ideas relating to technology and engineering education.

Materials appearing in the journal, including advertising, are expressions of the authors and do not necessarily reflect the official policy or the opinion of the association, its officers, or the ITEEA Headquarters staff.

REFEREE POLICY

All professional articles in Technology and Engineering Teacher are refereed, with the exception of selected association activities and reports, and invited articles. Refereed articles are reviewed and approved by the Editorial Board before publication in Technology and Engineering Teacher. Articles with bylines will be identified as either refereed or invited unless written by ITEEA officers on association activities or policies.

TO SUBMIT ARTICLES

All articles should be sent directly to the Editor-in-Chief, International Technology and Engineering Educators Association. Please submit articles and photographs via email to kdela-

ADVERTISING SALES

ITEEA Publications Department
703-860-2100
memberships.sales@iteea.org

SUBSCRIPTION CLAIMS

All subscription claims must be made within 60 days of the first day of the month appearing on the cover of the journal. For combined issues, claims will be honored within 60 days from the first day of the last month on the cover. Because of repeated delivery problems outside the continental United States, journals will be shipped only at the customer’s risk. ITEEA will ship the subscription copy but assumes no responsibility thereafter.

CHANGE OF ADDRESS

Go to the ITEEA website – www.iteea.org. Log in and edit your profile. It’s that simple.

POSTMASTER

Send address change to Technology and Engineering Teacher, Address Change, ITEEA, 1914 Association Drive, Suite 201, Reston, VA 20191-1539. Periodicals postage paid at Herndon, VA and additional mailing offices.

Email: kdela-paz@iteea.org
Website: www.iteea.org

May 1, 2020

STEM CTL Safety Micro-Badging Professional Development Series: Safer Makerspaces

www.iteea.org/microbadge.aspx

June 1, 2020

STEM CTL Safety Micro-Badging Professional Development Series: Accident Reports! A Blessing and a Curse

www.iteea.org/microbadge.aspx

June 22-23, 2020

2020 Delaware STEM Conference Catch the Wave!

Tonyea.Mead@doe.k12.de.us or Renee.Parsley@doe.k12.de.us

June 27-July 1, 2020

National TSA Conference Inspire a Shared Vision

Gaylord Opryland Resort and Convention Center, Nashville, TN

tswweb.org/events-conferences/2020-national-tsa-conference

April 1, 2020

STEM CTL Safety Micro-Badging Professional Development Series: Large Power Tools

www.iteea.org/microbadge.aspx

April 2-4, 2020

National Robotics Challenge World Championship Marion, Ohio

https://www.thenrc.org/

April 23-26, 2020

USA Science & Engineering Festival Walter E. Washington Convention Center Washington, DC

https://usasciencefestival.org/

April 27-30, 2020

PATT38 University of Turku, Rauma Campus Finland


May 1, 2020

STEM CTL Safety Micro-Badging Professional Development Series: Safer Makerspaces

www.iteea.org/microbadge.aspx

June 1, 2020

STEM CTL Safety Micro-Badging Professional Development Series: Accident Reports! A Blessing and a Curse

www.iteea.org/microbadge.aspx

June 22-23, 2020

2020 Delaware STEM Conference Catch the Wave!

Tonyea.Mead@doe.k12.de.us or Renee.Parsley@doe.k12.de.us

June 27-July 1, 2020

National TSA Conference Inspire a Shared Vision

Gaylord Opryland Resort and Convention Center, Nashville, TN

tswweb.org/events-conferences/2020-national-tsa-conference

April 1, 2020

STEM CTL Safety Micro-Badging Professional Development Series: Large Power Tools

www.iteea.org/microbadge.aspx

April 2-4, 2020

National Robotics Challenge World Championship Marion, Ohio

https://www.thenrc.org/

April 23-26, 2020

USA Science & Engineering Festival Walter E. Washington Convention Center Washington, DC

https://usasciencefestival.org/

April 27-30, 2020

PATT38 University of Turku, Rauma Campus Finland

Save the Dates for Denver 2021!

March 24-27, 2021
Theme: Where Technology and Engineering Education Come to Life!

Strand 1: Defining the role of technology and engineering in STEM education.
Strand 2: Building partnerships to strengthen technology and engineering education.
Strand 3: Sharing technology and engineering education research and best practices.
Strand 4: Establishing career connections for all students.

Standards for Technological and Engineering Literacy: Feedback Requested

ITEEA recently released the third draft of the new Standards for Technological and Engineering Literacy (STEL) document for your review. It can be viewed at iteea.org/stel_review.aspx. Below the draft is a link to a survey to make providing feedback to the leadership team easy. Your comments on the draft STEL will be carefully considered. Reviewers may choose to be listed on the STEL Appendix D Acknowledgements page.

K-12 Teachers of Engineering in U.S. Lack Needed Preparation and Support from the Education System

Engineering is emerging as an important topic in K-12 education in the U.S. and is being incorporated into educational standards, instructional materials, and assessments. The Next Generation Science Standards (NGSS), for example, envision the integration of engineering concepts and practices with those from science, and the District of Columbia and nearly 80 percent of states have either adopted or adapted the standards.

A new report from the National Academies of Sciences, Engineering, and Medicine says there is a growing mismatch between the need for engineering-literate K-12 educators and the capacity of the U.S. education system to prepare and support these professionals. In addition, there are very few postsecondary programs that educate prospective K-12 teachers of engineering, and professional development experiences—through which the bulk of the current teaching workforce learned what they know about engineering and how to teach it—vary in duration, scope, and effectiveness. The report also finds little evidence that K-12 science teachers are being given opportunities to learn to incorporate engineering concepts and practices into their instruction, as described in NGSS.

The report includes 10 recommendations for improving the preparation of K-12 teachers of engineering geared toward a range of stakeholders, from federal agencies and private foundations with an interest in STEM education to colleges, accrediting bodies, and state departments of education, such as:

• Convening a collaborative dialogue among the many stakeholders to address the capacity issue.
• Ensuring that programs preparing preservice K-12 science educators or providing professional learning to in-service science teachers address the call in NGSS for students to connect their science learning to engineering ideas and practices.
• Creating partnerships between postsecondary engineering and engineering technology programs with schools/colleges of education to design and implement curriculum for the preparation of K-12 teachers of engineering.

In addition, to address lack of diversity, the report recommends that programs preparing prospective K-12 teachers of engineering make greater efforts to recruit and retain teacher candidates from populations currently underrepresented in STEM education and careers. A more diverse workforce that is encouraged to use inclusive pedagogies could help attract and retain a more diverse population of students interested in the study of engineering and in STEM-related careers, the report says.
Introduction

Teaching students the design process and providing opportunities for design is at the core of engineering/technology education. The design process is a key feature of technological literacy, and design is the most represented element within Standards for Technological Literacy (ITEA/ITEEA 2000, 2002/2007; Lewis, 2005; Wicklein, 2006). Technology educators have access to a large collection of design process models from which to choose to introduce students to design. There remains a long-standing debate over which design-cycle process model is best to use in the technology classroom, and the recent increase in the variety of these choices has not lessened the debate. However, Lawson and Dorst (2009) indicated that no existing design process model fully represents the authentic process taken by designers. It is clear that the actual process taken by designers regardless of expertise is a messy and often unpredictable process. Although the debate for the “right” design model continues, technology/engineering teachers have options to choose from, and design process models are well documented. However, a complex process like design requires much more than just presenting students with a design-cycle model. There

by

Todd R. Kelley,
DTE

The hallmark of engineering/technology education should continue to be to promote technological literacy through engineering design, and a design brief is an important part of this heritage.
is so much more to design than a 8-, 10-, or 12-step process. Whichever design-cycle model teachers choose, the first steps of introducing the process are critical to students’ success. The early steps in the design process can provide students with the necessary directions for how to proceed. One possible teaching tool that can provide students with direction is the design brief. A design brief can help guide students through the problem-scoping phase of design. A design brief is one approach to introducing a design activity. Unlike the well-documented design process models, the design brief has not been clearly defined, and the key elements of a design brief are not clearly identified in technology education literature. This article will seek to identify, define, and describe key elements of the design brief and provide perspectives from an author with over 20 years of experience using the design brief in K-12 classrooms and as a research and design assessment instrument.

Background

Integrated STEM education provides engineering/technology education teachers a chance to share their common practices with math and science teachers. Over the years, I have enjoyed these exchanges with my colleagues from science and mathematics education. Several of my science education colleagues have been able to provide many resources to help me better understand how to introduce students to science inquiry. Equally, I was provided the opportunity to introduce them to some various design models, and together we created a design-process model for elementary teachers to use in their classrooms. Teaching at a university with a large engineering program, my colleagues have been well educated about the design process and had several years of successfully teaching design to elementary teachers before I joined the faculty in 2008. However, when I arrived at Purdue and began collaborating with STEM colleagues to create the curriculum materials for K-12 classrooms, I suggested creating design briefs to add to our STEM lesson plans. One science colleague asked: “What is a design brief?” so I quickly began to look for articles about design briefs to share and was shocked to find a void in the K-12 STEM literature about design briefs. Although I was able to locate some examples of design briefs, an explanation of the key elements of a design brief were missing. In an article from 1997, the authors suggested the use of design briefs to introduce elementary teachers and principals to design technology and project-based learning approaches to teaching during a summer professional development program (Ackerman, Etchison, Lydic, & Spiro, 1997). After discovering this void in the literature regarding design briefs, I initially wondered if I was making up this term. I believe a design brief is a key design tool and a very important pedagogical approach to teaching design, especially to young learners. Throughout this article, I will seek to define a design brief and provide a detailed description of this design pedagogical tool.

The Design Brief Defined

A design brief is an outcome of an initial meeting between a designer and a client. The initial meeting often results in the designer crafting a design brief, a common approach used by designers in architecture, graphic design, industrial design, and engineering. This allows the designer and the client to set the expectations of the design job and define the necessary outcomes. However, for the purpose of K-12 STEM education, I define a design brief as:

- A design brief is a one-page document that provides a designer with a basic description of a design problem. A design brief usually contains a list of constraints and criteria of the problem.

The design brief can also provide additional information to the designer about the needs of the client or end user. The amount of information contained in the design brief often is based on the level of the learners’ experience with design. More information may be provided to the designer if the students are novices to design and need additional information to begin creating a design solution. The teacher may choose to create a list of materials or tools available for use when creating a prototype solution. Although a design brief may contain more than one page, ideally the writer should seek to keep the document to one page; after all it is a “brief!”

Purpose of a Design Brief

The purpose of a design brief is to provide students with some key background and description of the design problem. It begins to frame a problem in such a way that students can begin to explore the problem. A well-constructed design brief allows students to have necessary details about the problem and the needs of the client without too much information to restrict the designer. Consider how Dym, Agogino, Eris, Frey, and Leifer (2005) define engineering design. They state:

- Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints” (p. 104).

Core elements of the design brief are embedded within this engineering design definition, including (a) end users’ needs; (b) client objectives (criteria); and (c) identified constraints. Some suggest that all technology education students should create their own design brief, thus providing opportunity for them to define ill-defined problems and remain open-ended in order to lead to multiple design approaches. I believe there are some flaws in this approach to teaching K-12 students. I agree with other technology educators who suggest that, as educators, we should seek to prepare students to have the ability to define design problems as
well as foster their ability to identify their own design problems. However, these skills may not be fully developed until after multiple years as students of design. I would propose that engineering/technology educators seek to help students possess the ability to create their own design problem statements and create their own open-ended challenges during students’ final capstone experiences. Until then, I suggest that teachers continue using a design brief.

Teachers can scaffold student learning by progressively providing fewer constraints and/or allow students more choices of prototyping materials. For example, for very young children or early novice designers, the teacher may need to restrict the prototyping materials available based upon students’ limited modeling skills. This approach may simplify the process of making a prototype. As students become more and more experienced with design and prototype production, the design brief becomes more ambiguous, with fewer details about the problem, requiring the designer to identify key details about the problem as well as the approach to design a solution. Additionally, the teacher can provide structure to the process by setting key constraints about a design problem, not to limit design ideas but to help frame the scope of the problem. Students new to design often need structure and the establishment of key guidelines and constraints for a design problem in order to remain focused on the problem. Constraints can also help eliminate potential problems that can arise when students have complete, unrestricted freedom in the design task. Locating the ideal number of constraints usually only comes with years of experience teaching design.

The Anatomy of a Design Brief

Most design briefs have the following key features: (a) a picture or graphic to set the context; (b) a short problem statement or scenario; (c) a list of identified constraints and criteria; (d) a list of prototyping materials; and (e) a final statement telling students how to begin the design process (Figure 1). Although not every feature is necessary or used by design brief writers, most of these features are present. The following are suggestions from years of experience creating design briefs.

Setting the Context With a Picture

When setting the context for a design brief it is helpful to provide an image at the beginning of the document. An image provides a visual for the reader to quickly orient themselves to the context. However, the writer of the design brief should carefully consider the type of image to use. An image selected should never imply a design solution or uncover details about a design problem that will cause fixation by the designer. Design fixation is a real phenomenon, and students are very sensitive to impulses that might lead them toward a design idea. Design fixation should be avoided at all costs, as it has been proven to be a restriction to creativity (Kelley & Sung, 2017; Jansson & Smith, 1991). Additionally, we have discovered several examples of design fixation while conducting design research studies with K-12 students (Kelley, Brenner, & Pieper, 2010). Providing a simple graphic or image that provides a context but has no design implications is best. For example, a teacher created a design brief for elementary students with a design problem of designing a better candy bag. This design problem provided an excellent introductory design task that used simple materials and was an object familiar to students. The image in the design brief was of a pile of candy; this provided a nice visual context for the design brief without containing any reference to a possible solution. For this design brief, it would not be helpful to provide any images of bags, as they might influence students’ final bag designs (see candy bag lesson, https://stemedhub.org/resources/363).
An additional suggestion is for design brief writers to consider utilizing a local context to help students see the design assignment as a real-world problem. Often this authentic approach to describing a design problem can bring additional motivation for students who can identify with the client or the local problem. For the candy bag design brief, the author used the name of a local candy store and expressed that the store owner needed a new line of candy bags because the current ones did not meet customers’ needs. This detail to the design problem statement set the context for the design brief without causing design fixation.

Scenario or Problem Statement

The problem statement or design scenario provides the designer with a basic description of the design problem. The statement should be brief. Too often design scenarios provide too much detail that can overload students. The problem statement should include an identifiable client and end user, who are typically different people. For example, many of the design briefs I have created have a client from manufacturing or from a design firm who is seeking help to create a product for an identified end user. For example, consider a possible design brief that contained a scenario for creating a new line of camping tents. The camper in this case is not the client. A camper rarely has a custom tent made for him or her; they purchase the tent from a camping-supply store. The stores get retail equipment from camping manufacturers. The client in this case is the camping supply manufacturer who is seeking a new tent design. Young designers should learn how to identify the client and the end user within the scenario. This is important information because the designer must meet the needs of both the client and the end user. Each individual will have different needs, and these should be considered while in the midst of design. When students present their final design solutions, they should be encouraged to identify how their design meets the needs of both the client and the end user.

Constraints and Criteria

A teacher can help guide and support students’ development in design by establishing some guidelines for a design task. Every design task contains constraints; in fact, some have defined engineering as an approach to improve the current conditions of a design problem under defined constraints. Constraints are the limitations usually embedded within the design problem. A teacher can add their own constraints on the design due to costs or material limits. Teachers often limit the time students have for the design task as a constraint. Cost is another real-world constraint. Some teachers set fictitious costs for the materials so that students learn to establish a budget for their final prototype design. This is an effective approach to educating students to carefully manage resources, since no engineering project is completed without costs.

Most teachers understand constraints of a design problem, but often struggle to understand the difference between constraints and criteria. Despite searching for literature on the difference between constraints and criteria, there do not seem to be strong definitions on criteria. For the purposes of this article, criteria can be defined as the identified features desired by the client. A client may set some design standards for the design, such as a specific size limit, or designate an overall final retail price, so the designer reaches for these criteria while designing. Sometimes criteria can also be considered constraints, but again, I believe it becomes criteria when it is set by the client to ensure that the designer seeks to address these desires through their final design.

Design Brief Closing Statement – Next Steps Task

For young learners, the design brief author may want to add a closing statement to give students direction on what to do next. Often this statement is short, but the teacher might want to cue students to prior lessons or resources that have been provided to guide the design process. The closing statement might suggest the students begin brainstorming ideas individually and then share these ideas with a design team. Sharing ideas should preferably be done using design sketches. One science inquiry tool that is helpful to guide students to plan their next steps is called a KWHLAQ (Barell, 2007, p. 86). Some engineering/technology educators might be familiar with a KWL (What do you already Know? What do you Want/need to know? What do you expect to Learn?). The modified KWL includes: H – How and where will you search for the information? A - How will you Apply what you have learned? And Q - What new Questions do you have following your inquiry? When collaborating with science teachers, this is a tool often used for inquiry tasks, and this approach prompts students to ask themselves key questions about how they need to gather and use information. Information gathering is a necessary skill in design and yet an area of struggle for many secondary students (Mentzer, 2014; Mentzer & Fosmire, 2015). As students get more experience in design, a closing statement is not necessary, and students will create their own approach to the first steps they will take during the design task.

Final Remarks

Simple tools of design such as the design brief should be foundational elements of a technology education classroom, and although technology educators have used design briefs for years, a void does exist in design education and technology education literature that clearly defines and provides a detailed description of the design brief document. The purpose of this article is to promote the discussion about design briefs and provide one perspective of the anatomy of a design brief. It is the author’s hope that readers will use this article in the future when creating their own design briefs and helping their students read and respond to
a design brief. The hallmark of engineering/technology education should continue to be to promote technological literacy through engineering design, and a design brief is an important part of this heritage.

References


Todd R. Kelley, Ph.D., DTE is an associate professor in Technology Leadership and Innovation at Purdue Polytechnic University. He can be reached at trkelley@purdue.edu.

This is a refereed article.
Introduction

High school Technology and Engineering (TE) classes are, in the majority, comprised of male students (USDE, 2012). This data point is also true in middle and junior high school elective TE classes. In light of the rapid growth of technology and engineering career opportunities, the lack of women students enrolling in middle, junior high, and high school TE classes is problematic. If the enrollment disparity is not addressed, then jobs in the technology and engineering industry will continue to be dominated by males, which may limit the innovation and growth of the TE industry. In an effort to understand and address this issue, a junior high CTE/TE teacher decided to modify how he organized his classes—which he believed would be a simple and low-cost solution.

The teacher was concerned because he felt that technological literacy was for all people, and if only male students were taking his class, then in some ways he was failing as a teacher. Over the years he said he had made efforts to invite more female students to take TE classes by recruiting them from the one TE class required for all 7th graders, by making posters advertising his program and classes, and by sending letters and flyers home to all the female students in his school detailing activities and learning outcomes experienced in his TE classes. Most of his efforts resulted in limited enrollment changes.

The following is an anecdote from the teacher about this experience. He wrote:

“As a junior high teacher, I teach classes that are both required and elective. The required class I teach is 7th grade College and Career Awareness. At the end of the school year, I...”

by Thomas Walsh and Geoffrey A. Wright, DTE
had a conversation with a female student and asked her if she was taking my class the following year. She said that she was going to and was excited. Sadly, the next day she came to me and told me that her parents would not allow her to take my class because it was a class for boys. This old persistent stereotype is holding my female students back, and worse, the stereotype prevents female students from becoming more prepared for their future degrees and careers.

After a few years of trying to convince females to take my classes or any of the other tech and engineering classes offered at my school, the classes were still mostly comprised of male students. In my required class, I had a good mix of male and female, but I wanted to build a strong program that promoted equity to both male and female students outside of the required class; therefore, I needed more female students in my other (elective) classes.”

The teacher’s “simple and low-cost” solution was to change his classes from mixed gender to solely male or female classes. He went to his administration and proposed the idea of having an all-female technology and engineering class to help increase enrollment. The administration seemed on board, and they said they would try to implement the idea. Sadly, it was later rejected because they were unsure that the school could actually offer such a class at the school. The administration suggested that they had to check into the feasibility and legality of having gender-exclusive classes. This was somewhat perplexing because the same class would be offered twice, one for female students, and the other for male students.

Consequently, at the beginning of the next school year the teacher went to his administration and proposed the idea a second time. This time the teacher had done some research into other schools that offered all-female classes, and explained that although any student could enroll in either class, two classes would be advertised as one being for female students, and the other for male students. The teacher explained that he was going to cover all of the same standards and objectives in each class, but that he would adjust all of the class assignments toward female interests. The reason the teacher decided to modify his assignments was a result of a research project that investigated a similar topic. The study took a “new angle on gender research by specifically considering whether there is a gender gap caused by the models implemented to teach biology (the specific lesson examples and content used to teach a broader biology topic, e.g., dust mites as a model of symbiosis), and how these models affect student interest, attitude, and learning” (Jensen, In press).

The initial part of the research asked students in kindergarten through 6th grade to circle the image about which they’d prefer to learn, e.g., butterflies or spiders; ladybugs or termites; eagles or flamingos. The data showed that the female students favored butterflies, ladybugs, and flamingos, whereas the male students favored learning about spiders, termites, and eagles. In light of the research the teacher presented, the administration agreed to the proposed two classes (Class A: female, and Class B: male).

The teacher shared that he was immediately able to observe the benefit of his decision:

“I was able to fill multiple classes with all females. Mission accomplished, right?! No. I learned several other important things. Not only did I fill my classes with more female students, but I learned a lot about student behavior, classroom management, and student performance. For example, I learned that I could cover more material in my all-female classes than in my male-dominated classes. I believe this was a result of the female students being more mature and more focused academically.”

The teacher also shared several other interesting insights. First, he observed that the all-female class was more effective in solving engineering problems, completed projects quicker, and had better overall grades than his mixed-gender class, and much quicker than his all-male class. As a result of these observations, the teacher decided to do some further investigation. He decided to collect some data from an ad hoc experiment about how engineering stereotypes affected his classes.

Background

Nontraditional careers are those dominated by one gender. Matt Rocheleau presented data about the percentage of female students in various STEM fields (Table 1):

<table>
<thead>
<tr>
<th>Engineering Career</th>
<th>Percent Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer and Hardware</td>
<td>24.7%</td>
</tr>
<tr>
<td>Industrial</td>
<td>20.3%</td>
</tr>
<tr>
<td>Chemical</td>
<td>20.1%</td>
</tr>
<tr>
<td>All other</td>
<td>12.2%</td>
</tr>
<tr>
<td>Civil</td>
<td>10.8%</td>
</tr>
<tr>
<td>Electrical</td>
<td>10.8%</td>
</tr>
<tr>
<td>Aerospace</td>
<td>7.8%</td>
</tr>
<tr>
<td>Mechanical</td>
<td>6.4%</td>
</tr>
</tbody>
</table>

The data suggests that there is not a career where even one quarter of the engineers are female. Data such as this and many other studies clearly highlight that engineering careers have been, in the majority, filled by males for many years, and engineering still remains a heavily male profession (Rocheleau, 2016).

Research, however, shows that in recent years the female enrollment in engineering majors at the university level has increased; ironically, industry only shows that 13% of engineers are female.
increasing female enrollment in technology and engineering classes: an all-female class

(Rincon, 2018). Researchers have found that, despite the efforts to promote engineering for females, there remains a climate not optimal for female engineers. Thirty percent attribute leaving engineering, or other STEM majors and careers, because of a male-centric work environment (Rincon, 2018). Because of this, stereotypes of the past—“engineering is a male field”—are still propagated today. Obviously many efforts are needed to correct this stereotype.

One common solution many universities are offering is to provide more scholarships to females who study engineering, which has led to some enrollment success. An additional potential solution is to expose female students to engineering at an earlier age (Koebler, 2011).

In recent decades there have been a lot of organizations, such as the Society of Women Engineers (SWE), working to encourage female engineers. Even campaigns like “I Look Like an Engineer” with hashtags #ILookLikeAnEngineer on many social media platforms are trying to change perceptions and stereotypes. They do this by picturing female or racially diverse engineers. The goal of these campaigns is to help people overcome the stereotypical image of a white male engineer. They had a lot of success, including over 86,000 tweets in over 50 countries sharing the message. SWE and other programs and organizations believe that awareness is the primary key to helping eliminate the false stereotype.

Findings from the All-Female Jr. High Technology and Engineering Classes

In light of the qualitative observations the teacher made, he did some further reading about teaching engineering to specific groups, be it gender, ethnicity, or age. The teacher found a study by researchers in Beijing (Lui, et al., 2019). An experiment was conducted in which researchers had students draw engineers. The teacher took this same idea and gave his students 10-15 minutes to draw an engineer. He did not mention gender so as not to bias the results. He decided to have his classes draw what they believed an engineer looked like. He anticipated that females would draw male-looking engineers, as that is what Lui's research discovered.

The demographics of the teacher’s classes was that two classes were completely female between the ages of 12 and 13. The classes were composed of mostly middle class Caucasian students. Table 2 (below) shows a demographic description.

The results from the drawing experiment showed that not one student from the mixed class drew a female engineer. However, in the female classes at least 42% of the drawings were clearly female engineers. Below is a table with the data from the drawings.

<table>
<thead>
<tr>
<th>Classes</th>
<th>Male Engineer</th>
<th>Female Engineer</th>
<th>Undetermined Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed</td>
<td>16</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Female 1</td>
<td>8</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>Female 2</td>
<td>11</td>
<td>12</td>
<td>11</td>
</tr>
</tbody>
</table>

This data is interesting because no one in the mixed class drew a female, while 29 females in the all-female classes clearly drew female engineers. More students may have drawn females, but 16 drawings from the female classes were too difficult to determine if the drawing was clearly male or female, and were thus labeled in the table as "undetermined."

Table 2. Ethnicity Demographics

<table>
<thead>
<tr>
<th>Classes</th>
<th>White</th>
<th>Native American</th>
<th>Pacific Islander</th>
<th>Hispanic</th>
<th>Asian</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed</td>
<td>31</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>35</td>
</tr>
<tr>
<td>Female 1</td>
<td>29</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>Female 2</td>
<td>28</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>35</td>
</tr>
</tbody>
</table>
increasing female enrollment in technology and engineering classes: an all-female class

In summary, females do see themselves or other females as engineers when they are grouped with other females in an engineering-type class. In contrast, males did not see (draw) any engineers as females. The stereotype therefore may be perpetuated by males.

Observational Data

The teacher also found that classroom management in an all-female class is less challenging than an all-male or mixed class. The teacher shared that:

“Females are quieter and more respectful to the instructor when compared with the more male-dominated class. Additionally, female students listen to the directions better (I had to re-state expectations and repeat instruction much less in the female classes than the male classes), and females are less distracted by their fellow classmates. Additionally, the all-female classes took more time to plan and figure out the assignments than the mixed or male classes did. By doing this they were able to finish the assignment quicker than their mixed counterparts.”

The teacher also said that: “The all-female classes’ ideas were more creative and the solutions more fully solved. And the female classes worked better as collaborative teams. For example, when a student finished their work they would ask if they could help other students in the class. Overall, the completion rate of assignments and the correctness of the work is higher with the all-female classes.”

Curriculum Map For the all-Female Class

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Description</th>
<th>Standards for Technological Literacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is a Computer?</td>
<td>Introduction on how to use a computer</td>
<td>STL 1</td>
</tr>
<tr>
<td>*Where Am I?</td>
<td>Make a map of classes</td>
<td>STL 3 / STL 17</td>
</tr>
<tr>
<td>Robotics</td>
<td>Robotics unit</td>
<td>STL 17</td>
</tr>
<tr>
<td>Photography</td>
<td>Take 30 pictures using rules of composition</td>
<td>STL 17 / STL 4</td>
</tr>
<tr>
<td>*Photoshop</td>
<td>Photoshop various pictures</td>
<td>STL 17 / STL 4</td>
</tr>
<tr>
<td>3D design ring</td>
<td>CAD ring drawn and 3D printed</td>
<td>STL 17 / STL 19</td>
</tr>
<tr>
<td>Beakman motor</td>
<td>Simple electric motor</td>
<td>STL 16</td>
</tr>
<tr>
<td>*Interior design</td>
<td>Made a floor plan of an apartment</td>
<td>STL 17</td>
</tr>
<tr>
<td>*Hydroponics</td>
<td>Grow lettuce using hydroponic techniques</td>
<td>STL 15</td>
</tr>
<tr>
<td>*Upcycle</td>
<td>Reused or repurposed an object</td>
<td>STL 5 / STL 13</td>
</tr>
<tr>
<td>Key fob</td>
<td>Leatherworking</td>
<td>STL 19</td>
</tr>
<tr>
<td>Fix my classroom</td>
<td>Used design process to redesign my classroom</td>
<td>STL 9</td>
</tr>
<tr>
<td>Candle Holder</td>
<td>Metalworking</td>
<td>STL 19</td>
</tr>
<tr>
<td>*Fast Track</td>
<td>Woodworking</td>
<td>STL 19</td>
</tr>
</tbody>
</table>

Curriculum Map For the Mostly Male Class

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Description</th>
<th>Standards for Technological Literacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is a Computer?</td>
<td>Introduction on how to use a computer</td>
<td>STL 1</td>
</tr>
<tr>
<td>*Who am I?</td>
<td>Make a poster all about you</td>
<td>STL 3 / STL 17</td>
</tr>
<tr>
<td>Robotics</td>
<td>Robotics unit</td>
<td>STL 17</td>
</tr>
<tr>
<td>Photography</td>
<td>Take 30 pictures using rules of composition</td>
<td>STL 17 / STL 4</td>
</tr>
<tr>
<td>3D design ring</td>
<td>CAD ring drawn and 3D printed</td>
<td>STL 17 / STL 19</td>
</tr>
<tr>
<td>Beakman motor</td>
<td>Simple electric motor</td>
<td>STL 16</td>
</tr>
<tr>
<td>*Capstone</td>
<td>Using the engineering design process, came up</td>
<td>STL 5 / STL 13</td>
</tr>
<tr>
<td>Key Fob</td>
<td>Leatherworking</td>
<td>STL 19</td>
</tr>
<tr>
<td>Fix my classroom</td>
<td>Used design process to redesign my classroom</td>
<td>STL 9</td>
</tr>
<tr>
<td>Candle Holder</td>
<td>Metalworking</td>
<td>STL 19</td>
</tr>
<tr>
<td>*Penny Hockey Board</td>
<td>Woodworking</td>
<td>STL 19</td>
</tr>
</tbody>
</table>
A final interesting observation the teacher made was student grades. He shared that at his school each day there is a grade check of all the students for all classes. He reported that the female classes on average had higher grades than the mixed classes.

**Conclusion**

Although this article highlights only one teacher’s effort to increase female interest in engineering, his findings about female enrollment and performance are interesting. He found that female enrollment increased when an all-female class was offered. Stereotypes of engineers being all male decreased in the all-female classes. Female classes needed less classroom management, were more creative, took less planning time and, in the end, finished assignments more completely and accurately than mixed classes.

Although many of the observations and data outlined above seem positive towards all-female engineering classes, there were some limitations to what the teacher did. First, he may have had only females sign up because they wanted to be with their friends. Also, by simply offering a new class, numbers could have increased as opposed to females actually being interested in engineering. It would be important to track his class(es) to see if the findings remain constant.

Regardless of the limitations of the teacher’s informal research study, his efforts should be applauded, as he is making efforts to reduce biases and stereotypes. Additionally, his story provides a helpful context, lens, and anecdote others could use to make similar changes, or use to further their own efforts to grow their programs, classes, and enrollment, in addition to breaking down stereotypes.

**References**


**Thomas Walsh** is a junior high Technology and Engineering Teacher at American Fork Junior High. He is also a master’s student at Brigham Young University (BYU) in the Technology and Engineering Education program.

**Geoffrey A. Wright, Ph.D., DTE** is an associate professor of Technology and Engineering Studies at BYU. His areas of teaching and research focus on STEM education, innovation, media arts, and computational literacy. He can be reached at ge.wright@gmail.com.

**Ad Index**

Goodheart-Willcox ................................................................. 2
Kelvin .................................................................................. 39
Mastercam ............................................................................ 40
What has been your secret to success as an educator and educational leader?
During my 34 years as an educator, I have tried to model lifelong learning. I often told my students, “I don't know, let's see what we can find out,” and included them on my journey as I took classes. My journey was not to just teach but challenge myself as I grew in my teaching. Taking on new challenges kept me energized. Often these challenges were out of my comfort zone, but I persisted even if I knew I might fail. When I attended professional development sessions, my goal was to find at least one “thing” I could use to improve my teaching.

I also wanted my students to know I was human. I arm wrestled them, went to their dances, events, and even their funerals. I laughed with them, laughed at myself, and smiled a lot, for each day was a new opportunity.

To keep professionally charged, I not only belonged to professional organizations, I participated in them. This allowed me to network with exceptional educators around the world. These experiences gave me the courage to evolve and change my classroom to meet the needs of the learners.

What lessons from your parents have you carried through the years?
I was fortunate to have grown up in an extended family where life lessons came from many generations. Technology lessons came from my great-grandmother. I will never forget when she said, "To think I came across South Dakota in a covered wagon and now I'm watching a man walk on the moon." My grandmother taught me the importance of listening without judgment. My parents were consistent with their lessons, too. They often reminded us that: “Life is not fair. Sometimes you just need to work a little harder." And, “Everything can be taken from you except your education. So, keep learning because life has no guarantees.” Most importantly my parents taught me, “Never judge someone until you have walked a mile in their shoes.”

What have you learned that you would want to pass on to younger generations?
- Life is a system. Everyone's job is important.
- Be an active participant in life and know that it gets messy.
- The golden rule works.
- Be humble, grateful, and kind to everyone.
What special challenges have you faced as a woman in a mostly male-dominated field?
Strong female role models in the technology and engineering field were almost nonexistent. It was also a challenge to find supportive male role models. Some people did not realize I was serious about what I chose to teach. Often, finding men were promoted before women, I had to work twice as hard to be considered for the same promotion. Today women still face the challenge of fair pay and benefits. Sadly, there is the mindset that women do not face these same challenges today. Many times I feel women have made progress only to find my daughter, who is also in a male-dominated field, encountering the same challenges in her career as I did in mine.

Do you have any recommendations for creating a more inclusive community/classroom or words of advice for working with underrepresented populations?
Equity in the classroom starts by seeing the individual—not the color of their skin, their intellectual capability, the clothing they wear, nor their spirituality—look for the person. When teaching, use your strengths and work on your weaknesses. Be consistent: “Say what you mean. Mean what you say.” And above all, treat everyone with respect.

What are you looking forward to next?
We have impressive leaders in ITEEA. They are devoted to providing an array of opportunities for students and teachers. I am honored to be a participant in the Standards Revision Project. I look forward to the results of this collaboration. And as always, I look forward to the smiles of children every day.
making cents of
the nature of engineering

Students often mention that their ideas have changed because the model they drew on paper during Day One did not translate well to real life.

Next Generation Science Standards (NGSS) notes that all students can benefit from knowledge of engineering design practices: defining problems, developing solutions, and optimizing (NGSS, 2013). Design activities provide a useful vehicle for teaching engineering design practices because they reflect the systematic problem solving that characterizes the work of engineers (NRC, 2009). However, it is becoming increasingly important for students to go beyond engaging in design by reflecting upon the nature of engineering (NOE) and wrestling with questions such as, “What do engineers do?” and “What is engineering?” (Pleasants and Olson, 2018).

This article describes an activity in which middle school students are asked to create a product to help a fictional bank sort coins. This design activity can be used to meet NGSS middle school engineering standards three and four (MS-ETS1-3, MS-ETS1-4) that target optimization and the iterative nature of engineering (see NGSS Table 3 on page 24). Over the course of three 45-minute class periods, students identify the criteria and constraints of the problem, create a model, and then gather and analyze data to optimize their coin sorters. Teachers ask questions throughout this process to prompt students to reflect on their in-class experiences with the coin sorters and explore how those experiences might relate to what engineers really do. This explicit and reflective approach of planning representative activities and asking reflective questions demonstrably helps students deepen their understanding of the nature of science (Khishfe & Abd-El-Khalick, 2002), and we have found it applies equally to teaching NOE.
Day One: Constraints and Models

The teacher introduces the activity by telling students that they are part of a design team, and a bank has approached them to design a product to sort coins. The teacher then asks, “What questions do you have for the bank?” Students talk about this question in small (table) groups and then discuss their ideas as a class. Allowing students to talk in groups gives them time to generate more ideas of their own before the class discussion. During the class discussion, the teacher writes each of their questions on the board. Example student questions are listed in Table 1 below.

Once there is a list of 4-6 questions on the board, the teacher asks students, “How will the answers to these questions affect your work on the project?” and, “Why do you think engineers need to identify these types of questions before they start working on a project?” Students often discuss how knowing exactly what the bank wants in a coin sorter makes it easier for them to design something that will make the bank happy. They also talk about how materials and time influence (and often limit) what can be designed. The teacher then explains to students that engineers call these types of limits “constraints” and writes this new term on the board. To make sure that students understand this new term, the teacher asks, “What might happen if an engineer doesn’t understand the constraints of a project?” Students confirm their understanding by answering that engineers might not get something done in time, might make something the bank doesn’t want, or plan to make something for which they don’t actually have the materials. After this short NOE discussion, the teacher answers the student-generated questions on the board to the best of their ability (see Table 1 for example teacher answers).

Once students understand the expectations for the activity, they are asked to begin planning their designs in table groups of 2-3 students. The students are not given access to materials at this point. This is done to discourage students from using a hands-on, trial-and-error type approach that is not reflective of the work of engineers (NRC, 2009). While students discuss their plans, the teacher walks around the room and checks in with each table group.

If table groups are having a hard time generating ideas for their coin sorter, the teacher can show them a video (example: www.youtube.com/watch?v=X5f5JE-xNn4) that demonstrates how fruit is sorted based on size. The teacher can then ask students to consider how they might use what they see in the video to help them with their coin task.

Most groups draw pictures to plan their coin sorters (Figures 1 and 2). While students are planning, the teacher stops the class and says, “I know you aren’t finished yet, but we notice a lot of groups are drawing pictures. Why is that helpful to you?” Or, if no groups are drawing pictures the teacher can ask, “Why might it be helpful for you to draw a picture?” Students generally recognize that the drawings help them communicate their ideas and visualize whether those ideas will work. The teacher then tells students that their drawings are a type of model (and write “model” on the whiteboard) and asks, “Why do you think real engineers use models?” Students speculate that real engineers use models for similar reasons and often recognize that it is easier for engineers to make changes to a model than to a final product.

Table 1. Student questions for the bank and potential teacher answers.

<table>
<thead>
<tr>
<th>Student Question</th>
<th>Teacher Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much time do we have?</td>
<td>The rest of the class period.</td>
</tr>
<tr>
<td>How do you want the coins sorted?</td>
<td>In pennies, nickels, dimes, quarters.</td>
</tr>
<tr>
<td>How big should the coin sorter be?</td>
<td>It should fit on your desk.</td>
</tr>
<tr>
<td>How many types of coins?</td>
<td>Four (pennies, nickels, dimes, quarters)</td>
</tr>
<tr>
<td>What can we use to make it?</td>
<td>Cardboard, tape, glue, paper, scissors</td>
</tr>
<tr>
<td>Does it need to count the value of coins?</td>
<td>Not at first, but maybe (see “Extension Activity” below.)</td>
</tr>
</tbody>
</table>
Day Two: Iterations and Collaboration

Day Two begins with the teacher asking students, “How have your ideas changed since you first started working on your coin sorter?” Students often mention that their ideas have changed because the model they drew on paper during Day One did not translate well to real life. If students do not come up with this idea, the teacher can scaffold them by asking, “How is your coin sorter different from the picture you drew yesterday?” The teacher then asks students to state specific reasons that their coin sorter designs differ. Students may incorrectly assume that all drawings are models. To address this misconception, the teacher asks, “How is the model you drew different from other types of drawing you might do?” Students often say that they are drawing something they plan to create later. If students do not mention materials in their answers, the teacher asks, “How does your model show what materials you plan to use?” and “Why is it important for a model to reflect materials?” By the end of the discussion, students should understand that a model is made with the intention of communicating structure, materials, and how a design will function.

After the discussion of models, students can continue their work, this time with access to materials including cardboard, tape, glue, paper, scissors, and a variety of coins. The teacher continues to monitor the class by walking around the room and checking in with each group. At the end of the class period, students are asked to make sure their names are on their coin sorters and to store them safely for Day Two.

Students may incorrectly assume that all drawings are models. To address this misconception, the teacher asks, “How is the model you drew different from other types of drawing you might do?” Students often say that they are drawing something they plan to create later. If students do not mention materials in their answers, the teacher asks, “How does your model show what materials you plan to use?” and “Why is it important for a model to reflect materials?” By the end of the discussion, students should understand that a model is made with the intention of communicating structure, materials, and how a design will function.

Day Three: Optimization, Trade-Offs, and Design Process

Class begins with a quick carousel activity. The teacher directs students to leave their coin sorter on their home group table and then rotate in groups to the other tables. This encourages students to consider the coin sorters that their classmates created. The teacher then asks students to compare their coin sorter designs. Students often note that some of the coin sorters operate differently, are made with different combinations of materials, or vary in size. The teacher then asks them, “How could you determine which design is the best?” Students brainstorm as a class and generate a list of methods on the board (Table 2). Together, the class decides on a method to collect data; students generally choose to see which design sorts coins the fastest. To make sure that students have a clear idea of how to collect this data, the teacher asks them, “How can we make sure each group is timing in the same way?” As a class, students decide when to begin and end timing (e.g., start timing when fingers let go of coin, stop timing when you hear the last coin drop) and what timing device to use (e.g., cell phone, stopwatch, clock). The teacher also asks, “Why might it be important for each group to use the same num-
ber of coins?” Students reply that they can’t compare times with other groups if they are each using a different number of coins. When the teacher is satisfied with a clear procedure, students are directed to work in groups to time their coin sorters and then record their results on the board for all to see.

When all student groups have recorded their times on the board, the teacher asks the class, “Based on these results, which coin sorter is the best?” Students of course answer that the coin sorter with the fastest time is the best. The teacher then asks, “Even though this coin sorter had the fastest time, why might it not be the very best coin sorter?” Hopefully, students think back to the list of methods (Table 2), recognizing that multiple criterion are used to evaluate a design. The teacher then directs students to decide on a method to collect data on a different characteristic of the coin sorter (e.g., accuracy) and again has them test and record their results on the board. Students should test and collect data on 2-4 characteristics.

When students have finished collecting data, the teacher asks them, “How could the data we collected help you make your coin sorter better?” Students generally answer that they could see where their coin sorter wasn’t very good based on the data and then work on making that part better. The teacher helps students connect this analysis task to the work of real engineers by asking, “How do you think real engineers use data to continually improve their designs?” Students respond that engineers use the data to identify what they need to improve. The teacher explains to students that engineers call this idea “optimization” and writes this new term on the board list.

The teacher then asks students, “How did you decide what changes were most important to make to your coin sorter?” Some students answer that it was more important to them to have a faster coin sorter, and others felt it was okay to have a coin sorter that was a little slower if it was easier to operate. The teacher asks students, “How do engineers decide what changes to make?” Students talk about how engineers judge designs by how well they meet the constraints and how well they work, but they also use their opinions. At some point students note that sometimes engineers must consider the good and the bad of their choices. The teacher tells students that these are called “trade-offs” and explains that engineers use data and their personal values to decide what is best (Norman, 1998).

The activity ends with a discussion of the NOE idea that a single design process may misrepresent the work of engineers (Kruse, et al., 2017; Pleasant & Olson, 2018). The teacher begins by asking students, “What things did you do to create your coin sorter?” Students typically describe their process using the

Table 2. Possible methods to collect data on coin sorters.

<table>
<thead>
<tr>
<th>Question</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which design sorts the fastest?</td>
<td>Give students a set amount of coins and a timer. Students record the amount of time it takes for the coin sorter to sort the amount of coins in each sorter.</td>
</tr>
<tr>
<td>Which design sorts the most accurately?</td>
<td>Give students a set amount of coins and have students record how many coins are in the accurate place.</td>
</tr>
<tr>
<td>Which design is easiest to use?</td>
<td>Have students rotate to different groups and see if they can figure out how to work the machine without verbal instructions.</td>
</tr>
<tr>
<td>Which design uses the least amount of materials?</td>
<td>Have students measure the materials they used in their coin sorter.</td>
</tr>
</tbody>
</table>

Figure 3. Student coin sorter with horizontal divisions.

Figure 4. Student coin sorter with vertical divisions.
making cents of the nature of engineering

following steps: create a model, build a coin sorter, collect data, make changes. To help students see that this process actually varied from group to group, the teacher says, “To what extent do you have to do these things in the same order?” Students begin to realize that they do not have to use the same step-by-step process to create a coin sorter. For example, some students made changes to their model after building their coin sorter because they were trying to communicate new ideas to members of their group. The teacher ends the class period by asking students, “Why is there no single design process that all engineers follow?” Students answer by explaining that engineers take different actions based on how and when their ideas change, or when they see things not working.

Assessment

The teacher may assess students’ views of the NOE throughout the three-day activity by using any of the questions in Table 3. In this article the questions are used as discussion prompts, but they can also be used as exit slips, journal reflections, or quick-writes. For example, the teacher might ask students to complete an exit slip after Day One using the following question: “Why do you think real engineers use models?” Correct student responses may include that drawings/models help them communicate their ideas and visualize whether those ideas will work or not, as well as that it is easier for engineers to make changes to a model than to a final product. An incomplete response would be that the model is just a drawing of the design.

To assess NGSS standard MS-ETS1-4 in addition to NOE views, the teacher can have each group make a three-column chart at the conclusion of Day Three that lists (1) the changes they made to their designs (on Day Three), (2) why they made each change, and (3) how it affected their design (in both good and bad ways). See Table 4 for example student responses. Student explana-

<table>
<thead>
<tr>
<th>Nature of Engineering Topics</th>
<th>Teacher Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraints</td>
<td></td>
</tr>
<tr>
<td>• What questions do you have for the bank?</td>
<td></td>
</tr>
<tr>
<td>• How will the answers to these questions affect your work on the project?</td>
<td></td>
</tr>
<tr>
<td>• Why do you think engineers need to identify these types of questions before they start working on a project?</td>
<td></td>
</tr>
<tr>
<td>• What might happen if an engineer doesn’t understand the constraints of a project?</td>
<td></td>
</tr>
<tr>
<td>Models</td>
<td></td>
</tr>
<tr>
<td>• Why might drawing a picture help you in your task?</td>
<td></td>
</tr>
<tr>
<td>• Why do you think real engineers use models?</td>
<td></td>
</tr>
<tr>
<td>• How is the model you drew different from other types of drawing you might do?</td>
<td></td>
</tr>
<tr>
<td>• How does your model show what materials you plan to use?</td>
<td></td>
</tr>
<tr>
<td>• Why is it important for a model to reflect materials?</td>
<td></td>
</tr>
<tr>
<td>Iteration</td>
<td></td>
</tr>
<tr>
<td>• How have your ideas changed since you first started working on your coin sorter? How is your coin sorter different from the picture you drew yesterday?</td>
<td></td>
</tr>
<tr>
<td>• What might cause real engineers to change their designs?</td>
<td></td>
</tr>
<tr>
<td>Optimization</td>
<td></td>
</tr>
<tr>
<td>• How could you determine which design is the best? What characteristics would the best possible coin sorter include?</td>
<td></td>
</tr>
<tr>
<td>• How could the data we collected help you make your coin sorter better?</td>
<td></td>
</tr>
<tr>
<td>• How do you think real engineers use data to continually improve their designs?</td>
<td></td>
</tr>
<tr>
<td>• How did you decide what changes were most important to make to your coin sorter? How do engineers decide what changes to make?</td>
<td></td>
</tr>
<tr>
<td>Collaboration</td>
<td></td>
</tr>
<tr>
<td>• How has working in a team helped you?</td>
<td></td>
</tr>
<tr>
<td>• How might engineers benefit from working in teams?</td>
<td></td>
</tr>
<tr>
<td>• Why do students in the class have different ideas?</td>
<td></td>
</tr>
<tr>
<td>• How might culture influence engineers’ experiences and knowledge?</td>
<td></td>
</tr>
<tr>
<td>• Why would it be important for engineers to work with people who do not have the same culture and experiences?</td>
<td></td>
</tr>
<tr>
<td>• How does this help them come up with better designs?</td>
<td></td>
</tr>
<tr>
<td>Design Process</td>
<td></td>
</tr>
<tr>
<td>• What things did you do to create your coin sorter?</td>
<td></td>
</tr>
<tr>
<td>• To what extent do you have to do these things in the same order?</td>
<td></td>
</tr>
<tr>
<td>• Why is there no single design process that all engineers follow?</td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Example Student Responses.

<table>
<thead>
<tr>
<th>Changes made to design:</th>
<th>Why change was made?</th>
<th>How it affected the design?</th>
</tr>
</thead>
<tbody>
<tr>
<td>We made the incline more steep.</td>
<td>Our coin sorter was slower than the fastest coin sorter in the class.</td>
<td>It sorted coins faster but not as accurately.</td>
</tr>
</tbody>
</table>

We made the incline more steep. Our coin sorter was slower than the fastest coin sorter in the class. It sorted coins faster but not as accurately.

Students should specifically mention data collected. In addition, the teacher may ask students to reflect on the following NOE question: “How do engineers decide what changes to make to their designs?” Correct responses include the following: it makes it a better fit for the bank, or data from the model was used to improve the design.

We use a standards-based system in our classrooms. That is, rather than assigning points to students’ responses, we identify whether a student has met the standard. Rather than collecting points, students use the examples above to create a body of evidence that shows they have come to understand the NOE. Our job is to determine if the body of evidence meets the standard using a dichotomous (yes/no) approach.

Conclusion

As students come to understand the NOE, they will see that:

Creativity is inherent in the engineering design process. Optimism reflects a world view in which possibilities and opportunities can be found in every challenge and an understanding that every technology can be improved. Engineering is a “team sport;” collaboration leverages the perspectives, knowledge, and capabilities of team members to address a design challenge.” (NRC, 2009, p.152).

We hope a greater diversity of students will consider careers in engineering as they come to understand engineering and design to be creative, social processes that solve meaningful problems.

References


Sarah Voss is a graduate student in Science Education at Drake University in Des Moines, IA. She can be reached at sarahvoss@drake.edu.

Hannah Klinker is a graduate student in the School of Education at Drake University in Des Moines, IA. She can be reached at hannahklinker@gmail.com.

Jerrid Kruse is an associate professor of Science Education at Drake University in Des Moines, IA and can be contacted at jerridkruse@gmail.com.

*This is a refereed article.*
The excitement of summer break arriving may have best been described by country music artist Kenny Chesney in his hit song Summertime, “…just like a long-lost friend you ain’t seen in a while, you can’t help but smile” (Wiseman & McEwan, 2006). For educators and students alike, this is a much-needed vacation to help reinvigorate their thirst for teaching and learning. However, the weeks leading up to summer break can be stressful for instructors and administrators, as they are ultimately responsible for inspecting and cleaning up their STEM education facilities to ensure a safer start the following academic year. It was almost three years ago that we published safety recommendations for the start of a new school year (Love & Roy, 2017). As the sun sets on another academic year, Safety Spotlight comes full circle by providing recommendations for closing down a makerspace or lab in preparation for summer break.

**The OAH Approach**

The thought of cleaning up a lab after a busy semester or marking period can be a daunting one. However, if approached using the three categories depicted in Figure 1, it becomes a much more manageable task. There is a considerable amount of overlap among...
these three areas, which is why the Organizational, Administrative, Housekeeping (OAH) approach should be viewed as a systematic approach working toward one goal—maintaining safer STEM facilities. The following section describes each area of the OAH approach with examples.

Organizational Considerations

This section encompasses paperwork tasks as well as other actions requiring organization for compliance with federal, state, and local legal requirements.

Student Safety Documentation – All students will have to retake safety tests upon returning the following school year, but instructors should maintain these valuable safety records (e.g., safety tests, safety acknowledgement forms, safety assignments, etc.) until students graduate as part of developing a legal paper trail. If an accident occurred, the instructor should keep all safety documentation for the students involved. The statute of limitations for negligence in most states is 2-3 years from the date of the harm. For example, in the state of Connecticut, parents or legal guardians can file a lawsuit as “next friends” if the child is under 18 years old. While the 2-3 years rule is the same for children as well as adults in Connecticut, in other states, the timeframe for minors to file a lawsuit on their own behalf may not start until their 18th birthday.

SDS (Safety Data Sheet) – In conjunction with inventorying chemicals and other hazardous materials, the SDS binder should be checked to ensure any new hazardous items have an SDS on file. The SDS binder should be organized by current items and old items. Each SDS should be dated so the school knows when that item was obtained. Old SDSs should be kept on file for at least 30 years in the event that an employee or retiree develops symptoms resulting from a chemical or material to which they were exposed. The instructor, school nurse, school chemical hygiene officer, and local fire marshal should all receive copies of the updated SDSs. School districts may opt to use an online SDS management system to help inventory hazardous materials, and organize and update SDSs. If using an online system, the SDS must still be readily accessible in the event of an accident.

Disposal – Appropriate disposal of hazardous chemicals and materials is critical for a safer teaching/learning environment. Throughout the school year, hazardous chemicals for disposal need to be stored appropriately in a secure area like the chemical storeroom or a locked flammable cabinet. Make sure chemical containers are placed in trays in case of leakage. Also, have all chemicals labeled along with copies of their SDSs. Check the chemical inventory for those chemicals that have designated “life spans” (e.g., peroxides). Additionally, items like lithium batteries can become explosive. These and other hazardous items can be very dangerous and cause explosions/fires. Instructors should work with their school system to make sure only certified and reputable hazard waste contractors are used. Remember, the school owns the chemical legally from cradle to grave! Resources such as SDSs (Section 13 – Disposal considerations), Flinn Scientific catalogs (Chemical Disposal Procedures – Safety Reference) and others have critical information on proper disposal of chemicals.

Storage – Appropriate storage and security of hazardous chemicals are also critical. There are several important resources that should be used to assure storage of these hazards is done in a safer way. Examples include the following:

SDS Section 7 – Handling and Storage provides recommendations on the conditions for safer storage, including any incompatibilities. It also provides advice on specific storage requirements (e.g., ventilation requirements). Check out the National Science Teaching Association’s (NSTA) September 27, 2019 Safety Blog titled “Safer Storage” (http://blog.nsta.org/2019/09/27/safer-storage/). It contains valuable information that should be considered for storing hazardous chemicals in chemical storage rooms, storage cabinets, and refrigerators, based on legal safety standards and better professional safety practices. Lastly, Flinn Scientific’s catalog has a special section on chemical storage patterns for specific chemical categories and compatibilities.

Administrative Considerations

This section includes items that the instructor must complete and keep on record as evidence that appropriate safety actions were taken if an accident occurs. These can be time-consuming but are critical if there is a serious safety incident involving potential litigation.
Inspection Report – Roy and Love (2017) discuss the importance and details of conducting a thorough inspection report at the end of each semester. The Pennsylvania Department of Education's Technology Education Safety Guide provides an excellent inspection checklist for school systems to use (www.teeap.org/Publications/safety.html). While conducting these inspections it is important for instructors to document all results and share a copy with their administration. This should involve tasks ranging from testing engineering controls (e.g., eye wash, emergency power shut-off switches, machine guarding, dust collection systems, etc.) to restocking your first aid kit.

Inventory – This includes three parts: chemical and hazardous materials inventory, tool and equipment inventory, and non-hazardous item inventory (e.g., computers, cardstock, etc.). Chemicals and hazardous materials should be safely checked for expiration date, proper storage/security, appropriate labeling from the manufacturer, and the SDS on file. A list of all chemicals/hazardous materials, expiration dates, and storage locations should be documented and updated each year, and this should be kept on file by the school system's designated Chemical Hygiene Officer (required under OSHA regulations). Flinn Scientific provides excellent resources for helping inventory chemicals. Tool and equipment inventory helps to deter theft and document the condition of these items over time.

Budget Planning – During the instructor’s thorough inventory of items they may find an excess of items or ones that need to be reordered. This can help generate a list of items ordered each year and aid in budgeting for future years based on past trends. The inspection and inventory tasks can also help in budgeting for upcoming expenses such as preventative maintenance or replacement costs.

Work Orders – While conducting the safety inspection, instructors may recognize facility or equipment issues that require the expertise of trained maintenance personnel. For example, if there is a frayed cord or missing plug ground prong on a piece of equipment, instructors should not attempt to install a new cord. They should submit a request to have their school system’s electrician fix these types of issues. If an instructor installs a new cord and there is an accident found to be the result of the cord they installed, they could be liable. Teachers should not be afraid to use the resources and expertise provided by their school system.

Training and Insurance – At the end of the year it is good practice for instructors and administrators to check when their professional liability insurance policy will expire and make a note on their calendar to renew it. Professional liability policies such as those available to ITEEA members through Forrest T. Jones & Company (FTJ) provide very reasonably priced plans that could cover expensive legal fees in the event of an accident. If there will be new equipment arriving in the facility, or if an instructor will be expected to teach new activities and processes involving hazards for which they are untrained, they should contact their administration in writing requesting to attend training on appropriate hazards. Under OSHA regulations, employers have a responsibility to provide appropriate training for their employees relative to any new hazards in the workplace (e.g., hazardous chemicals, power tools, etc.).

Security – After spending time inventorying and verifying the condition of items, it is important to secure these items by locking them in the appropriate storage areas. Instructors may also consider removing all keys from the power switches of equipment. This effective energy lock-out will deter theft and abuse of equipment. It also will limit the risk of someone gaining access to hazardous items over the break and sustaining an injury from them.

Housekeeping

This section provides some final considerations. While certain housekeeping tasks should be performed more than just once a year, the end of the school year provides an opportunity for conducting housekeeping tasks in a more thorough manner.

Cleaning – Throughout the year students are handling many items in a makerspace and lab. During flu season teachers are generally more cognizant about sanitizing desks, handles, electronics, and other items students are handling. The end of the school year is a good time to use disinfectant wipes to clean items before storing them away. Do not forget about places where students place other body parts like their eyes (e.g., microscopes). Instructors should thoroughly sanitize and clean all personal protective equipment (PPE). At a minimum this should include washing aprons/jackets, gloves, and all safety goggles/glasses/face shields. Cabinets with ultraviolet light can sanitize safety goggles/glasses, but dish detergent and warm water can help clean off residue that has built up over the course of the
year. This is also a good time to clean out and sanitize any refrigerators in a makerspace or lab. Furthermore, removing dust or dirt that has built up on lighting fixtures, fume hoods, equipment, and other items over the course of the year can help reduce fire hazards.

Instructors must remember that they have a responsibility to ensure that appropriate ventilation is provided and proper PPE is worn by everyone participating in the cleaning process. It is also critical that the instructor ensure equipment and tools are unplugged or the breaker switch is turned off while cleaning them. This is especially important if students are assisting with the cleaning tasks as seen in the Cureton v. Philadelphia School District ruling (Love, 2013).

Safety Zones and Signage – As part of the safety inspection report, instructors should ensure that all safety zones are clearly marked, in good shape, and all signage matches the current equipment, tools, and processes in that area. Instructors should also check nonskid strips and the function of all electrically operated signs.

Replacing Parts – A major component of housekeeping is the inspection and replacement of items like ventilation filters, blades, and fluids. The distilled water used in the cooling pump for a laser engraver should be changed according to the manufacturer’s recommendations. The end of the school year provides a great time to change the distilled water for better machine performance and to prepare for the next school year. As instructors are conducting their safety inspection report, they may find used or worn parts that need to be replaced. If these require major replacements that could impact the safer operation of the machine, it is recommended that you request a certified technician make those repairs. It is critical for instructors to thoroughly inspect all safety guards and either lock a machine out of order or replace the guard with a manufacturer-recommended part before it can be used again. Similar to the cleaning process, instructors must ensure all equipment and tools are unplugged or the breaker switch is turned off while performing any maintenance tasks.

Preventative Maintenance Measures – There are a number of preventative maintenance measures that should be performed periodically to increase machine/tool performance and longevity. These should be performed according to the manufacturer’s equipment/machine manuals. Moving parts that require being greased or oiled should be tended to at this time. Another consideration is the humidity in your makerspace or STEM lab and the impact it can have on causing certain equipment to rust, especially the shiny tabletops of woodworking equipment. One option is to run a dehumidifier in the facility, but this can be costly in terms of electricity and requires continual drainage. The other option is to use a rust prevention agent such as BoeShield T-9. This will provide a wax-like coating that resists rust while also not attracting dust to stick to it. If using a rust prevention agent, be sure to follow the manufacturer’s recommendations for ventilation while applying and also the required drying time before use.

Conclusion

As this article asserts, there are a number of items to consider when preparing to close up a makerspace or STEM lab for summer break. It can be a daunting task if items are not kept up with throughout the school year. The OAH approach can assist in ensuring that critical tasks are considered and completed. Each task plays an integral role in the overall mission of providing a safer facility from year to year. Instructors and administrators should work collaboratively in conducting and communicating the results of these end-of-year activities. The OAH approach has the potential to help schools improve their STEM education safety plan, proactively address foreseeable safety hazards, avoid costly lawsuits, and generate documents that reveal trends to help budget and save money.

References


Tyler S. Love, Ph.D. is an assistant professor of Elementary/Middle Grades STEM Education and Director of the Capital Area Institute for Mathematics and Science (CAIMS) at Penn State University’s Capital Campus. He can be reached at tsl48@psu.edu.

Ken R. Roy, Ph.D. is the chief science safety compliance adviser for the National Science Teaching Association (NSTA) and Director of Environmental Health & Chemical Safety for Glastonbury Public Schools in CT. For current safety information, follow Dr. Roy on Twitter @droysafersci. He can be reached at safesci@sbcglobal.net.
Introduction

Many ideas have surfaced over the last several decades about creating artificial islands for moving unwanted industrial processes out of the normal environment. These ideas have centered around such things as energy production, manufacturing, heavy industry, recycling, and chemical/processing plants. In this challenge, student teams can address using an artificial island for recycling batteries of all kinds.

Background

Students must first identify the kinds of batteries that can be recycled, such as lead-acid, lithium-ion, etc. What is the general process for doing this? What are the chief materials streams and recycle residues? Learning how the process is configured is important as well. Determining who performs this recycling function today and learning about how this is done can be important to this design challenge.
What concerns does this industrial activity pose to the general community, such as:

- Worker safety?
- Environmental impact-liquid/air emissions?
- Disposal of waste streams/materials?
- Handling of recycled materials?
- Spill mitigation?

What are the general methods, practices for dealing with this, and the regulations that govern them?

How large a manufacturing facility is needed to support this process on land—concerns such as:

- Operating staff.
- Building area—single or multiple floors.
- Support services like electricity, natural gas, etc.
- Roadways and access.
- Special accessory facilities.

Designing the Artificial Island

The island should be designed to support this recycling process and ideally do it better than the land-based operation. So, the basic question becomes: how have artificial islands been constructed before? Research the basic construction techniques that have been used and settle on a design. How can the island be protected against the vagaries and destructive nature of water-borne storms and effects like wind-driven waves and tides?

Encourage the student teams to build scale models of the island design they favor. From where and how do the materials necessary to construct the island come? What might be the time required to build the island? What other benefits could an artificial island realize for the nearby onshore community:

- Fishing areas?
- Recreation opportunities?
- Possible location of wind turbines?
- Jobs?
- Co-location of other industrial processes?

Explore the benefits versus community costs to be incurred.

Would an island be needed after all? Are there alternatives like a reconditioned large ship or maybe barges tied together? Look for creative alternatives.

Obviously, there will be no vehicular traffic via roads, so now provision must be made to move things to and from the island via boat or large ships. This implies docking and terminal points where various input/output shipments can be accomplished. There could be some interesting and applicable technology here from the offshore oil loading and unloading facilities used around the world today.

Should spills be anticipated, what kinds of protective barriers would be built onto the island to protect against water contami-

nation? Certainly, the island will experience inclement weather, and the anti-contamination systems alluded to above must be able to accommodate this as well.

The utility services to the island must be brought from shore, or maybe these facilities must be produced on the island as well, using things like generators, solar energy systems, wind energy, bottle-fuel gases, etc. How might this affect the size of the island? Just how far should the island be from shore? Where is an ideal location for the island (certainly not estuaries or fish spawning/breeding areas)? How about loading docks and distribution facilities on the island?

Final Thoughts

Is this activity any different than planning a colony on a remote place like another planet, the moon, under the sea, or at the South Pole?

Strive to have your students balance their approach to this by identifying and evaluating the impacts and cost benefits of the artificial island.

If your school is near a body of water perhaps you can personalize the activity by selecting a spot in the water where this design challenge might be located. It could make for a better team activity, as things would be more familiar and closer to home. Otherwise, select a spot in your state that is well known and design around that spot.

Urge the teams to think both broad and deep about the challenge, looking at as many possible impacts and how to minimize them.

Harry T. Roman is a retired engineer/inventor and author of technology education/STEM books, math card games, and teacher resource materials. He can be reached at htroman49@aol.com.

April 2020 technology and engineering teacher 31
Introduction

In order to feed the world’s growing population, farmers will need to produce 70% more food by 2050 than they did in 2006 (Bruinsma, 2009). To meet this demand, farmers and agriculture companies are turning to Internet of Things (IoT) technologies and data visualization to optimize analytic capabilities and, ultimately, enhance their production through digital agricultural practices (Jayaraman, Palmer, Zaslavsky, & Georgakopoulos, 2015). However, few students are given the opportunity to explore the potential and impacts of modern “digital” agriculture during their educational experience. Therefore, this article will provide an example instructional activity combined with the principles of IoT technology and agriculture that could be used or mimicked to present students with an advanced look at an essential field related to food production and the growing population. Specifically, the instructional context of this les-

By exposing students to the concept of digital agriculture earlier in their lives, they will be able to develop the proper mindset to advance the field further when they enter the professional world.
son was developed to be situated within the Grand Engineering Challenge of Managing the Nitrogen Cycle (National Academy of Engineering, 2019). The activities of this lesson directly relate to this Grand Engineering Challenge because students will develop a means of surveying farmland for nitrogen deposits and explore ways for farmers to better manage their crop production. This exercise will also enhance the rigor of engineering design and provide socially connected relevance to learning. Digital agriculture is an idea in which many students around the world, and in the Midwest U.S. specifically, can find interest, as they may be surrounded by agriculture in multiple forms. By exposing students to the concept of digital agriculture earlier in their lives, they will be able to develop the proper mindset to advance the field further when they enter the professional world. The challenge included in this lesson centers on students designing and programming a robot to monitor a field for nitrogen deposits with the intent of optimizing fertilization practices.

Agricultural Advances and Fertilization of Crops

Without advances in agricultural practices and technology, humanity’s ability to produce enough food for the entire population would have fallen short millennia ago (Zimdahl, 2015). Settled agriculture, machine-assisted practices, and the introduction of science and chemical engineering have all improved the overall yield of agricultural production. While some are quick to point out the adverse effects of these advances (Foley, DeFries, Asner, Barford, Bonan, Carpenter…& Helkowski, 2005), in his book, Six Chemicals that Changed Agriculture, Zimdahl (2015, pg. 188) closes by arguing that without such advances in agriculture, humans would have run short of space and food long ago:

"...barring a worldwide disaster, the human population will continue to increase for several decades. There is no land for agriculture to expand. That is not news to international organizations, most countries, nongovernmental organizations, companies engaged in agriculture, faculty of Colleges of Agriculture, and farmers. It may be a revelation to the vast majority of people who don’t farm. After all, how can there be a problem, the grocery store is always full!"

History of Agricultural Fertilization

People have known for more than 2000 years that the addition of certain substances to soil improved the yield of plants (Ganzel & Reinhart, 2019). The addition of manure, bird droppings, and even ground-up human bones, have all been used in an attempt to improve the production of farmland (Maxwell, 2014). Even without a full understanding of which nutrients were needed, and why these might be effective, individuals in Europe were encouraged during World War I to save the fat and bones from their food for use in fertilizer (Figure 1).

The use of human bones—and other less-than-desirable substances—to improve agricultural yield has not always been met with optimism. For example, several newspapers from the 1800s include commentary surrounding the ethical, moral, and political ramifications of using bones (some of which were reportedly dug up from battlefields, tombs, and churches) as fertilizer (Maxwell, 2014). For example, the Westmorland Gazette (16 November 1822) records:

"It is estimated that more than a million bushels of human and unhuman bones were imported last year from the Continent of Europe...It is certainly a singular fact, that Great Britain should have sent out such multitudes of soldiers to fight the battles of the country upon the Continent of Europe, and should then import their bones as an article of commerce to fatten her soil''

Despite the storied history of fertilization, today the most common nutrients added to soil to increase agricultural yield are less controversial as they are chemically synthesized (Ganzel & Reinhart, 2019). Nitrogen, which is pulled from the soil by plants during growth, can be added back to the soil artificially through fertilizers. The addition of this fertilizer not only results in higher yields, but also provides less of a need to rotate crops (Phoslab, 2013). Originally the process of fertilizing plants with nitrogen was quite dangerous, as nitrogen is one of the main ingredients in explosives and often resulted in accidental explosions during shipping or application (Ganzel & Reinhart, 2019). This danger was in part due to the form of nitrogen, which was originally applied as pellets on the surface; however, as this method was highly dangerous, innovations were attempted until a new approach was developed wherein nitrogen was applied directly beneath the surface of the field and then covered with new soil (CropNutrition, 2019)—a practice still in use today.

Even with improved safety around the application of nitrogen, there remain looming concerns with the impacts of nitrogen fertilization on the environment. Specifically, nitrogen run-off from fertilization has been linked with "dead zones" where aquatic life cannot survive. Relatedly, nitrogen production has been linked with global warming and the associated consequences (Elliott, 2019). These concerns suggest that additional effort may be
needed to satisfy the demands of a growing population while also balancing concerns around environmental damages.

**UAVs, Data Visualization, and Agriculture**

Within recent years there has been a surge in the popularity and prevalence of Unmanned Aerial Vehicles (UAVs), often referred to as drones, for both personal and commercial purposes (Strimel, Bartholomew, & Kim, 2017). This trend has been attributed to the technological advancements that have resulted in easier piloting and lower costs for production (AUVSI, 2013). As these UAV capabilities continue to advance, so does their application across a variety of industries. Specifically, UAVs are revolutionizing the agriculture industry, as UAV imaging capabilities are providing farmers with effective and more cost-efficient tools to track important conditions such as field drainage, crop damage and disease, and nitrogen deficiencies in soil. The sophisticated imaging and sensing technologies with which UAVs are now equipped, in combination with advanced IoT capabilities, have now enabled farmers to harness the data revolution and achieve what is now known as “digital agriculture.” Within this new world of digital agriculture, UAVs can collect and process data in a way that facilitates informed decisions and control of agricultural equipment to boost crop yields, minimize waste in practices such as irrigation and fertilization, and ultimately increase a farm’s profitability. While increasing profitability is, of course, a benefit to the industry, the societal implications can be extremely critical, as climate change, a boom in overpopulation, and other factors pose a threat to the current food supply and production levels.

One key practice toward effectively harnessing the UAV-collected data is the data-visualization process. Data visualization is the process of representing data with the help of graphs and other visual representations, which can support individuals in analyzing complex data (Mittal, Khan, Romero, & Wuest, 2018). It is intended to clearly convey and communicate information through graphical means, enabling end users to comprehend data in a much more explicit fashion (Fry, 2008; Lee, Butavicius, & 2003). Visualization is important when working with sensor data (Kubicek, Kozel, Stampach, & Lukas 2013; VanWijk, 2005). When properly selected, this approach makes working with the data more comfortable for the user, and the data can be understood more quickly and easily (Kubicek, et al., 2013; Wachowiak, Walters, Kovacs, Wachowiak-Smoliková, & James, 2017). With suitable visualization, it is possible to find patterns, connections, or similarities in observed agricultural data (Dvorsky, Snasel, & Vozenilek, 2010). This makes it much more convenient than the manual analysis of raw sensor data, which is oftentimes difficult for a person to understand (Kubicek, et al., 2013).

Sensor data usually exist as numerical values; therefore, the process of understanding or analyzing them is not trivial (Kubicek, et al., 2013). In many cases, finding patterns, differences, and commonalities is hardly possible without deeper analysis or visualization. Visualization of agriculture data (Hashem, Yaqoob, Anuar, Mokhtar, Gani, & Ullah, 2015) from sensor observations can be utilized to provide insight into what the data represents, making it easier to understand and interact with the data (Fry, 2008; Richter, 2009).
Technology and Engineering Classroom Connections

Can recent advances in technology such as UAV imaging, satellite/sensor data collection, and IoT/GPS-enabled machinery be used to engage students meaningfully in tackling such a problem? For example, can we task students with using technology, sensors, and data to devise a new solution to more effectively and efficiently apply nitrogen fertilizer? We present here a lesson plan, which challenges students to solve the problem of excess nitrogen fertilization—collected in water runoff—through advances in UAV technology, data visualization, automation, sensing, and control. Specifically, this lesson challenges students to use technology tools to collect data, visualize patterns, and make informed design decisions (Figure 2).

As students work together in teams to improve the targeted application processes and procedures of farm equipment (e.g., tractor) for nitrogen fertilizers with an intent of maintaining crop production while also protecting waterways and the environment (Figure 3), they can become intrinsically connected to this socially relevant activity.

Conclusion

Engaging students in activities such as this, which center on the Grand Engineering Challenges and socially relevant contexts, may provide new opportunities for engaging and inspiring students to make connections, think critically, and excel in creative opportunities. Further, enhancing TEE classrooms by drawing on the historical underpinnings and the subsequent technological advancements may increase student’s interest in, and connection to, such topics.

NOTE: Lesson plans for this activity are located online at www.iteea.org/TETApril20SRC.aspx.

References


NGSS@NSTA: https://ngss.nsta.org/PracticesFull.aspx


Scott Bartholomew is an assistant professor of Engineering/Technology Teacher Education at Purdue University, West Lafayette, IN. He can be reached at sbartho@purdue.edu.

Greg J. Strimel, Ph.D., is an assistant professor of Technology Leadership and Innovation and the coordinator of the Design & Innovation Minor at Purdue University. He can be reached at gstrimel@purdue.edu.

Vetria Byrd is an assistant professor of Computer Graphics Technology and Director of the Byrd Data Visualization Lab in the Purdue Polytechnic Institute at Purdue University Campus in West Lafayette, Indiana. She can be reached at vlbyrd@purdue.edu.

Vanessa Santana is an undergraduate Engineering/Technology Teacher Education student at Purdue University. She can be reached at vsantana@purdue.edu.

Jackson Otto is an undergraduate Engineering/Technology Teacher Education student at Purdue University. He can be reached at ottoj@purdue.edu.

Zach Laureano is an undergraduate Engineering/Technology Teacher Education student at Purdue University. He can be reached at zlaurean@purdue.edu.

Brian DeRome is an undergraduate Engineering/Technology Teacher Education student at Purdue University. He can be reached at bderome@purdue.edu.

This is a refereed article.

ITEEA is now accepting Presenter Applications for the 2021 Conference. Applicants should align potential presentations with the conference theme, which focuses on the way educators make technology and engineering education relevant for all. Educators use active learning, authentic assessments, collaboration, and put research into practice in order to help technology and engineering come to life!

ITEEA’s Elementary STEM Council is sponsoring the 3rd Global Design Challenge for Elementary STEM to provide students with a chance to solve a real problem, and show the world that everyone can help find solutions to these global challenges.

The Process
Elementary STEM students from around the world will work in small design teams to solve the GDC outlined below. As students attempt to solve the GDC, the elementary teacher will document the process with a simple portfolio that describes the problem-solving process, the products developed, results of product testing, as well as the final product presentations. Photos and videos of proposed solutions will be posted on the Elementary STEM Council’s Facebook® site. The design teams will be evaluated and the winning team will be invited to present their solution during the International Technology and Engineering Educators Association Annual Conference in Denver, Colorado on March 24-27, 2021. This team will also be featured in the March 2021 edition of The Elementary STEM Journal.

The Global Design Challenge
One of the original Grand Challenges (NAE, 2008), called for engineers to design systems that helped people live more healthy lives. Search online using the phrase “grand challenges” to find more information. The 2020 GDC calls on you and your team to develop a product that might help solve a worldwide dilemma that we are all facing in 2020.

In 2020, nations around the globe are struggling to prevent the spread of the Coronavirus 2019 (COVID-19). COVID-19 is caused by a new virus and health care officials do not yet have adequate or effective vaccines for the virus. However, the CDC does know that washing hands often with soap and water for at least 20 seconds is a great way to prevent the spread of the virus, especially after going to the bathroom; before eating; and after blowing your nose, coughing, or sneezing (Centers for Disease Control and Prevention (CDC), 2020).

The most common problem is that most people do not wash their hands often enough, nor long enough.

Challenge:
Can you work as a member of a small design team to develop or modify a product or device that will encourage people to properly wash their hands for at least 20 seconds?

LEARN MORE/READ THE FULL CHALLENGE AT iteea.org/ESCGDC20.aspx

Questions? Email Michael Daugherty at mkd03@uark.edu or Thomas Roberts at otrober@bgsu.edu.
Did You Know?

ITEEA Maintains an Online Directory of Universities Offering Degrees in Technology and Engineering Education

Looking for Institutions that offer Bachelor’s, Master’s, and Doctoral Degrees in Technology and Engineering Education and Related Fields?

ITEEA’s Directory of Institutional Members can help you find the right fit as you move forward with your educational goals! Learn more today about state-of-the-art programs and opportunities at:

www.iteea.org/InstitutionalMembers.aspx

Is YOUR institution interested in being part of the Directory?
www.iteea.org/InstitutionalMembership.aspx
FREE SHIPPING Offer applies only to USA School Orders over $50 and Canada School Orders over $500 USD. Does not apply to overnight, overseas, oversized, overweight or hazardous products. Does not apply to shipping costs that are more than 10% of the order. Other restrictions may apply. Offers expire 09/30/20.

USA code: SHIPUSA0930
CANADA code: SHIPCAN0930

Catalog prices in USD $. Open purchase orders accepted from USA & Canada public schools.

NEW

KELVIN® ECONOMY S.T.E.M. LABS FOR ELEMENTARY TO HIGH SCHOOLS

KELVIN® Gr. 4-7 S.T.E.M. Lab: Land Transportation, 842493

Basic Economy S.T.E.M. Labs (Gr. 4-7)
- Aeronautics & Flight
- Land Transportation
- Water Transportation
- Mechanical Engineering
- Electricity
- Pneumatics
- Beams & Triangles™
- Kre8® Modeling

Advanced Economy S.T.E.M. Labs (Gr. 5-12)
- Aeronautics & Flight
- Water Transportation
- Mechanical Engineering
- Work, Machine & Gears
- Kre8® Vehicles
- Motors
- Alternative Energy: Wind, Solar & Hydro

NEW

KELVIN® Gr. 7-12 S.T.E.M. Lab: Advanced Aeronautics & Flight, 842491

Find More Economy S.T.E.M. Labs at www.kelvin.com

NEW

KELVIN® Kel-Air™ ORIGINAL Air-Powered Dragster Launcher

THE KELVIN® ORIGINAL NOT A COPY!

 ONLY $245

Also available with Exact Digital Pressure Display, $289

KELVIN® Balsa StiKutter™ 990198, $9.95 or $8.95 ea./10+

KELVIN® Storage Units for S.T.E.M.
Mix & match to create S.T.E.M. areas within a classroom, organize inventory and storage.

KELVIN® HAS A VARIETY OF PROJECT PARTS AT GREAT PRICES!

Front Wheels
Rear Wheels
Gears
Motors
Pulleys
Propellers

THE KELVIN® ORIGINAL NOT A COPY!

Easily Cut Balsa!
Introducing the Mastercam Quick Part Series.
Streamlined, project-based lessons from the world’s #1 CAM software.

These hands-on tutorials are a fun way to teach and learn Mastercam, with everything you need to get your students up to speed and on pace. You even get a simplified Mastercam interface to make sure your students can focus on what’s important.

Cam education moves quick – and you can, too.

ALWAYS FREE FOR EDUCATORS – DOWNLOAD NOW!

www.mastercam.com/quickpart