VOLUME 81 ISSUE 2

technology and engineering TEACHER

October 2021

www.iteea.org

ITEEA's 84th Annual Conference:

Standards for Technological and Engineering Literacy: The Role of Technology and Engineering in STEM Education—Keys to Success!

PRE-REGISTRATION IS NOW OPEN!

With over 100 in-person and virtual learning sessions; preconference workshops; the ITEEA STEM Showcase; the latest products and services; competitions; special strands on Elementary STEM, STEL, DEI, Collaboration, and Making and Building, the 2022 Orlando conference offers an unparalleled Integrative STEM Education professional development opportunity.

It's not too late to be a STEM Showcase presenter—capitalize on the opportunity to share your knowledge with your colleagues while creating some great PR for your program! The STEM Showcase provides a forum to feature your best exemplar of technology and engineering instruction. Apply now at https://tinyurl.com/STEMShow22.

Want to apply for—or nominate someone for—an ITEEA award or scholarship? The deadline for most is December 1—and awards and scholarships will be presented in Orlando. Apply today at www.iteea.org/AwardsScholarships.aspx.

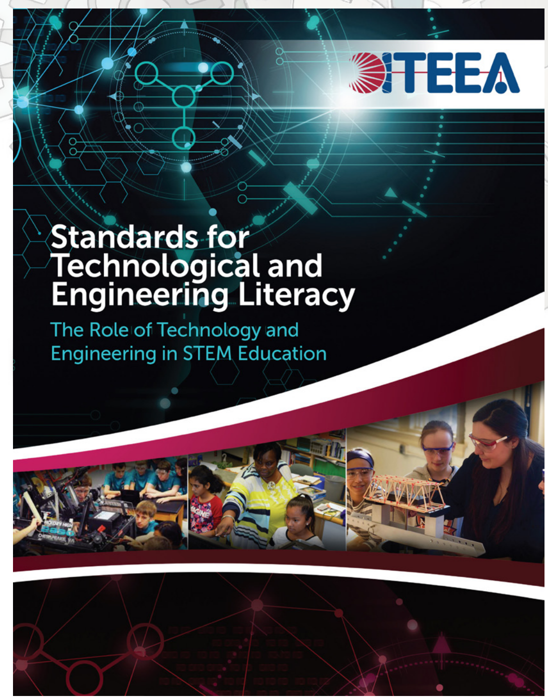
Early bird preregistration is open! Preregistration provides many benefits, including saving TIME and MONEY as well as eligibility to win a $100 gift card.

ITEEA orlando March 9-12, 2022

Preregistration now open!
For the latest conference information, go to www.iteea.org/ITEEA2022.aspx

Standards for Technological and Engineering Literacy is here!

What ALL students should know and be able to do in order to be technologically and engineering literate.



Standards for Technological and Engineering Literacy (STEL) provides an up-to-date roadmap for classroom teachers, district supervisors, administrators, states, and curriculum developers to promote technology and engineering education program development and curriculum design from Pre-K through twelfth grade.

The universals of technology have changed since the original *Standards for Technological Literacy* was published in 2000. The 2006 *Rationale and Structure* document and relevant literature published since *STL* was released were used to inform the current revision project. This update includes reducing the number of standards and benchmarks and adding new content such as crosscutting concepts to mirror the practices of contemporary standards developed for other disciplines.

The document is now available in print, ePub, and PDF formats and will soon be part of a dedicated interactive website, including curriculum development resources.

STEL is available on the following formats at www.iteea.org/STEL.aspx:

As a viewable PDF (FREE)

As downloadable/printable PDF
(FREE for ITEEA Members/$25 for Nonmembers)

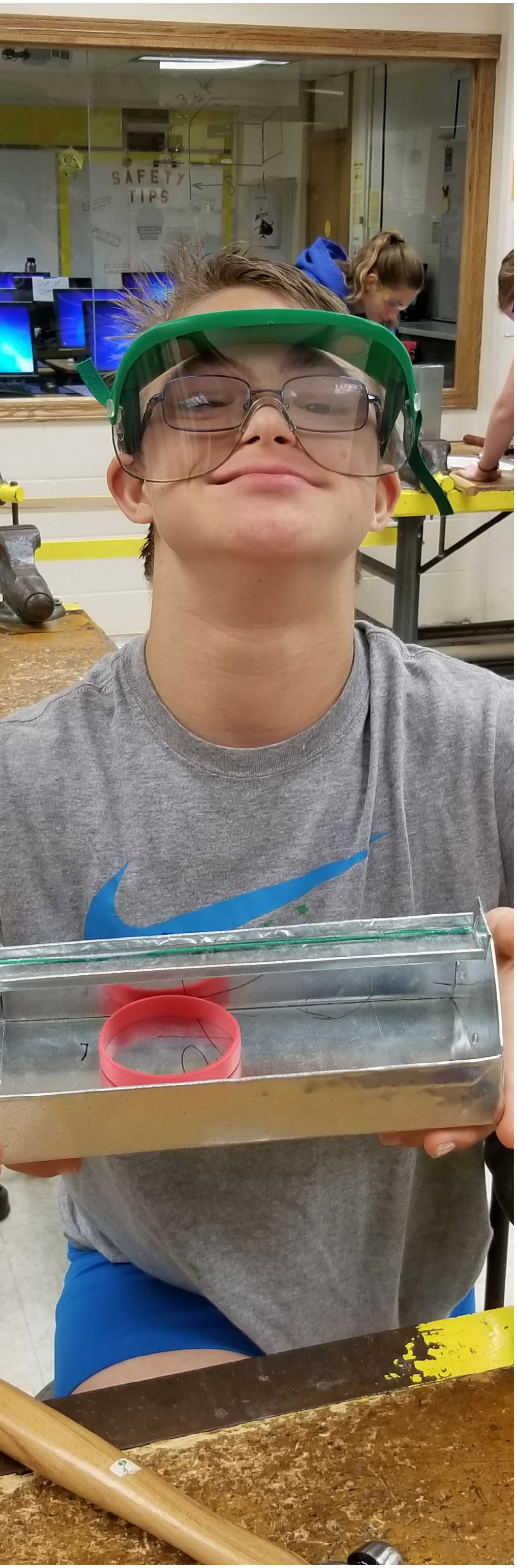
As an EPub
(FREE for ITEEA Members/$25 for Nonmembers)

As a printed publication.
Members: $27/Nonmembers: $38
*Shipping fees apply

For more information, visit the *STEL* webpage at www.iteea.org/STEL.aspx.

This work was made possible through grants from the National Science Foundation and the Technical Foundation of America.

ITEEA
Technology and Engineering bring STEM to Life!
International Technology and Engineering Educators Association
iteea.org



contents

features

DESIGNING TO ENGINEER A SAFER WORLD P.8
Introduces the problem-solving approach of engineering to elementary and secondary students, where individuals of all genders can gain a greater appreciation for the role of engineers in society and reinforce their science and mathematics learning.
By Donatille Mujawamariya, Janelle Fournier, Shelina Adatia, and Catherine Mavriplis

ENGINEERING CAPSTONE EXPERIENCE: MAPPING THE WAY P.15
A discussion of successful strategies and barriers to overcome when implementing a technology and engineering capstone course.
By Joseph S. Woodard and Edward M. Reeve, DTE

TRANSFORMING T&E EDUCATOR INPUT P.21
Provides middle and high school Technology and Engineering Educators with a more thorough understanding of an engineering approach to the teaching and learning of mechanics.
By Andrew J. Hughes and Chris Merrill

A RURAL TEACHER'S LOOK AT EQUITY P.26
In this article, the author sets out to test a hypothesis about resources at urban versus rural schools.
By Adam Kennedy

departments

ON THE ITEEA WEBSITE P.5

STEM EDUCATION CALENDAR P.6

STEM EDUCATION NEWS P.7

LET'S COLLABORATE! P.30

TEACHER HIGHLIGHT P.34

ENGINEERING IN ACTION P.36

CLASSROOM CHALLENGE P.42

On the cover: *Seventh-grade student Alex is proud to show off his finished tool tray crafted from a single flat piece of sheet metal.*

on the iteea website

ITEEA Updates Conference Webpages as 2022 Conference Preregistration Opens

ITEEA has revamped its Conference webpages in time for the mid-September launch of 2022 Conference Preregistration. An Overview page includes an invitation video from ITEEA President, Dr. Virginia R. Jones, DTE, as well as a listing of Important dates and the 2022 Conference Theme and Strands.

Other tabs include information for how to Exhibit, Tips for Securing Funding, Presenter Resources, and to secure Housing at the Caribe Royale, the location for the 2022 Conference in Orlando. View the updated Conference pages at www.iteea.org/ITEEA2022.aspx

stem education calendar

ITEEA orlando March 9-12, 2022

March 9-12, 2022

SAVE THE DATE!

for ITEEA's 84th Annual Conference!

October 1, 2021
Deadline for Applications to Present in the STEM Showcase at ITEEA's 84th Annual Conference in Orlando, FL, March 9-12, 2022
www.iteea.org/ITEEA2022.aspx

October 13, 2021
7:00pm EDT
ITEEA's Roundtable Discussion Series
ITEEA's Technology and Engineering Education Collegiate Council
FREE TO ALL!
www.iteea.org/roundtable.aspx

October 20-21, 2021
Resilience in STEM Education: STEMathon
Two-day, *fully virtual conference* featuring exciting content in K-12 STEM fields, will inspire attendees with stories of STEM learning in varied learning environments and leave you with practical applications for your own schools moving forward!
https://tinyurl.com/STEMathon21

November 18, 2021
6:00pm EDT
ITEEA's Roundtable Discussion Series
ITEEA's Elementary STEM Council
FREE TO ALL!
www.iteea.org/roundtable.aspx

December 1, 2021
Deadline for ITEEA Awards and Scholarship
www.iteea.org/awardsscholarships.aspx

December 8, 2021
7:00pm EDT
ITEEA's Roundtable Discussion Series
Cultivating Creativity in the Classroom
FREE TO ALL!
www.iteea.org/roundtable.aspx

January 19, 2022
7:00pm EDT
ITEEA's Roundtable Discussion Series
Recruiting and Retaining Girls in the T&E Classroom
FREE TO ALL!
www.iteea.org/roundtable.aspx

February 16, 2022
6:00pm EDT
ITEEA's Roundtable Discussion Series
Teaching Sustainability Education
FREE TO ALL!
www.iteea.org/roundtable.aspx

March 9-12, 2022
ITEEA 84th Annual Conference
Caribe Royale All-Suite Hotel and Convention Center
Orlando, FL
www.iteea.org/ITEEA2022.aspx

April 13, 2022
7:00pm EDT
ITEEA's Roundtable Discussion Series
Recruitment, Retention, and Diversity
FREE TO ALL!
www.iteea.org/roundtable.aspx

MAY 18, 2022
7:00pm EDT
ITEEA's Roundtable Discussion Series
Teaching Energy and Power
FREE TO ALL!
www.iteea.org/roundtable.aspx

technology and engineering TEACHER

TECHNOLOGY 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.

ITEEA is an affiliate of the American Association for the Advancement of Science.

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.

ADVERTISING SALES
ITEEA Publications Department
703-860-2100
membership.sales@iteea.org

EDITORIAL 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 kdelapaz@iteea.org. Maximum length for manuscripts is eight pages. Manuscripts should be prepared following the style specified in the Publications Manual of the American Psychological Association, Seventh Edition.

Editorial guidelines and review policies are available at www.iteea.org/Publications/Journals/TET.aspx.

SUBSCRIPTIONS
Subscriptions are included in member dues. Nonmember subscriptions within the U.S. are $110. All other subscriptions are electronic at $70. Single copies are $10 for members; $11 for nonmembers, plus shipping and handling. Electronic single copies are $8.50.

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.

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: kdelapaz@iteea.org
Website: www.iteea.org

stem education news

ITEEA Selects Dooley as Executive Director

The International Technology and Engineering Educators Association (ITEEA) is pleased to announce the selection of Kelly Dooley, PE, as its new Executive Director/CEO. Dooley joins ITEEA with over eight years of association management experience, including a proven track record of working collaboratively with volunteer boards and committees, visioning and implementing professional development programs, and supporting the development of industry standards.

Complementing her experience, Kelly also holds a master's degree in management, specializing in nonprofits and associations, equipping her with further knowledge of organizational theory and behavior, strategic planning and implementation, and process and outcome evaluation. Her creative problem-solving approach to association challenges, strong leadership and communication skills, and commitment to constant growth and improvement will be an asset to ITEEA. Read the full News Release at www.iteea.org/News/282/193783.aspx

ITEEA Announces New Staff Leadership Additions

The International Technology and Engineering Educators Association (ITEEA) is announcing two additions to its headquarters leadership team.

ITEEA is pleased to announce that Stephanie Gilmore joined the ITEEA leadership team on August 23rd as Director of Engagement.

This is a new senior-level position with key responsibilities to create pathways and alliances between ITEEA, its members, the field at large, and create avenues for funding engagement initiatives.

In late August, ITEEA's STEM Center for Teaching and Learning welcomed Scott Weiler as the STEM CTL™ Director of Innovation.

STEM CTL™ strengthens professional development and advances technological literacy. Center initiatives are directed toward four goals: development of standards-based curricula; teacher enhancement; research concerning teaching and learning; and curriculum implementation and diffusion.

Designing to Engineer a Safer World

It is imperative to promote engineering and its positive effects on women and society, but also to make girls and women aware that they too possess the skills to drive change.

by Donatille Mujawamariya, Janelle Fournier, Shelina Adatia, and Catherine Mavriplis

It is said that necessity is the mother of invention. With that saying comes an association with a do-it-yourself tinkerer alone in their basement. But how is engineering linked with innovation? What role does engineering play in the design process and how do engineers design solutions? We, the women behind *Le génie au service des femmes:* Rethinking the Faces and Spaces of Engineering, believe that engineering is the means through which society can creatively innovate to solve problems affecting individuals on a large scale. Public safety, for instance, has long been a concern for women, particularly with injustices such as date rape still very prevalent. Solving these issues is not a solitary endeavour but rather a team effort that requires a diversity of agents in order to devise truly effective solutions addressing a wide range of problems.

In this era of a global pandemic, due to the spread of the coronavirus disease (COVID-19), public safety for all citizens is of paramount importance. This situation naturally presents an opportunity to introduce the problem-solving approach of engineering to elementary and secondary students, where individuals of all genders can gain a greater appreciation for the role of engineers in society and reinforce their science and mathematics learning.

Photo Credit: Anna Shvets

Uncovering the Beauty of Engineering

Innovation is central to engineering. Our team's approach is one that has been relatively unexplored to date: engineering by women for women—a means of empowering women to study and explore careers addressing issues of particular relevance to womankind. This five-year study (2017-2022), funded by the Social Sciences and Humanities Research Council of Canada, is a collaboration between two University of Ottawa researchers, Professor Donatille Mujawamariya (Faculty of Education) and Professor Catherine Mavriplis (Faculty of Engineering).

In order to promote this research and to advocate for the importance of women's contributions, we facilitated a workshop at the 17th biennial conference of the Canadian Coalition of Women in Engineering, Science, Trades and Technology (CCWESTT). While many noteworthy points were brought up during the workshop, by far the most pertinent was in response to the following question: Can you think of devices that women need or any devices that need to be improved for women? The innovation that came to light is that of a specialized nail polish.

Nail polish has long been a go-to for women (and men) who wish to project a more "polished" look. Yet, when thinking of nail polish, very few people have likely contemplated its chemical engineering or its contribution to women's safety… that is, until recently. A group of engineering students taking nail polish to the next "coat" seem to have caught the attention of the media with their nail polish detecting date rape drugs. Their concept, although complex, is simultaneously simple: if the nail polish comes in contact with a drink containing a date rape drug, it changes colour, thus indicating the presence of a drug and potentially preventing sexual assault (North Carolina State University, 2015) and promoting women's safety.

The Gender Perspective in Engineering

The date rape drug-detecting nail polish is but one example of the type of activity in which girls take an interest—activities directly addressing girls or society at large. Indeed, according to Kekelis et al. (2014) and Reinking & Martin (2018), girls want hands-on activities in which they can solve social problems (Gilbert, 2017; UNESCO, 2017). We therefore propose a lesson plan that delves into another public safety problem that our society is currently facing—how to reduce the spread of the coronavirus.

During this pedagogical activity, students of all genders will act as young engineers to design a product that can help to keep people safe from the spread of the virus. Students can be creative in their designs and make choices that interest them (i.e., choose a specific focus). The proposed lesson plan also allows students to explore, ask questions, persist, and problem solve, which may be a first for girls as they may never have had the opportunity to do so in relation to STEM (Science, Technology, Engineering and Mathematics) activities (Reinking & Martin, 2018; Wang, 2012). STEM pedagogical examples have traditionally been male-oriented, such as the typical physics ballistics problems (Smith, 2012).

While students undertake the design process, they are invited to learn more about gender-diverse engineers who are currently working to keep us safe. By highlighting the work of a diversity of engineers, we allow students, but especially girls, to see themselves doing similar work. Because of gendered socialization, girls may not have been exposed to female engineers and to the engineering profession (Reinking & Martin, 2018)—hence the need to provide same-gender role models.

This engineering design activity is meant to be done in groups to offer students the opportunity to work on their collaboration skills. It also allows educators to clarify that engineering is not a solitary career (as is often portrayed in the media) but instead requires collaboration amongst many people with varied backgrounds, experiences, perspectives, and skill sets. Thus, the idea that the vocation of engineering should have professionals of different genders is reinforced.

Once the students' prototypes are designed and built, the pupils are asked to reflect on their successes and pitfalls. The idea behind this is to continue to instill a growth mindset in students, and again, to have them act as engineers who learn from their failures, iterate, and improve their designs.

Lesson Plan: Dare to Design a Coronavirus-Free World

Context of Public Engineering Education in Canada

In Canada, most elementary and high schools do not offer engineering courses and the majority of Science and Mathematics curricula do not explicitly mention the use of the engineering design process. However, provincial Ministry of Education curriculum documents are open to interpretation and teachers can integrate engineering into their courses. In fact, many studies have been conducted to explore how engineering education can enhance K-12 students' content knowledge acquisition. Hsu, Purzer, and Cardella (2011), Madara and Namango (2016) and Wiswall, Stiefel, Schwartz, and Boccardo (2014) have all stated that K-12 engineering education helps students better understand mathematics and science concepts. When students are faced with a problem using the engineering design process, they can apply their STEM content knowledge, along with their critical- and creative-thinking skills (Bybee, 2010; Kimmel et al., 2006). The US National Academy of Engineering and National Research Council (2009) add that students who are exposed to engineering education prior to university have a better understanding of the work done by engineers and have improved technology literacy. Finally, educating children and teenagers about engineering is pivotal for gender diversity in this traditionally male-dominated field (UNESCO, 2017). For these reasons, we advocate for engineering education in elementary and secondary schools.

Introduction

This lesson plan focuses on the coronavirus, also known as SARS-CoV-2 or COVID-19, from a public safety perspective. This pandemic has affected each country and community differently. In Canada, the spread of the virus saw an exponential growth in cases during the winter and spring of 2020 (Public Health Agency of Canada, 2020). While Canadians have made significant progress in "flattening the curve," adjusting to a new normal in order to stop the spread of the virus remains a struggle.

Although the media has highlighted the work of scientists who dedicated countless hours towards the design of a viable vaccine, we believe that they have overlooked the work of engineers. Engineers play an equally pivotal role in finding innovative solutions to stop the spread of the coronavirus. In this lesson plan, students will be engineers-in-training, designing creative solutions to conquer the virus.

Question: Through the design of a prototype, how can we help to stop the spread of the coronavirus?

Grades: 4-12

Curriculum Connections

The proposed engineering activity can be integrated into Technology, Science, and Mathematics courses at the elementary and secondary levels, as it can be modified to most grade levels. While elementary educators might take a more generalized approach to the proposed problem, secondary teachers can provide specific information related to the courses being taught. For example: virus replication might be the focus of Biology courses; issues of public safety (such as factors contributing to the rapid spread of infectious diseases, and air and water resources) in Environmental Science courses; exploring matter, more specifically how soap breaks down the lipid structure of a virus (UNESCO, 2020), in Chemistry courses; and exponential functions in Mathematics courses.

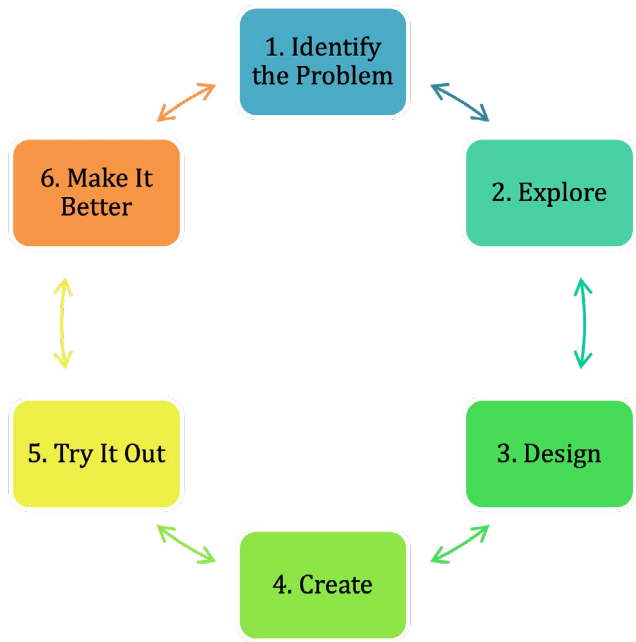
Before Getting Started

If students have never used the design process or discussed engineering as a field of study and profession, educators and students can start by brainstorming. For example, asking questions such as who are engineers? What tasks do they accomplish? What is their professional purpose? Teachers can provide examples of engineers who are making a difference in the world by referring to resources such as Engineers Without Borders (Engineers Without Borders Canada, n.d.). The goal is to get students to understand that engineers find creative solutions to society's problems. Following the brainstorming session, teachers discuss the design process with their students, walking through the steps of the process, taking time to explain the importance of each step.

Steps of the Design Process

The design process is applied by engineers to solve problems that have multiple solutions. Most of these problems require interdisciplinary knowledge, thus leading to STEM (Science, Technology, Engineering, and Mathematics), STEAM (Science, Technology, Engineering, Arts, and Mathematics) or even STREAM (Science, Technology, Reading/wRiting, Engineering, Arts, and Mathematics) projects.

The design process involves six steps (The Works Museum, 2016):



Once students have a better understanding of the process they will be undertaking, teachers can then present the problem that the students will address and begin the design process.

Design Process

1. Identify the problem

To initiate students to the problem they will be addressing, provide them with a news report or article that depicts the current state of their community with regard to the coronavirus. Alternatively, a personal account from someone who had the virus can be shared.

Ask students to identify a specific problem related to the coronavirus that they could help to solve. For example, designing masks that do not fog up glasses, finding ways of ensuring physical distancing and patient isolation when necessary, and addressing the lack of personal protective equipment. Then, keeping their chosen problem in mind, students should address the following question: *Through the design of a prototype, how can we help to stop the spread of the coronavirus in our community and worldwide?*

This step will require students to conduct some research in order to better understand the design challenge and to set objectives and success criteria. We encourage placing students in heterogeneous groups (three to four students per group to maximize the efficiency of online or in-person interactions) (Chang & Kang, 2016) to complete the design process as diverse groups will think of a wider range of criteria and solutions (Khandani, 2005).

Photo Credit: Mart Production

To help ameliorate the logistics of online group work in online PBL contexts, we recommend group sizes no larger than three to four. Members of these groups have to agree on acceptable and useful ways of interacting and "meeting" together (whether in chatrooms, telephone conversations, email, or asynchronous discussion boards).

2. Explore

The second step requires students to explore the problem and to investigate what others have done to try to solve it. Students could ask questions such as: What have others done? Why hasn't it worked or how could it be improved? What constraints need to be considered (time, money, etc.)?

We recommend showcasing the work of gender-diverse individuals and companies who are helping to solve this problem. It will be important to provide examples that are suitable for students' grade levels (i.e., not too simple nor overly complex).

Some suggestions include:

- Midia Shikh Hassan (co-manager, Centre for Entrepreneurship and Engineering Design) and collaborators at the Richard L'Abbé Makerspace at the University of Ottawa are working with The Ottawa Hospital to improve the design of face shields. They are able to produce 10 to 20 face shields within two hours. Additionally, they are working on ventilator designs, which (once completed) will be shared online for others to produce (Molina, 2020). This example could be useful to share with students of all ages, as all curious minds could work on the design of face shields.
- Materialise, a Belgian-based 3D printing company, has created a hands-free door opener so that people don't have to worry about touching door handles with their hands but can instead use their arm (Sher, 2020). Although designed by engineers, this device is simple enough to be explored by students of all ages.
- Ellen Cathrine Anderson, CEO of EpiGuard, and her team have designed the EpiShuttle, a patient isolation and transport system (Nordrum & Strickland, 2020). The idea is to provide patients with the treatment they need, without putting others at risk and contaminating the environment (EpiGuard, 2019). While this idea could be presented to students of all grade levels, the details of the ventilation system would be better suited for middle or secondary school students.
- Zhanfeng Cui, a chemical engineer and the director of the Oxford Suzhou Centre for Advanced Research, and Wei Huang, a professor of Engineering Sciences at the University of Oxford, are collaborating to develop a rapid test for the coronavirus. Professor Huang points out that: "The beauty of this new test lies in the design of the viral detection that can specifically recognise SARS-CoV-2 RNA and RNA fragments. The test has built-in checks to prevent false positives or negatives and the results have been highly accurate" (University of Oxford, 2020, para. 2). Furthermore, the designed technology can identify an infected patient more quickly, thus helping to reduce the spread of the virus. "The technology only requires a simple heat-block which maintains a constant temperature for RNA reverse transcription and DNA amplification, and the results can be read by the naked eye" (University of Oxford, 2020, para. 3). Since this example is more technical in nature, it would be more appropriate to share with secondary school students.

Examples such as these are important because they not only showcase the diversity of solutions but also the diversity of individuals who can be engineers. Once students have explored the work of other engineers, introduce concepts from different STEM fields that would be useful and appropriate for student grade levels (Hacioglu et al., 2017). Facilitate discussions on microbiology/virology (characteristics, replication, and propagation of viruses), pathogens and diseases, disease transmission and prevention, public health issues, the immune system, medical technologies, exponential functions, etc. This information will assist students in identifying a specific problem that they would like to address and in designing a prototype (Khandani, 2005). Hacioglu et al. (2017) report that the practice of incorporating science concepts during the second step of the design process led to student-teachers recognizing the importance of this process as a way to develop creative thinking skills, gain a better understanding of the scientific method, and improve students' communication skills.

Grade Level Modifications

For students at the elementary level, teachers may decide to provide a specific problem to solve. For instance, healthcare professionals are increasingly experiencing irritation at the back of their ears due to the pressure of elastics from face masks. Students could thus develop a prototype of a mask without elastics behind one's ears (Scott, 2020).

Photo Credit: Andrea Piacquadio

3. Design

The third step is to design. Students will use their creativity to generate ideas to solve the problem. Engineers use the knowledge they acquired during the first two steps to devise new solutions and to select the solution that is most suitable (Khandani, 2005). Students could draw their ideas/potential solutions on paper or by using digital drawing or sketching software. If students have not done enough exploration, they may need to backtrack to the second step (as illustrated by the bidirectional arrows in the design process scheme).

4. Create

Once students have chosen their "best" idea, they will need to create a prototype. The prototype does not necessarily have to be a scale model, but it should be functional in order to be able to test it out.

5. Try it out

Then comes the fun part! Students will try out or test their prototype under real-life conditions. While testing is in progress, students should be reflecting on the strengths and weaknesses of their design. Teachers should remind students to exercise appropriate precautions when testing their designs.

6. Make it better

The sixth and last step involves evaluating and refining the solution to ensure that it effectively solves the problem (i.e., making it better). Students should critically examine their solution by asking questions like: What worked? What did not work? How could this be modified to be more effective? The design process is iterative, meaning that the prototype should be reworked multiple times. The failures of prototypes lead to learning and better solutions (Khandani, 2005).

Assessment

As a form of formative or summative assessment, students can be asked to keep a journal to document their thinking and progress throughout the engineering design process. Teachers can also ask students questions, thereby engaging them in discussion, following each step of the design process. Additionally, students could be required to present their prototypes to the class and/or to provide a written report of their work, including both successes and failures of the design.

Alternative Ideas to COVID-19

Instead of basing the lesson plan on the COVID-19 pandemic, educators could also choose to base it on another public safety issue, as was done with the nail polish project. For example, students could focus on affordable housing, protection from natural disasters, safety in schools, transportation-related crashes, and pedestrian and bike injuries.

Concluding Remarks

The integration of engineering education and the promotion of engineering by women for women in the K-12 classroom are potential solutions to inspiring women to pursue studies and careers in engineering, thereby reducing the gender gap in this field. When bringing engineering into the classroom, educators can tailor examples to appeal to diverse genders of students. One way to do this is to present students with a real-world problem that requires solutions. For girls, this is especially important as "they want to design systems that make people healthier and safer and preserve the environment and make the world a better place" (Seepersad, 2016, para. 12).

The specialized nail polish is a prime example of a product that was designed with a specific purpose in mind—the safety of women. The proposed lesson plan on the ongoing global pandemic follows a similar objective—public safety. Since these examples directly target and, more importantly, help a specific group or groups of individuals, they are likely to be of interest to girls.

It is often said that people don't know what they don't know; thus, it is imperative to promote engineering and its positive effects on women and society, but also to make girls and women aware that they too possess the skills to drive change.

When the engineering profession reaches a better gender equilibrium, we expect to see advancements in knowledge and diversification and intensification of services and products offered. These impacts could in turn result in better health and well-being for all members of society and a greater respect for research and technological innovations by women for women. With the support of people of all genders, educators, and other professionals, we can bring women's issues to the forefront and continue to design in order to engineer a safer world.

References

Bybee, R. W. (2010). Advancing STEM Education: A 2020 Vision. *Technology and Engineering Teacher, 70*(1), 30–35.

Chang, B., & Kang, H. (2016). Challenges facing group work online. *Distance Education, 37*(1), 73–88. https://doi.org/10.1080/01587919.2016.1154781

Engineers Without Borders Canada. (n.d.). *Engineers Without Borders Canada.* www.ewb.ca/en/?gclid=EAIaIQobChMItbPFiNr-36gIVC4nICh1NQAj1EAAYASAAEgLWj_D_BwE

EpiGuard. (2019). *EpiGuard – Medical isolation and transportation systems.* https://epiguard.com/

Gilbert, H. (2017, October). A Surefire Way to Engage Girls in STEM. *Microwaves & RF.*

Hacioglu, Y., Yamak, H., & Kavak, N. (2017). The Opinions of Prospective Science Teachers Regarding STEM Education: The Engineering Design Based Science Education. *GEFAS\GUJGEF, 37*(2), 649–684.

Hsu, M.C., Purzer, S., & Cardella, M. (2011). Elementary Teachers' Views about Teaching Design, Engineering, and Technology. *Journal of Pre-College Engineering Education Research (J-PEER), 1*(2). https://doi.org/10.5703/1288284314639

Kekelis, L., Larkin, M., & Gomes, L. (2014). More Than Just Hot Air: How Hairdryers and Role Models Inspire Girls in Engineering. *Technology and Engineering Teacher, 73*(5), 8–15.

Khandani, S. (2005). *Engineering Design Process.* Education Transfer Plan. https://resources.saylor.org/wwwresources/archived/site/wp-content/uploads/2012/09/ME101-4.1-Engineering-Design-Process.pdf

Kimmel, H., Carpinelli, J., Burr-Alexander, L., & Rockland, R. (2006). *Bringing Engineering Into K 12 Schools: A Problem Looking For Solutions?* 11.288.1-11.288.16. https://peer.asee.org/bringing-engineering-into-k-12-schools-a-problem-looking-for-solutions

Madara, D. S., & Namango, S. (2016). Perceptions of Female High School Students on Engineering. *Journal of Education and Practice, 7*(25), 63–82.

Molina, K. (2020, March 23). U of O lab putting 3D printers to use in fight against COVID-19. *CBC.* www.cbc.ca/news/canada/ottawa/maker-space-university-of-ottawa-3d-printing-face-shields-1.5507011

National Academy of Engineering and National Research Council. (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects.* The National Academies Press.

Nordrum, A., & Strickland, E. (2020, April 17). *Engineering During the Coronavirus Pandemic.* IEEE Spectrum: Technology, Engineering, and Science News. https://spectrum.ieee.org/at-work/innovation/engineering-during-the-coronavirus-pandemic

North Carolina State University. (2015, October 6). More than a nail polish. *College of Engineering News.* www.engr.ncsu.edu/news/2015/10/06/more-than-a-nail-polish/

Public Health Agency of Canada. (2020, July 23). *Coronavirus disease (COVID-19): Outbreak update* [Alerts; education and awareness]. Government of Canada. www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection.html

Reinking, A., & Martin, B. (2018). The Gender Gap in STEM Fields: Theories, Movements, and Ideas to Engage Girls in STEM. *Journal of New Approaches in Educational Research, 7*(2), 148–153. https://doi.org/10.7821/naer.2018.7.271

Scott, D. (2020, April 20). Lesson plan: Inventing in a pandemic for the tiniest among us. *PBS NewsHour Extra.* www.pbs.org/newshour/extra/lessons-plans/lesson-plan-inventing-in-a-pandemic-for-the-tiniest-among-us/

Seepersad, C. C. (2016, October 16). *How to involve more women and girls in engineering.* The Conversation. http://theconversation.com/how-to-involve-more-women-and-girls-in-engineering-55794

Sher, D. (2020, March 16). Materialise shows 3D printed door opener for coronavirus containment efforts. *3D Printing Media Network.* www.3dprintingmedia.network/materialise-shows-3d-printed-door-opener-for-coronavirus-containment-efforts/

Smith, T. (2012). Engaging Girls in Physics: Some suggestions for 'girl friendly' teaching strategies. *Advances in Gender and Education, 3,* 13–19.

The Works Museum. (2016). *Engineering Design Process.* https://theworks.org/wp-content/uploads/2017/01/EDP_The_Works_Museum_2016_web.jpg

UNESCO. (2017). *Cracking the code: Girls' and women's education in science, technology, engineering and mathematics (STEM).* https://unesdoc.unesco.org/ark:/48223/pf0000253479

UNESCO. (2020, April 6). *How Soap Kills COVID-19 on Hands.* https://en.unesco.org/news/how-soap-kills-covid-19-hands

University of Oxford. (2020, March 18). *Oxford scientists develop rapid testing technology for COVID-19.* University of Oxford - News & Events. www.ox.ac.uk/news/2020-03-18-oxford-scientists-develop-rapid-testing-technology-covid-19

Wang, H.H. (2012). *A new era of science education: Science teachers' perceptions and classroom practices of science, technology, engineering and mathematics (STEM) integration.* [Doctorate, The University of Minnesota]. http://conservancy.umn.edu/handle/11299/120980

Wiswall, M., Stiefel, L., Schwartz, A. E., & Boccardo, J. (2014). Does attending a STEM high school improve student performance? Evidence from New York City. *Economics of Education Review, 40,* 93–105. https://doi.org/10.1016/j.econedurev.2014.01.005

Donatille Mujawamariya *(dmujawar@uottawa.ca) is full professor, Faculty of Education, University of Ottawa and the chair of Unité de recherche éducationnelle sur la culture scientifique.*

Janelle Fournier *(jfour055@uottawa.ca) is a PhD candidate in the Faculty of Education at the University of Ottawa and is passionate about promoting gender diversity in STEM.*

Shelina Adatia *(sadat028@uottawa.ca) is a PhD candidate in the Faculty of Education at the University of Ottawa and is studying the inclusion of Culturally and Linguistically Diverse (CLD) learners in French Immersion.*

Catherine Mavriplis *(Catherine.Mavriplis@uottawa.ca) is a full professor of Mechanical Engineering at the University of Ottawa and holds the NSERC Chair for Women in Science and Engineering.*

This is a refereed article.

engineering capstone: mapping the way

Spending several months on a design problem is a unique challenge for students and teachers, but the learning is as real as it gets.

by Joseph S. Woodard and Edward M. Reeve, DTE

Introduction

Technology and engineering programs across the country are attempting and struggling to implement capstone courses that focus on students solving an engineering design problem consisting of multiple ill-structured problems, many of which are not identifiable from the outset. In the State of Utah, the Utah Board of Education and its career and technical area, known as technology and engineering (T&E) education, has developed a one-credit course entitled "Engineering Capstone" (Utah Board of Education, Technology and Engineering Education, 2018a). The purpose of this course and its description are below.

> *As members of an engineering team, students apply science, technology, and mathematical concepts and skills to solve engineering design problems or to significantly innovate existing products. Students research, develop, test, and analyze designs using criteria such as cost, effectiveness, safety, human factors, and ethics. Long term project development by student teams and regular interaction with and presentations to members of industry are essential components to the success of this course (p. 1).*

Such courses are typically offered during the school day at an assigned time and often a large group of students will take the class. However, in this article, this was not the case.

The T&E teacher showcased here teaches in a small rural school. The school includes Utah's engineering capstone course, but it has proven difficult to fill as a regular class. With only one T&E teacher in the school, greater emphasis has been placed instead on exploratory high school engineering coursework. However, three senior students approached the teacher and wanted to take the engineering capstone course to increase their knowledge and skills in T&E education.

The T&E teacher approached the principal who agreed to offer the capstone course in an after school (non-traditional) setting. The teacher agreed to teach the one-credit course focusing on an engineering design challenge. This article details how the teacher successfully developed and delivered this non-traditional engineering design course.

After the course was approved, the teacher reviewed Utah's Engineering Capstone Course to make sure that the strands and standards identified in the course would be covered (Utah Board of Education, 2018a). An example of "key" Utah strands and standards covered in the course and how they align with *Standards for Technological and Engineering Literacy [STEL]* (2020) is shown in Table 1. In addition, the teacher reviewed the "capstone project rubric" associated with the course (Utah Board of Education, 2018b). The rubric was used as intended by industry mentors to evaluate the students' final project.

In the course, the major strands required students to apply the engineering design process (EDP) and to develop a solution to an engineering design problem. The teacher reviewed many models of the EDP and noted that they were similar in their ideas. The teacher chose the engineering design model developed and highlighted at TeachEngineering (n.d.) and modified it for the capstone course. The students would be required to apply an EDP that would require them to:

(1) Identify the problem, including its needs, constraints, and stakeholders,
(2) Research the challenge, including identifying possible solutions,
(3) Build a prototype,
(4) Test and evaluate the prototype, and
(5) Communicate the results and improve as needed.

Identify the Problem

One major challenge was to identify the engineering problem that the students would address and was driven by the students who identified a need for the school district to have an augmented reality (AR) sandbox. The teacher was focused on supporting students in choosing a design problem, which meant staying very involved without attempting to steer the decision. For broad ideas,

Table 1

***Utah Strands and Standards for the Engineering Capstone Course and their match to the new* Standards for Technological and Engineering Literacy (STEL)**

Utah's Engineering Capstone Course Strands and Standards (2018)	***Standards for Technological and Engineering Literacy [STEL]* (2020)**
Strand 2: Students will describe a formal engineering design process to address and a specific design problem Utah Standards: #1-5	**Standard #1:** Nature and Characteristics of Technology and Engineering Benchmarks: 1Q & 1R **Standard #7:** Design in Technology and Engineering Education Benchmarks: 7W, 7X, 7Y, 7Z, 7AA, 7BB, 7CC, & 7DD.
Strand 3: Functioning as part of a team, students will design a solution to an engineering problem. Utah Standards: #1-2	**Standard #2:** Core Concepts of Technology and Engineering Benchmarks: 2T, 2V, 2W, & 2X
Strand 6: Students will evaluate and reflect on their design process and will report on each step of their process. Utah Standards: #1-4	**Standard #8:** Applying, Maintaining, and Assessing Technological Products and Systems Benchmarks: 8N, 8O, 8P, & 8Q

the teacher directed them to the National Academies' list of "Grand Challenges for Engineering" (NAE, 2008). From there, the students eventually identified a specific project. Within the grand challenge of improving education in science and discovery, they settled on the idea of making an augmented reality sandbox.

When applying the EDP to solve a real-world problem, it is important for all stakeholders involved with the project to be consulted. In this project, the stakeholders included:

- The technology and engineering teacher who would supervise the students.
- The school's geography teacher who would help in developing the learning outcomes associated with the project and use the AR sandbox.
- The school administration who would approve the non-traditional course.
- Teachers at other schools who would use the AR sandbox in their classrooms.
- The students involved in the project who were enrolled in the engineering capstone course.
- The school's educational technology specialist.
- The school's information technology (IT) technician.
- A small business owner and community leader.

Making initial contact with each stakeholder was important as it helped inform how the design problem was defined. The contact also established a support network that would be needed throughout the project. These individuals, once informed of the project, were also able to help with ongoing follow up on the project's progress.

Having students define their "own problem" from a world of possibilities and help make the stakeholder contacts was important. Having them identify the problem helped them to assume ownership in the project and motivated them throughout the project.

Research and Identify Possible Solutions

Outside of an engineering capstone, the research phase is an aspect of the design process that the teacher has found to be often rushed or even overlooked. This supports the work of Mentzer et al. (2015), who reported that "High school students' lack of information gathering reduces their ability to engage in authentic engineering design experiences" (p. 428).

The teacher has observed that information gathering in a design process is a phase that takes place using some combination of computerized research, notetaking, and seeking information from other people. In the AR sandbox project, the students used computerized research, notetaking, and made initial contacts with supportive stakeholders early in the project. Early contact with the supportive stakeholders was very beneficial to the students as contact with these individuals helped to keep students motivated and they provided students with very helpful advice in the designing and building of a mock-up for the project. Since the course was introduced in the middle of the school year, it did not begin with funding in place for supplies. However, a non-functioning mock-up was available after an attempt by previous students in an introductory T&E course: essentially a crate of sand on an old A/V cart, with a projector haphazardly mounted atop an eight-foot board on the side. The students were able to scrutinize and disassemble the original mock-up. Although the mock-up had obvious shortcomings, it offered an alternative to waiting for uncertain funding. The mock-up represented the attempt of earlier students on a very limited budget to make something workable, which was exactly what the current engineering capstone course students were themselves facing. Students were being forced to plan and strategize—exactly what was needed during the second month of the project. The lack of a defined budget kept the students' research open to include every lowest-cost to highest-cost possibility. Even when a grant was secured, the exact amount available to utilize on the project was open for ongoing negotiation. In this way, the teacher facilitated the broadest and longest-lasting research effort he has ever seen with high school students as they worked to develop a defensible plan and budget for the AR sandbox project.

Build a Prototype

Once funding was available for prototyping, the students had more clearly defined the problem. The teacher encouraged them to create a list of specific criteria and constraints. The list they developed noted:

- The size of the box should maximize the number of students who could gather around it and should be made using locally available materials.
- The height should be able to provide students in approximately Grades 4-10 a good viewing experience.
- The stand for the box must be able to hold the weight associated with the project.
- The depth inside the box should allow for maximum topology variations.
- The whole prototype should remain easily portable and fit through school doorways.
- The shape of the sand area should be correctly proportioned for the aspect ratio of the projector that was used to "augment" reality with the topographical overlay.

This list was one clear outcome of the students' previous weeks of brainstorming while staying in contact with stakeholders and others. In those discussions the students were able to define the project's criteria and constraints. Importantly, this list had not defined the problem from the outset, nor had it constrained the breadth of students' research or the process of ideation.

Prior to finalizing the final list of criteria and constraints, the students drew up several ideas about which mentoring partners provided input. As the time for prototyping came, the teacher took care of the budgeting details and ensured that the students had a plan of work to account for how their time would be spent. The number of details could potentially balloon into a larger project. There were also structural concerns of containing so much heavy sand as well as how to make the project portable.

For the project, a computer and audio/visual (A/V) projector would be needed. Adapting an available computer became its own IT design problem. Finding out how different A/V projector specifications affected their possible placements in the design was another complex question that students had to address.

Throughout, the teacher's role was not to manage the project, but to keep students from getting "tunnel vision." Each checkpoint and daily interaction with the teacher were important in maintaining progress. The teacher knew that constant refocusing was needed and he was able to facilitate this by asking the student team broad questions related to the project on a regular basis. This relationship kept the teacher involved and informed, but it kept the students as the leaders and main participants in the construction of the prototype.

Figure 1.
AR Sandbox Prototype. Photo and permission to use courtesy of Geoff Liesik.

Building the prototype (Figure 1) required students to be detail-oriented as they had to firmly adhere to the project's criteria and constraints. For example, the box width was driven by doorways, its length by a 4:3 projector aspect ratio, and the height of the sides by sand's angle of repose. Wheels were dictated by the stability, strength, and smoothness required. A framework was designed based on the height of the intended child users and the physical constraints on the rest of the project. Each of these portions of the prototype found the teacher supporting students in different ways (e.g., providing them with the next wave of materials, a new workspace or tools, or by ensuring that they interact with other stakeholders and mentors).

Implementing the prototype also meant setting up the computer components, getting the software properly configured, calibrating and testing the unit, and routing the various cables and cords. All these considerations had to be accounted for in some form early on, but none were completely spelled out until that portion of the prototype was made. Drawings and CAD models were made along the way for each aspect of the project, which allowed it to be less overwhelming on a day-to-day basis. Throughout the prototyping phase, the teacher routinely asked broad questions and this formative evaluation pushed students to think creatively.

Test and Evaluate the Prototype

Building the prototype required students to continually test their ideas throughout the project. For example, the students built a sandbox on wheels to see if its height made it viewable to all students. In this design challenge, it was found that industry mentors and others gave feedback more readily on the evolving physical prototype than on the students' drawn plans. Sometimes the team would face a setback as one design idea conflicted with plans for another aspect. The teacher's role in this phase was to be supportive through setbacks and encourage students to continue testing until an ideal situation could be achieved.

During project design, the students' early testing determined that the computer needed a larger graphics card, which meant the PC would need a larger power supply, which needed special cable connections to fit an older computer. Another challenge that arose with testing was determining appropriate aspect and throw ratios for the projector. Testing with two borrowed projectors (neither a good fit) was also a learning experience. In each of these unforeseen steps, the teacher would consider and approve changes and contact, or have the students contact, stakeholders knowledgeable in that area.

In solving these problems, the students learned the importance of knowing how systems interact with one another and the need for communication and interdisciplinary cooperation. As the apparent needs and budget evolved, they also gained experience with purchasing procedures and requesting funding. All of this helped the AR sandbox be a capstone project in which students were experiencing authentic project-based learning. The teacher's critical role here was to help students experience testing embedded in the design process. Specifically, the T&E teacher ensured that testing occurred early and often. Throughout the project, especially in building the prototype, the teacher helped students overcome setbacks by providing them with continual support and guidance as they solved the various real-world problems they encountered.

Figure 2.
Students showing their AR prototype Sandbox to children at a school board meeting. Photo and permission to use courtesy of Geoff Liesik.

Communicate the Results

The final phase of the project was the most rewarding for the students. The opportunity for recognition was a meaningful and important part of the capstone course experience. The casual involvement of others to test it at various stages helped boost motivation throughout the project. Toward the end of the project, the teacher and students had the opportunity to showcase the AR sandbox at two local events in the community and a local teachers' association invited the students to showcase their work. This allowed other adults to provide feedback to the students as they prepared to make more formal presentations.

For their final assessment, students were required to formally present their design process and prototype to those mentors whom they had consulted during the project, including individuals from industry and with technical expertise from education. To prepare, the teacher coached the students on how to develop and deliver a formal presentation. Initially, the students seemed "nervous" about the formal presentation, but the teacher coached them to relax by having them practice an "elevator pitch" to several other people and by reviewing the Utah capstone project rubric criteria (Utah Board of Education, 2018b) that would be used to evaluate them. The rubric form would be given to the mentors during the students' formal presentation and was designed to evaluate them in areas related to their introduction, presentation, conclusion, and presentation mechanics. Before the student presentation, the teacher made sure that invitations were extended to stakeholders and school personnel, as well as the industry evaluators, and students' families and friends.

The teacher also arranged for students to present their capstone project to the public at a school board meeting (Figures 2 and 3). The response was overwhelmingly positive among educators and families who were there with children of all ages receiving other recognition. The local media took an interest in the students' work, and a local photographer (Geoff Liesik) provided permission to use the photos shown in Figures 1-3. Although the local paper did not print an article on the student's project, the school and district enthusiastically shared the outcome of the project through its own social media channels.

Conclusion

This article details offering an engineering design capstone course in an after-school (non-traditional) setting as well as how the teacher ensured the students were successful in completing their engineering design challenge. Compared to most technology and engineering courses offered at the school, the engineering capstone design was different as it was driven by the students and the primary role of the teacher was to act as a mentor to help them to solve problems and succeed. Many lessons were learned in offering this course. Other teachers considering offering such a course should consider the best practices used in this course, as well as the potential barriers (see Figure 4).

The process of selecting this augmented reality sandbox project and seeing it through was a great experience for the engineering and technology students taking the capstone course. For the teacher, it was a very new experience in an active support role rather than traditional teaching. Many other and younger students saw the project in process and were inspired to want a capstone engineering experience in the next year or two. This project made a lasting impact by creating a tool for learning in a variety of classes that can be used for years to come. The teacher felt that the project increased his confidence in problem-based learning and looks forward enthusiastically to future cohorts of engineering capstone students, and the new in-depth projects which they will surely undertake.

Figure 3.
Students presenting their AR Sandbox Prototype to the local school board. Photo and permission to use courtesy of Geoff Liesik.

Best Practices Used	Potential Barriers
▪ Having a student team identify their own engineering design project increased student motivation. ▪ Having students do multiple iterations of the design and prototypes. ▪ Having students do in-depth research on their proposed project. ▪ Identifying all project stakeholders and getting them involved early in the project – having students contact stakeholders. ▪ Having the teacher continually using formative assessment (e.g., checkpoints at various stages during the project). ▪ Having students do multiple formal presentations on their prototype.	▪ An unusual schedule (e.g., after school) could affect student motivation. ▪ Complex budget. It needed to be developed by the students and many factors had to be considered. ▪ The course was not structured as a typical course and students often needed to be reminded of their roles and responsibilities. ▪ Making sure students regularly contacted stakeholders. ▪ Identifying and arranging appropriate community presentations.

Figure 4.
Best practices and potential barriers associated with offering a non-traditional engineering design capstone course.

References

Baker, J., & Reeve, E. (2019). Engineering design: On display. *Technology and Engineering Teacher, 79*(1). www.iteea.org/TETSept-19BakerReeve.aspx

International Technology and Engineering Educators Association (2020). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education.* Reston, VA: Author.

Mentzer, N., Becker, K., & Sutton M. (2015). Engineering design thinking: High school students' performance and knowledge. *Journal of Engineering Education (JEE), 104*(4), 417-432. DOI 10.1002/jee.20105

National Academy of Engineering (NAE), (2008). *NAE grand challenges for engineering.* www.engineeringchallenges.org/challenges.aspx

TeachEngineering (n.d.). *Engineering Design Process.* www.teachengineering.org/k12engineering/designprocess

Utah Board of Education, Technology and Engineering Education, (2018a, July). *Strands and standards, Engineering capstone.* www.schools.utah.gov/file/d1fe46a6-b20d-432d-a248-0aeb08c3a8fc

Utah Board of Education, Technology and Engineering Education, (2018b, August). *Capstone project rubric.* www.schools.utah.gov/file/24af062e-9951-4379-b789-97a76bca1702

Joseph S. Woodard *is a Technology and Engineering Teacher at Uintah High School. He can be reached at joseph.woodard@uintah.net.*

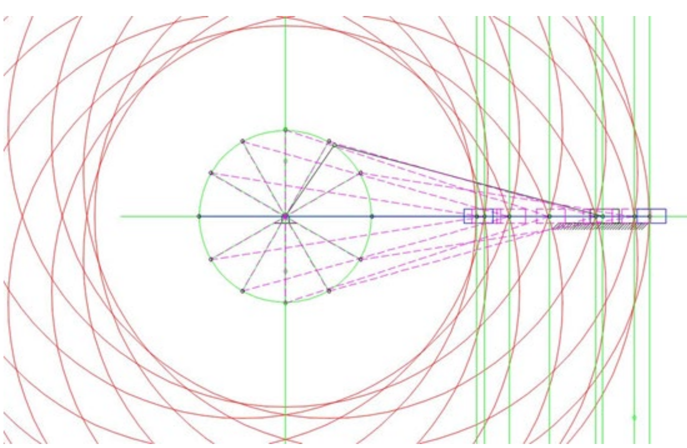
Edward Reeve, Ph.D., DTE, *is a Professor in Technology and Engineering Education at Utah State University. He can be reached at ed.reeve@usu.edu.*

This is a refereed article.

transforming technology & engineering educator inputs

into desired student outputs through mechanism analysis and synthesis

by Andrew J. Hughes and Chris Merrill, DTE



Applying the instantaneous center method for determining velocities of a mechanism's members during specific instances of the mechanism's motion is based on relatively simple mathematical relationships.

The intention of this article is to provide middle and high school Technology and Engineering Educators (T&EEs) with a more thorough understanding of an engineering approach to the teaching and learning of mechanics. During the teaching and learning of engineering content, in this case mechanics, the educator should attempt to align pedagogical content knowledge with engineering content knowledge and practices. T&EEs will also need to focus on terminology, structure, and applying theory to practical hands-on learning activities inside and outside of the classroom. T&EEs have the potential to foster middle and high school students' mechanical knowledge and the ability to apply this knowledge during engineering design experiences. As a robust understanding of mechanics is considered a requirement in college-level engineering programs, especially mechanical engineering, T&EEs should consider the development of students' engineering knowledge and ability to apply this knowledge paramount. T&EEs are always looking for new standards-based content focused on improving students' STEM-based skills and hands-on capabilities.

The standards and benchmarks to be utilized in this activity are:

Standards for Technological and Engineering Literacy (ITEEA, 2020):

- Standard 2: Core Concepts of Technology and Engineering
  - 2N. Illustrate how systems thinking involves considering relationships between every part.
  - 2T. Demonstrate the use of conceptual, graphical, virtual, mathematical, and physical modeling to identify conflicting considerations before the entire system is developed.
- Standard 6: Influence of Technology on Human Progress
  - 6F. Recognize that technological development has been evolutionary, the result of a series of refinements to basic inventions of technological know-how.
  - 6I. Analyze how the Industrial Revolution resulted in the development of mass production, sophisticated transportation and communication systems, advance construction practices, and improved education and leisure time.
- Standard 7: Design in Technology and Engineering Education
  - 7V. Evaluate and improve their own essential skills necessary to successfully design.
  - 7CC. Apply a broad range of skills to their design process.

Next Generation Science Standards (NGSS Lead States, 2013):

- Engineering Design
    - MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.
    - HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

In the September 2021 issue of *Technology and Engineering Teacher,* Hughes and Merrill (2021) began addressing the basic concepts inherent to mechanics, specifically related to kinematics (i.e., mechanism motion) of a four-bar mechanism. The teaching and learning associated with mechanisms traditionally begins with the study of kinematics and later adds the study of kinetics. This second article will continue to explain the process of educating students about mechanics. In this article, the authors present an introduction to a slider-crank mechanism design using CAD software to produce graphical representations of the mechanism's motion. The explanation of kinematics will be followed by an explanation of kinetics.

The study of Kinematics includes the study of motion, basic geometry of mechanisms, velocity, and acceleration of mechanism components (i.e., members or links) but does not include the forces that cause or affect motion. Kinetics, on the other hand, includes the analysis of forces on a mechanism's components to determine both the internal and external mechanism forces. Due to the inclusion of force analysis in kinetics, students learning about mechanisms more commonly begin by studying kinematics, first focusing on mechanism motion. The authors' favorite aspect of kinematics is that it helps students *conceptually visualize* mechanical motion using *graphical models.* Kinematics consists of both mechanism analysis and synthesis. As the names imply, mechanism analysis is the study of a mechanism's motion and mechanism synthesis is the design of a mechanism to yield desired motion characteristics. In the study of kinematics, it is important to begin by developing an understanding of the motion characteristics for given mechanisms.

Educating Students about Motion Characteristics

To help students develop an understanding of motion characteristics, teachers can begin by having them use CAD software to draw graphical models for a given mechanism. After students see the mechanism's motion graphically, educators can allow students to 3D print or produce the given mechanism using construction paper and cardboard to help further develop understanding of the mechanism's motion. Then students can modify the given mechanism to change its motion characteristics. There are two common modifications that help students further develop conceptual understanding of a mechanism's motion. The most common is inversion. Inversion is the process of fixing different links in a mechanism and in turn creating different motion characteristics. Another common modification is changing the length of any one member at a time. The next step is educators having students design and produce their own mechanisms. Finally, teachers can add analysis of velocities and accelerations to the understanding of motion using methods like effective component, instant center, relative, difference, calculus, graphical, and or any combination of these methods.

Graphical Motion of a Mechanism

Figure 1 is a slider-crank mechanism (i.e., slider-crank linkage). Figure 1 is basically a graphical representation of a single cylinder engine. In Figure 1, *Label 1* represents *member 1.* Member 1 is fixed and does not move. Member 1 represents the frame, both the engine block (left side of Figure 1) and the cylinder (right side of Figure 1). *Label 2* represents *member 2* and the engine crankshaft. *Label 3* represents *member 3* and the connecting rod. Finally, *Label 4* represents *member 4,* the slider or piston. The connections between members 1 and 2, 2 and 3, 3 and 4, and 1 and 4 are considered pivots as well as *kinematic pairs,* and more specifically *lower pairs.* Lower pairs have surfaces in contact, for example the surface of member 4, the slider, is in contact with surface 1, the cylinder wall. There are also *higher pairs.* Higher pairs only have one point in contact, for example a cam and follower. Hughes and Merrill (2021) addressed using Gruebler's equation to determine the degrees of freedom for a mechanism. In the case of the slider-crank mechanism, there is one degree of freedom, meaning the mechanism is considered a *constrained kinematic chain.* This basically means that only one member needs to be controlled in order to control the motion of the entire mechanism.

To help students begin graphically visualizing the slider-crank mechanism's motion characteristics, they should use CAD to first draw the slider-crank, and then add drawn layers representing the mechanism motion through every 30 degrees of member 2's rotation (Figure 2). The students can use different layers, line color, and line type to have a colorful, some might say artistic, graphical rep-

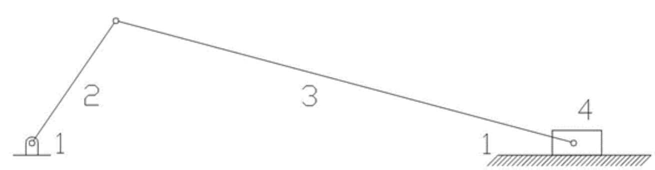


Figure 1.
Labeled Slider-crank Mechanism

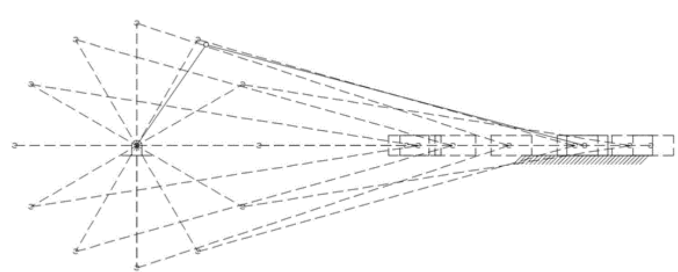


Figure 2.
Motion Characteristics

Figure 3.
3D Printed Slider-crank Mechanism

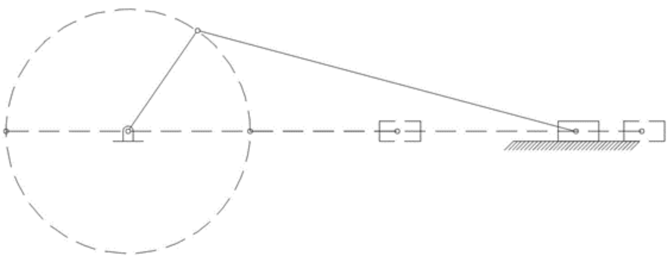


Figure 4.
Slider-crank Mechanism Extents

resentation of the slider-crank mechanism's motion (see page 21). At this point students will start to make connections between the graphical representation and the actual motion of a single cylinder engine or similar slider-crank mechanism. This is a good time to show a video of a single cylinder engine with cutaway operating. It is also a good idea for the educator to provide students with some already pre-made slider-crank mechanisms (Figure 3). In Figure 3, the slider (i.e., member 4) is connected to the frame (i.e., member 1) using a sliding dovetail. Figure 4 represents the extents of this slider-crank mechanism's operation. In Figure 4, member 4 is slid as far left and right as possible based on the current mechanism design (i.e., the relationship between members 1, 2, 3, and 4).

Instantaneous Centers

There are many methods for analyzing the velocities and accelerations of each member in a mechanism, as mentioned above. Arguably the simplest is the instantaneous center method (i.e., instant center method) or velocities by centro method. Hughes and Merrill (2021) addressed how to begin thinking about a mechanism using the instant center method. The goal is to graphically and conceptually visualize a mechanism's motion as rotational motion around an instant center (i.e., point). When visualizing the mechanism's motion, it is important for students to determine how may instant centers exist using this equation; number of instant centers = $\frac{(n\,(n-1)}{2}$ where *n* is the number of members in the mechanism. For the slider-crank mechanism in this article, there are 4 members, which, based on the equation, means there are 6 instant centers.

Hughes and Merrill (2021) explained the use of Kennedy's theorem and the derived circle method to determine the labeling and location of the 6 instant centers. In Figure 5, all instant centers are visible. Kennedy's theorem basically states that any three bodies (i.e., members) having plane motion relative to one another have three instant centers, and these instant centers all lie on a straight line. For example, in Figure 5, you can see that members 1, 2, and 3 have instant centers 12 (said as *instant center one two*), 23, and 13. In Figure 5, you can see that instant centers 12, 23, and 13 all lie on a straight line, this is basically Kennedy's theorem.

Instant center 12 is a fixed instant center because it exists as a fixed center point around which member 2 rotates. Instant center 14 is an example of a unique fixed instant center. Although member 4 reciprocates on a linear path, imagine that member 4 oscillated on a circular path with a center of rotation at instant center 14. As you increased the radius of that circular path, the path would appear to be more of a straight line, especially for a short distance. The instant center 14 exists at infinity because member 4 reciprocates on a linear path. Instant centers 23 and 34 are considered *permanent* instant centers. Member 2 is always connected to member 3 and instant center 23 permanently exists in a circular path (i.e., centrode) defined by the rotation of member 2 and the oscillating motion of member 3. Additionally, member 3 is always connected to member 4, instant center 34 permanently exists along a straight-line path (i.e., centrode), which is defined by linearly sliding motion of member 4. Instant centers 13 and 24 are considered *imaginary* instant centers. Imaginary instant centers exist outside the mechanism at particular instances of the mechanism's operation and have similar characteristics as fixed or permanent instant centers. Instant

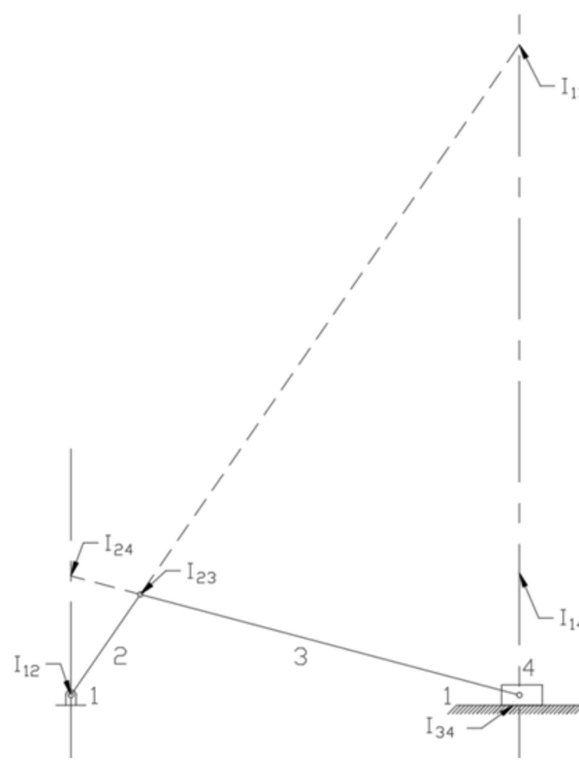


Figure 5.
Instant Centers Located

centers 13 and 24 move along the corresponding center lines as the mechanism moves (Figure 5).

Determining Velocities based on Instantaneous Centers

Applying the instantaneous center method for determining velocities of a mechanism's members during specific instances of the mechanism's motion is based on relatively simple mathematical relationships. The relationships are based on visualizing each member's rotation around an instantaneous center (i.e., point). The ability to determine velocities at any point in terms of pure rotation simplifies the analysis of mechanisms. The velocities of a mechanism's members can be determined through calculation and graphical measurement using CAD. It is a good idea to help students use both calculation and graphical methods when determining velocities.

Line of Centers Method

The line of centers method is a common method associated with determining velocities using instant centers. The line of centers method uses three links including (1) a known link, (2) an unknown link, and (3) a base link. These three links will also have three instant centers. The instant centers can be determined using the method previously explained. In Figure 6, to determine the velocity (ν_{34}), the three links needed are (1) member 2 (i.e., the know link), (2) member 4 (i.e., the unknown link), and (3) member 1 (i.e., the base link). The three instant centers for these links are 12, 14, and 24. The linear velocity of the point defined by instant center 24 (ν_{24}) is equal to the angular velocity of member 2 (ω_2) multiplied by the radii of rotation for instant center 24 ($\nu_{24} = \omega_2$ (12-24)). The radii of rotation in this example, denoted as 12-24, really means the distance between the center of rotation (i.e., instant center 12) and the point at which the linear velocity ν24 acts (i.e., instant center 24). If member 2 is rotating clockwise at a constant angular velocity of 200 RPM, the linear velocity ν24 is equal to 200 RPM multiplied by 1.46 inches (distance determined in CAD) or 292 in/min. As member 4 translates linear motion into only rotational motion, as in a single cylinder engine, it is known to be in *pure translation.* Additionally, linear velocity ν_{24} acts at a point (i.e., instant center 24) associated with member 4 with the same orientation as ν_{34}. As such, in Figure 6, this pure translation means that ν_{24} is the same as ν_{34}.

Kinetics

The term kinetics was classically used in mechanism analysis to describe the inclusion of force analysis. More recently the term dynamics has replaced the use of the term kinetics. Using the term dynamics makes practical sense considering the inclusion of force analysis in conjunction with mechanism motion. However, it is common for students to begin analyzing forces as if the mechanism is a rigid body. In a single cylinder engine, maximum pressure from combustion happens just after the piston passes through top dead center. In a four-stroke engine, the combustion pressure acts as a force on the piston during the power stroke, which moves the piston through the power, exhaust, intake, and compression strokes. The combustion pressure of an engine can vary based on various engine characteristics. The combustion pressure can be used to determine the force acting on the piston.

In Figure 7, the force from the combustion pressure, F, has been scaled to equal 1.5 lbs. The combustion force F produces a force R in member 3 and a force S in member 2. To determine forces R and S, the rectangular component forces must be used (i.e., R_x, R_y S_x, and S_y). Since force F is the only force introduced and it is directly on the x-axis, R_x must be equal to F. So, R_x equals 1.5 pounds of force. Using the component force equation, R_x = Rcos(9°), we see that R = 1.5 lbs. / .9877 or R = 1.52 lbs. Force R_y is calculated using this component force equation, R_y = Rsin(9°), R_y = 1.52 lbs.(.156) or R_y = .238 lbs. Similarly, force F must be equal S_x. So, S_x equals 1.5 pounds of force. Using the component force equation, S_x = Scos(30°), we see that S = 1.5 lbs. / .866 or S = 1.73 lbs. Force S_y is calculated using this component force equation, S_y = Ssin(30°), S_y = 1.73 lbs.(.5) or Sy = .865 lbs.

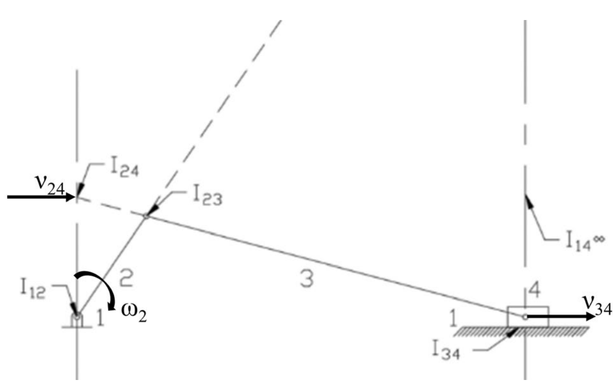


Figure 6.
Velocities by Line of Centers Method

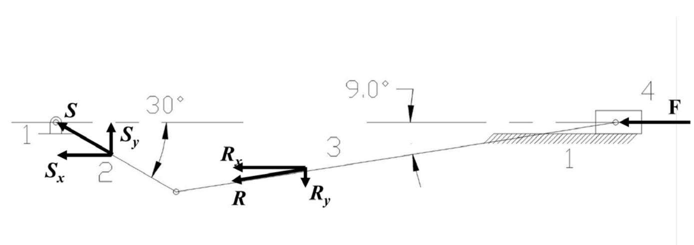


Figure 7.
Force Analysis

Conclusion

This article was a follow-up to a September 2021 *TET* article covering the analysis of a four-bar mechanism. The four-bar and slider-crank mechanisms are the two most common mechanisms for students first learning how to analyze them. The intention of this article was to provide a more thorough understanding of kinematics and kinetics that Technology and Engineering Educators could apply during mechanism design activities in their classrooms. The primary goal is for educators to apply this content to develop students' mechanism knowledge during practical hands-on learning activities in the STEM classroom. Students' ability to analyze and synthesize mechanisms is important for many common activities in Technology and Engineering Education and post-secondary success in engineering programs.

References

Barton, L.O. (1984). Mechanical Analysis: Simplified Graphical and Analytical Techniques. New York, NY: Marcel Dekker, INC.

Constans, E., & Dyer, K. B. (2018). *Introduction to Mechanism Design: With Computer Applications.* CRC Press.

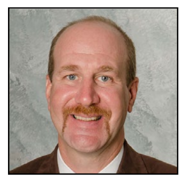
Hughes, A. J., & Merrill, C. (2021). Mechanism Design and Analysis: Developing an Understanding of Mechanism Motion through Graphical Modeling. *Technology and Engineering Teacher, 81*(1), 21-26.

International Technology and Engineering Educators Association (ITEEA). (2020). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education.* Reston, VA: Author.

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academies Press.

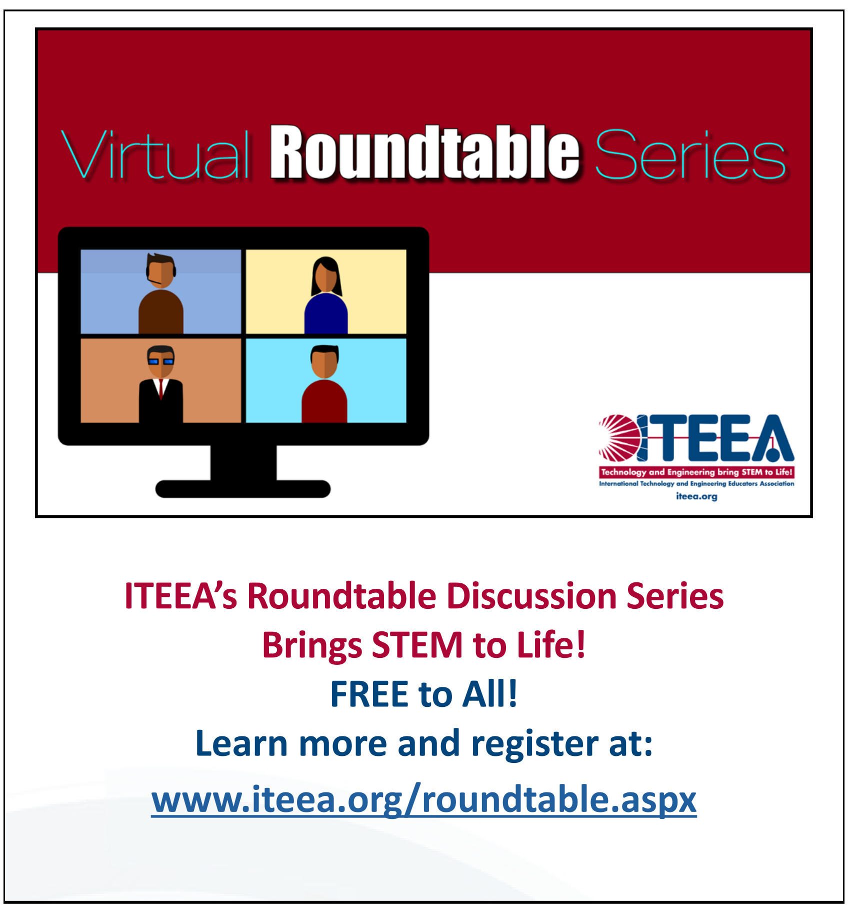
Rao, J. S., & Dukkipati, R. V. (2015). *Mechanism and machine theory.* New York: Wiley.

Andrew J. Hughes, Ed.D., *is an assistant professor in the Designated Subjects, Career and Technical Education, and Adult Education Program, Department of Educational Leadership and Technology at the California State University of San Bernardino. He can be reached at* andrew.hughes@csusb.edu.



Chris Merrill, Ph.D., DTE, *is a professor in the Department of Technology at Illinois State University, Normal, IL. He can be reached at* cpmerri@ilstu.edu.

This is a refereed article.



A Rural Teacher's Look at Equity

by Adam Kennedy

It was naïve to assume that everyone had opportunities similar to mine and this exercise has put my experiences into perspective.

While I have lived most of my life in a very rural setting, I have also had the opportunity to spend time in mid-sized cities like Pittsburgh, Indianapolis, and Nashville. As an individual who pursued a degree in Technology and Engineering Education, I often encountered a stereotype that urban schools are at a distinct disadvantage. Low graduation rates, budgetary concerns, subpar resources and technology, and more are issues commonly associated with urban environments. I questioned the accuracy of this stereotype and set out to explore programs at different cities in the U.S.

Previously, my only experience in an urban technology education setting was a single class at a high school in Lancaster, PA. It appeared to be a bare-bones type of class, which only furthered my assumptions, but also led me to want to explore different cities across the country. Given the stereotypes that were prevalent throughout my education, I assumed the resources would be extremely limited at all urban schools and was therefore quite surprised and interested with what I found.

Initially it was difficult to find articles or details about these programs, which are typically referred to as industrial arts, technology education, technology and engineering education, shop class, STEM, etc. After striking out with Google searches, I checked Chicago Public Schools' (CPS) website, where I discovered that CPS, along with many other urban school districts, refers to its technology and engineering education curriculum as career and technical education, or CTE (Chicago Public Schools, n.d.). This was a term with which I had no experience. CTE refers to different kinds of "elective" courses, such as the traditional technology education classes we all know, as well as to culinary, masonry, automotive, cosmetology, and many more. With this new information I dove deeper into this topic. I began to research specific cities and their respective educational institutions.

My first search led me to New York City Public Schools. One article outlined Aviation High School on Long Island. Photos and text illustrated an amazing high school that provides students with an environment that "combines rigorous coursework in language arts, mathematics, science, and social studies with world-class technical training" and an opportunity for graduates to "earn Federal Aviation Administration airframe and/or powerplant certifications." Aviation High School has gained nationwide recognition as one of the top high schools in the country, as reported by *U.S News and World Report* (Association for Career and Technical Education, 2012). Additionally, the school has relationships with leaders in the aviation industry. As technology and education teachers, we know the benefits of hands-on, real-world experiences, and the students at Aviation High School reap the benefits of these partnerships. For example, students are given the opportunity to work on functioning aircraft donated by FedEx, utilize a classroom located at JFK International Airport to simulate a real-world aircraft mechanic environment, and can intern with different companies like JFK International Airport, JetBlue, and Delta (Inside Schools, n.d.). At the conclusion of their coursework, students have the opportunity to gain jobs starting at $50,000 a year, and with a graduation rate of 88% compared the city-wide rate of 57%, many of these students have a real opportunity to change their family's trajectory (Association for Career and Technical Education, 2012). While Aviation High requires students to undergo an admission process, the fact that schools like this exist in urban settings is encouraging.

It is important to note that the application process, especially in urban settings, can present a barrier to many students. According to the AHS' website, the criteria used for admissions works on a percentage scale, with 30% of the criteria met by Sixth Grade June Report Card Grades, 30% is Seventh Grade September to January Report Card Grades, and 40% is Sixth Grade ELA and Math State Test Scores (Aviation High School, 2021). I have not verified whether the criteria were put in place due to the pandemic, or if this is standard practice, nor did I find distinct information regarding whether there was a cost to apply. With this information in mind, several things occurred me as potential issues with allowing this school to be available for everyone.

I understand that these schools are for bright students who meet specific criteria. That being said, there are students in urban settings with extreme disadvantages in terms of a difficult home life, socioeconomic challenges, undiagnosed learning disabilities, and others. It is reasonable to assume that a substantial percentage of these students may be at an academic disadvantage when it comes to grades and test scores. One study states that "for the specialized high schools, between 2005 and 2013, 5 percent of middle schools accounted for 50 percent of children admitted" (Robinson, 2016). This is a startling figure that can truly show the distinct advantages some students can gain in the admissions process, and I would venture to guess that in technical specialty areas like AHS, that number would be very similar, if not worse, as students with access to technical programs would want to pursue these over students who have never experienced technology and engineering education.

Lastly, it seems likely that Aviation High might alienate those individuals who don't realize their path until later in their secondary education. Often, technology and engineering educators don't recognize their "calling" until well into high school and often because of exposure and encouragement at that level. Without access to technology and engineering coursework, access to equipment and tutelage from a more experienced individual, or genuine curiosity to pursue resources to explore on their own, most will simply lose out on this opportunity. For students to be as prepared and knowledgeable as possible to choose a career that suits them, they need exposure to these types of careers in middle school, which can be almost non-existent in urban schools.

Next I explored Chicago Public Schools, which lists its programs under the CTE umbrella. The CPS website was very helpful, showing not only the pathways that students could take, but also where the programs are offered. Programs were offered in areas referred to as "Architecture and Construction" and "Manufacturing and Pre-Engineering." Diving a bit deeper into these areas, "Architecture and Construction" did have the basic architectural design component and was heavily focused on the trades. It offered the architecture program, but it also offered classes such as Welding, Electrical, HVAC, and more (Chicago Public Schools, n.d.). This seems to indicate that it's what I would consider a trade school, based on my experience in Pennsylvania. It was awesome to see that these schools had opportunities for students to explore the trades, as this is becoming much rarer. College is certainly not the end-all as is sometimes suggested and opportunities exist for great paying jobs without taking on any college debt.

In CPS, Architecture was the most prevalent in CTE programs, and was offered at five schools, which was reassuring. However, only one high school in the entirety of the Chicago Public School system offered welding. It's easy to see how common urban struggles like transportation, monetary resources, and exposure could make it difficult for students to be involved in this program. The likelihood that a student can gain exposure to this career outside that singular high school is very low. With only 1 out of 169 high schools in CPA offering welding, the average student has a 0.59% chance of getting an education in welding (*U.S. News and World Report*, n.d.). Architecture, while higher, still sits at only 2.95%.

Lastly, I wanted to look at an education system close to home, so I took a look at Philadelphia Public Schools. This website was difficult to navigate and took time to uncover the listing of CTE programs offered throughout the district. Construction and Manufacturing careers were one section, outlining the traditional trades like Carpentry, CADD, and Construction, but there were others like Mechatronics, Plumbing, and Facility and Property Maintenance. There were programs in Transportation that held Automotive Careers and Supply Chain, as well as programs in Information Technology (Office of Career and Technical Education, n.d.). I was impressed with the wide variety of programs offered—until I took a deeper dive and realized that carpentry, or at least woodworking, was offered in only two high schools (Office of Career and Technical Education, n.d.). With 55 schools in the Philadelphia public school system, only 3.64% offer carpentry, which I had assumed was widely prevalent in most areas (*U.S. News and World Report,* n.d.). Mechatronics and CADD were in only one high school (1.82%); six schools had an Engineering Technologies program (10.91%); and Welding was in only four schools (7.27%), to name a few (Office of Career and Technical Education, n.d.).

At the outset of this research, I was optimistic. When researching Aviation High School, it was incredible to hear some of the options for their students, and I began to think my assumptions about urban schools were off base. As I got to Chicago, I came to the realization that schools like Aviation High might be few and far between, as Chicago Public Schools had very limited options for CTE programs, and when you get into the math behind the situation, you are met with some very grim numbers. As I approached Philadelphia, I began to have an idea what to expect, and therefore was not shocked with what I found. I suppose at the end of the day it was naïve to assume that everyone had opportunities similar to mine and this exercise has put my experiences into perspective. I feel fortunate to reside in rural areas and to have had the opportunity to take as many of these classes as desired in high school and explore my creative and technological sides. It pains me to know that these opportunities are so scarce for students in urban communities. While I do not know how to solve these issues, I do know that I will continue to research and to broaden my knowledge of CTE and technology and engineering education in urban environments and work to develop solutions and plans for these students. This was certainly an eye-opening literature review, and I hope this was as transformative for some of you as it was for me.

References

Association for Career and Technical Education. (2012). *CTE's role in urban education*. https://files.eric.ed.gov/fulltext/ED569189.pdf

Aviation High School. (2021). *Updated Entrance Criteria.* www.aviationhs.net/groups/15804/admissions/admissions

Chicago Public Schools (n.d.) *Career and technical education (CTE).* Retrieved April 1st, 2021 from www.cps.edu/academics/career-and-technical-education/

Inside Schools. (n.d.) *Aviation career and technical education high school.* Retrieved March 25th, 2021 from https://insideschools.org/school/24Q610

Office of Career and Technical Education. (n.d.). *A head start on getting ahead.* Retrieved April 15th, 2021 from www.philasd.org/cte/our-cte-programs/

Robinson, G. (2016). The problem with NYC high school admissions? It's not just the test. *City Limits.* https://citylimits.org/2016/02/08/the-problem-with-nyc-high-school-admissions-its-not-just-the-test/

U.S. News and World Report. (n.d.) *Chicago Public Schools District.* Retrieved April 1st, 2021, from www.usnews.com/education/best-high-schools/illinois/districts/chicago-public-schools-110570

U.S. News and World Report. (n.d.) *Philadelphia Public Schools District.* Retrieved April 15th, 2021 from www.usnews.com/education/best-high-schools/pennsylvania/districts/philadelphia-public-schools-101796

Adam Kennedy *is a technology education teacher in the Cocalico School District located in Denver, Pennsylvania, and can be reached at* adam_kennedy@cocalico.org.

let's collaborate!

the importance of cybersecurity pathways and their accessibility

by Vukica Jovanovic, Otilia Popescu, Murat Kuzlu, and Petros Katsioloudis

This month's guest authors are Vukica Jovanovic, Otilia Popescu, Murat Kuzlu, and Petros Katsioloudis from Old Dominion University's (ODU) Department of Engineering Technology, Norfolk, Virginia.

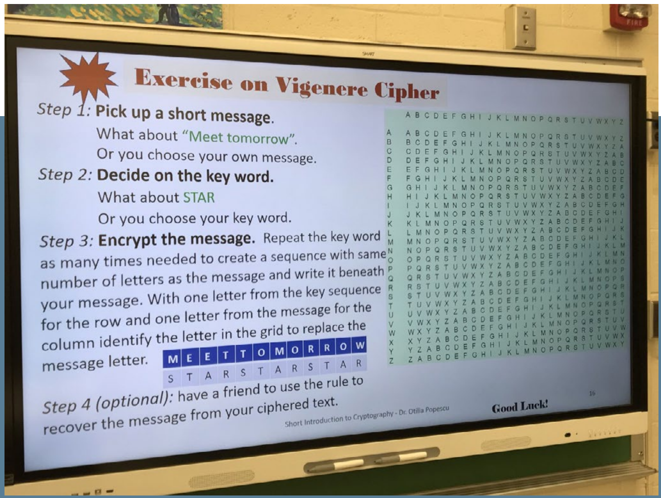
Dr. Jovanovic is currently serving as an Associate Professor of Engineering Technology and the Batten Endowed Fellow. She went through engineering pathways, completing her master electrician degree during Technical School in Serbia with pre-engineering programs focused on high-power voltage systems and maintenance of electro-mechanical systems. Her research includes engineering pathways, CTE education, digital thread, cyber physical systems, mechatronics, digital manufacturing, and broadening participation. She is the Director of Mechatronics and Digital Manufacturing Lab at Old Dominion University and a lead of Mechatronics Systems Design area of specialization.

I am very passionate about inspiring a new generation of the STEM workforce. Going through the engineering pathway myself since 9th grade, I have seen the value of technical education and early career choice. In high school, I learned so much about math and science, but also about the technical and applied aspects of STEM professions. I had one apprenticeship in electrical power and aluminum mill companies where I explored how the concepts from the classes convey to the real world. It was so much easier to learn all the equations and different aspects of technology from the textbook and my teachers after hands-on experience and real life industry exposure. Because of this,

Dr. Katsioloudis (ODU), Dr. Kuzlu (ODU), Mr. Crespo (NPS), Dr. Jovanovic (ODU), Mr. Meister (NPS) and Ms. Marshall (NPS) pictured here upon the laptops' delivery.

our project tries to create a bridge between industrial needs and high school technical education. We want to make sure students are receiving appropriate instruction that really matches the needs of the industry, so our collaborations span from high school to the industrial setting and from high school to the academic setting. We want to help high school students understand all of the different pathways and opportunities they have in the area of cybersecurity after high school graduation.

This summer Norfolk Public Schools (led by Deborah Marshall, Career & Technical Education (CTE) Teacher Specialist and Mr. Michael Crespo, Chair of Granby High School CTE Department) and ODU organized a Cybersecurity camp for our elementary and middle school students to inspire them to partake in the Cybersecurity Pathway. We established a series of fun activities that showcased applications of cybersecurity in the classroom like coding, cryptography, hands-on activities with Raspberry PI and Python, Cyber Range activities, and Capture The Flag challenges.

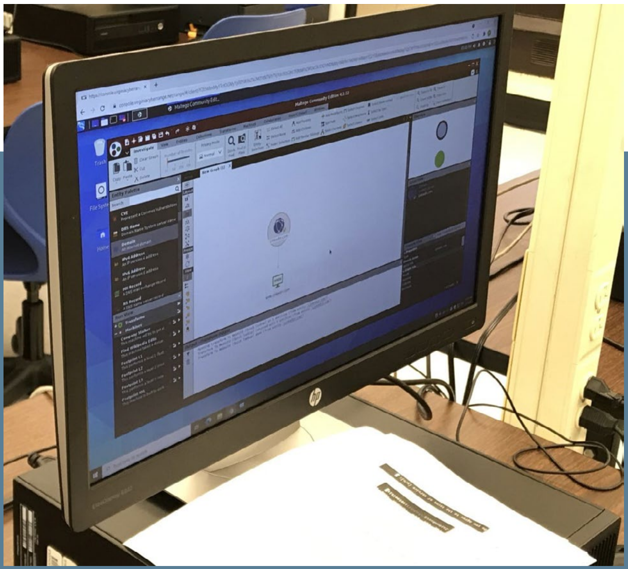


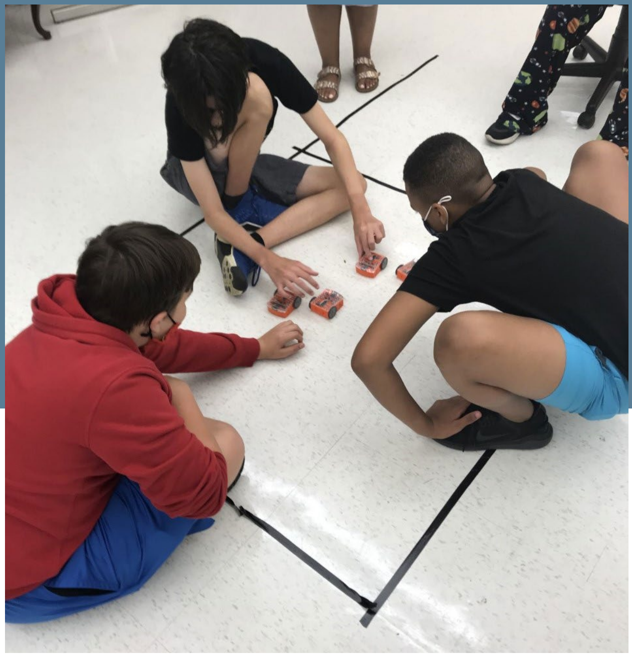
Dr. Popescu, Associate Professor in the College of Engineering, has expertise in electrical engineering, specifically in wireless communication systems. She is currently serving as Program Director for the Electrical Engineering Technology (EET) program, overseeing the curriculum and assisting students with transitions into the program and with their advising needs until graduation. In her position, she coordinates with the industrial advisory board for the program, making sure the curriculum keeps up with industry changes and graduates are prepared for the continuously changing job market.

Dr. Popescu joined the ODU team along with CTE high school teachers from Norfolk, and participated in developing cybersecurity course materials. This collaborative work developed mostly in a virtual environment for the past year, but this summer offered the opportunity to meet for in-person summer camp, and introduce middle and high school students to the cybersecurity field and inspire them to pursue related careers.

During Dr. Popescu's part of the summer camp, she introduced students to the area of cryptography. The basic concepts of steganography and cryptography were introduced along with various encryption algorithms. Students were first introduced to simple monoalphabetic substitution ciphers like Caesar and Vigenere ciphers, discussing the methods along with their weaknesses and what makes the ciphers easy to be broken. Several transposition ciphers were discussed including rail fence cipher, route cipher, columnar transposition cipher and Myszkowski transposition cipher. Students were instructed on how to work with these types of cyphers and do text encryption/decryption. Once the basic idea behind cryptography and encoding was explained, students were introduced to the next step in developing algorithms with the ultimate goal of implementing them in computer code using a chosen computer language. The structure of an algorithm, illustrated with the use of flowchart diagrams, and the simple Caesar cipher used as a starting example to explain the flowchart concept. The last step was to transpose the charts in C language to develop a computer-based encryption algorithm. Activities included in the summer camp were very attractive to the students because they started from something simple, similar to a puzzle game, but little by little students were able to see how these methods may be further applied for protecting information either when stored on a computer machine or during a transfer within a computer network. The activities were designed mostly to generate awareness and make the students curious to investigate further. It was essential to start with simple examples to get students engaged for them to see that these types of problems are within their grasp and that they are capable of pursuing pathways in cybersecurity.

Dr. Kuzlu, Assistant Professor in ODU's ET Department. Before joining ODU, he worked as a Research Assistant Professor at Virginia Tech's Advanced Research Institute (VT-ARI). His research interests include smart grid, demand response, smart metering systems (AMR, AMI, AMM), home and building energy management systems, co-simulation, wireless communication, and embedded systems.



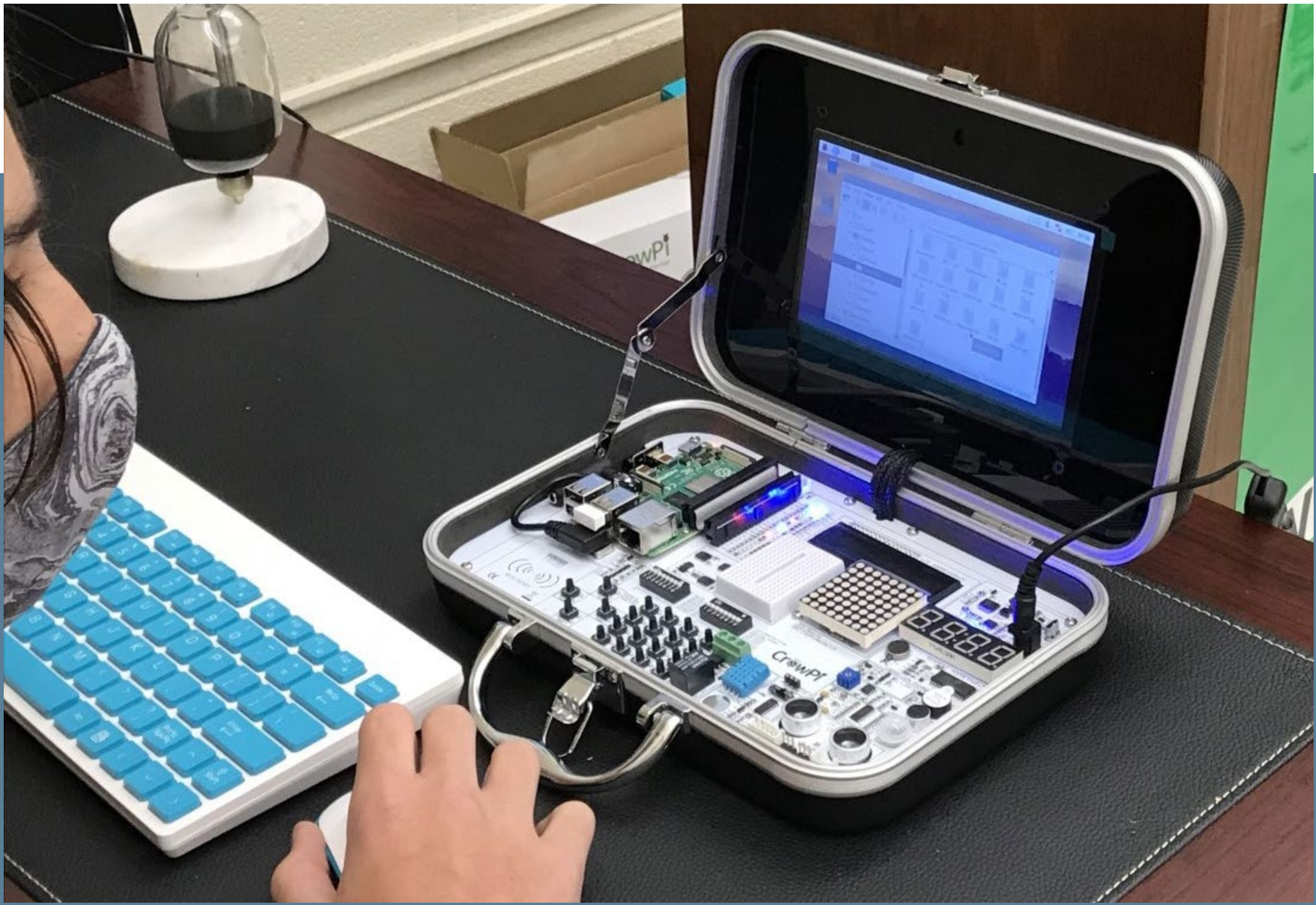


One part of the summer camp covered hands-on activities with CrowPi Board (a kind of Raspberry Pi development board specially designed for STEM education) and Python. The main objective of these hands-on activities was for students to learn hardware (i.e., Raspberry Pi) and a programming language (i.e., Python). Each session lasted about two hours and alternated between presentations and hands-on activities. For the lecture session, instructors used a PowerPoint presentation that included the introduction to the CrowPi, basics of Python, and various hands-on activities. CrowPi board was first introduced with its hardware components including Raspberry Pi 4, Bluetooth keyboard and mouse, earphone, gamepads, sensors, and other electronics and software components, i.e., Linux-based operating system. Then, Python programming language was introduced with an integrated development environment (IDE) for building Python applications. Ten hands-on activities with components were briefly introduced, including buzzer, button, sound sensor, light sensor, temperature and humidity sensor, motion sensor, ultrasonic sensor, touch sensor, tilt sensor, LCD (Liquid Crystal Display) display, and camera. Once CrowPi with components and basics of Python with IDE were introduced, students learned how to use Python and started to run applications on CrowPi. Students ran all ten hands-on activities alternating with a very short introduction including new components and types of projects. The presentation and all hands-on activities are also publicly available on the GitHub repository, https://github.com/muratkuzlu/CrowPi_Python_Projects.

Dr. Katsioloudis, Professor and Chair in the Department of STEM Education and Professional Studies at ODU. As a faculty member who earned tenure and moved through the academic ranks, he has earned the respect of colleagues as demonstrated by several awards, his publication record, teaching excellence, involvement in grants, and service to professional organizations, as evidence of his accomplishments in both empirical and practitioner-based STEM-related research. At ODU, he concurrently held positions as program leader for the undergraduate program in industrial technology, graduate program director, chair of the college human subject review committee, assistant chair, co-chair, and chair. As a part of the team Dr. Katsioloudis focused on the collaboration aspect in the grant between faculty and teachers towards the development of supplemental curriculum.

We need more people in our STEM workforce who are highly skilled to tackle the high tech challenges of dealing with cybersecurity attacks, handling malicious malware, and building the data-resilient infrastructure of tomorrow. The cybersecurity workforce is growing steadily but there is a wide gap in the number of available technical workforce who can fill in the available jobs. This trend is not going to change in the near future so we have to act quickly to address the needs of the industry, government, and educational institutions across the nation.

During our project the faculty, graduate, and undergraduate students from ODU worked with CTE teachers from Norfolk Public Schools, Norfolk, Virginia to develop educational supplemental materials for the following courses: Informational Technology Fundamentals and Cybersecurity Fundamentals. These modules can be downloaded from our project website here: https://sites.wp.odu.edu/odu-nps-cs-cybersecurity-pathway-for-cte/.



teacher highlight

Kurt Sanderson graduated from Northern Michigan University with a BS in Secondary Education Industrial Technology and attained a MA in STEM Education Leadership from The American College of Education. Born and raised in Elmhurst, IL, he currently teaches at the same middle school he attended.

Kurt Sanderson

Industrial Technology Teacher 6-8
Bryan Middle School
Elmhurst, IL

What inspired you to become a technology and engineering educator?

Teacher blood runs in my family. My father, who was also a Technology and Engineering teacher, gave me my first set of tools in my Easter basket as a kid. Since childhood, I've always enjoyed creating with my hands and sharing my passions with others.

What do you consider your greatest successes in the classroom?

A couple of my greatest successes in the classroom are connecting with my students and empowering them to discover and develop skills they didn't know they had. After my 8th graders move on to high school, I love hearing about how many of them choose to continue in the field because of how much fun they had in my classes. Even though my area is stereotypically dominated by boys, I do everything I can to empower girls to continue on in STEM subjects. The industry needs more women in STEM roles and the career exploration phase starts in middle school.

Can you share an example of a classroom failure from which you learned?

Even good kids have the ability to make poor behavioral choices when they are bored. Students who excel in this area need to be continuously stimulated with enrichment opportunities to fuel their interest and curiosity in this subject. My first year I only had the curriculum material I was given, and I did my best to keep up with that.

What is the best thing about being a T&E teacher?

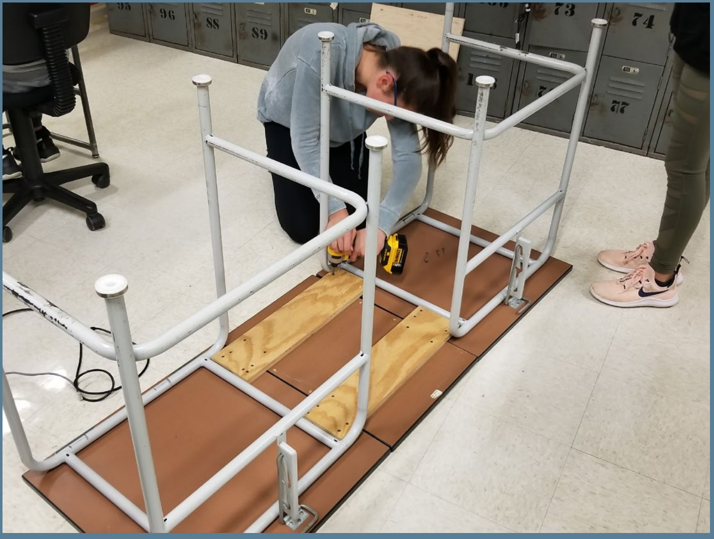
My favorite thing about my job is watching kids become autonomous in the workshop. It is a process and learning experience getting them there, but once they have the knowledge and skills to create and build safely on their own, seeing them work without teacher direction is very rewarding to me. Also, getting to explore other things out of curiosity. Of course, I have a curriculum to cover, but if a student shows interest in a particular topic or concept, let's dive in! The flexibility I have to teach kids what I believe is important is valuable to me.

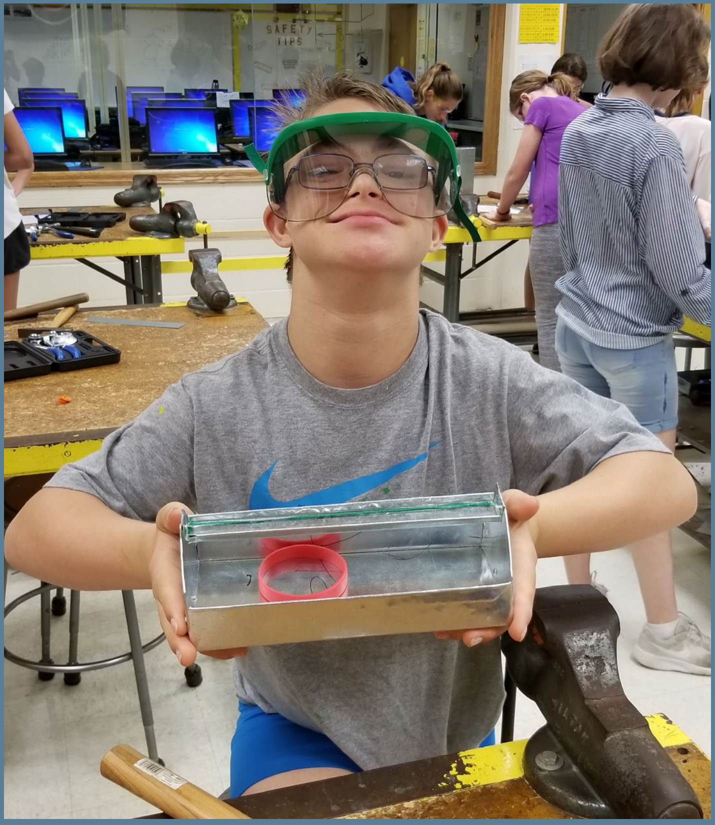
What would you say to students today who are considering careers as T&E educators?

Becoming a T&E teacher was the best decision of my life. If you would like a career that will keep you on your toes every single day, yet allow you to have fun working with kids, I couldn't recommend it more! Northern Michigan University prepared me well for what I was about to dive into. Other than COVID times, I have enjoyed pretty much everything about my job.

What are you planning to explore and pursue in your classroom in the near future?

In the near future I plan to explore collaborative 3D modeling projects. Collaboration on projects is such a common practice in many current career fields and web-based software is finally enabling students to practice this skill before they are thrust into the job market. Teaching how to collaborate on a bigger project is also a valuable skill for the work world of today and beyond.





using *Aladdin* as a tool to empower engineering learning

by Viranga Perera, Greg J. Strimel, and Alejandra J. Magana

With the publication of the Framework for P-12 Engineering Learning, *engineering will hopefully become more prominent and equitable across secondary education in the coming years.*

Introduction

Engineering learning, a three-dimensional construct that includes Engineering Habits of Mind, Engineering Practices, and Engineering Knowledge, has been well established and defined at the post-secondary level (Reed, 2018). Meanwhile, engineering within pre-kindergarten through 12th grade (P-12) classrooms continues to grow steadily. Changes introduced by *A Framework for K-12 Science Education* (National Research Council, 2012) and *Next Generation Science Standards* (NGSS Lead States, 2013) have started to place engineering within secondary science education, just as the inclusion of engineering design in *Standards for Technological Literacy* did within technology education classrooms at the turn of the century (International Technology and Engineering Educators Association, 2000/2002/2007). More and more students are now exposed to engineering learning prior to graduating from high school in a variety of courses like technology, science, and career/technical education classrooms, as well as informal learning programs. Nevertheless, engineering in its own right often remains a missing or minimal component of the learning experience for many students (Change the Equation, 2016; Miaoulis, 2010). To include engineering in a more prominent manner, the *Framework for P-12 Engineering Learning* (2020) has recently been published as a practical guide for developing coherent, authentic, and equitable engineering learning programs across schools. This guidance includes a definition of the three dimensions of engineering learning, principles for pedagogical practice, and common learning goals. The framework can support the development of in-depth and authentic engineering learning initiatives and provide building blocks toward the 2020 *Standards for Technological and Engineering Literacy.* As a component of the framework, engineering practices are detailed by describing core concepts that can support performing these practices with increased sophistication over time. Examples include making data-informed design decisions based on material properties and employing computational tools to analyze data to assess and optimize designs. In this *Engineering in Action* article, we introduce a freely available, open-source computer-aided design (CAD) software called *Aladdin* and discuss how it can support authentic engineering practice within secondary classrooms. Earlier works have suggested that *Aladdin* is an effective tool for implementing *Next Generation Science Standards* (e.g., Chao et al., 2018; Goldstein, Loy, & Purzer, 2017). Similarly, we make a case for using

Aladdin in secondary engineering education and discuss how recommendations of the *Framework for P-12 Engineering Learning* map to specific features of the software.

What is *Aladdin*?

Aladdin (formerly known as *Energy3D*) is a freely available, open-source CAD program that has been developed specifically to help students learn about designing energy-efficient buildings and renewable energy solutions (Xie, Schimpf, Chao, Nourian, & Massicotte, 2018). It also allows education researchers to study actions that students perform within the platform (e.g., Seah & Magana, 2019; Vieira, Seah, & Magana, 2018). Since the software is easy to use and has built-in tutorials, students can quickly learn how to model a simple building (e.g., see Figure 1). They can then start to do analyses to understand if their designs meet their needs (e.g., being within a certain budget and being an energy-neutral building). *Aladdin* can be downloaded for free on both Mac and Windows computers from the following website: https://intofuture.org/aladdin.html. The development of a cloud-based version is currently underway to make it even more powerful and accessible.

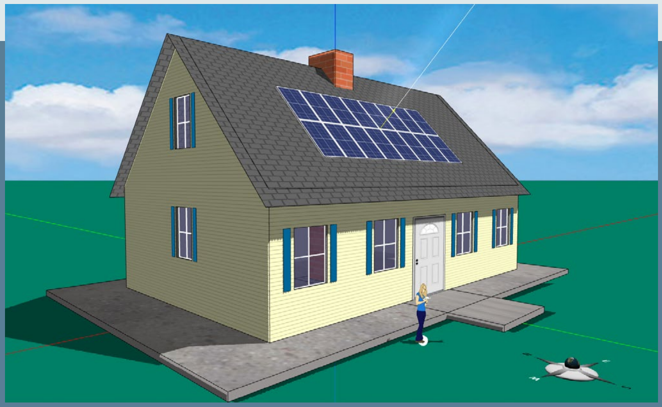


Figure 1.
An example house in *Aladdin*

Is Aladdin an Effective Teaching Tool?

Previous education research suggests that Aladdin is an effective tool for helping secondary education students specifically to learn important engineering concepts. Goldstein, Omar, Purzer, & Adams (2018) found that middle school students benefited by working on a design project using Aladdin; importantly, even if their projects were relatively simple. Furthermore, in their study, also with middle school students, Dasgupta, Magana, & Vieira (2019) showed that Aladdin helped students to learn principles of thermodynamics and heat, and allowed them to perform systematic experimentation to create better building designs. Magana et al. (in press) demonstrated different learning activities enabled by Aladdin within middle school, high school, and pre-service teacher classrooms. They found that students in all classrooms increased their conceptual understanding of thermodynamics. Students in those classrooms also produced feasible designs (i.e., met the design criteria and were energy efficient).

How Can *Aladdin* Be Used With the New Engineering Framework?

The *Framework for P-12 Engineering Learning* describes *engineering learning* as being composed of three areas: *Engineering Habits of Mind, Engineering Practice,* and *Engineering Knowledge.* We will illustrate how *Aladdin* can be used to teach students each of these areas within *engineering learning.*

Engineering Habits of Mind

Engineering Habits of Mind consist of *optimism, persistence, collaboration, creativity, conscientiousness,* and *systems thinking.* While *Engineering Habits of Mind* should be modeled through specific teaching practices, *Aladdin* can still help promote these habits. Specifically, students can learn about *systems thinking* by modeling buildings within *Aladdin.* They can understand how designing a building requires both identifying important components of a building system (e.g., location, size, and energy) and quantifying how those components interact with one another. Considering that almost all contemporary engineering now relies on the extensive use of CAD tools, early introduction of CAD concepts and usage in P-12 education may foster engineering habits of mind in an even more practical sense.

Engineering Practice

Engineering Practice involves *engineering design, material processing, quantitative analysis,* and *professionalism.* Each of these components of *Engineering Practice* involves a number of skills. Here we will demonstrate how *Aladdin* can help students learn skills for each component listed above.

Engineering design involves a number of skills such as problem framing, information gathering, ideation, engineering graphics, design communication, and decision making. We will particularly focus on decision making, as *Aladdin* has built-in analysis tools to help students make better design decisions. After students have modeled a building, they can quickly perform an annual energy analysis to determine the net energy usage of their building. Figure 2 shows an example annual energy analysis with net energy shown in circular orange markers and connected by a thick black line. The annual energy analysis tool allows students to quantify which months of the year require more energy. They will additionally be able to identify components of their building that require significant energy and try to mitigate that energy use. Since the annual energy analysis tool only takes a few seconds or a few minutes to run, students can easily explore how changes to their building design affect the energy use of the building.

In real-world engineering projects, engineers need to account for material properties such as thermal, mechanical, and electrical characteristics. The *material processing component of Engineering Practice* involves a number of skills such as manufacturing, measurement and precision, fabrication, casting/molding/forming, separating/machining, joining, conditioning/finishing, safety, and

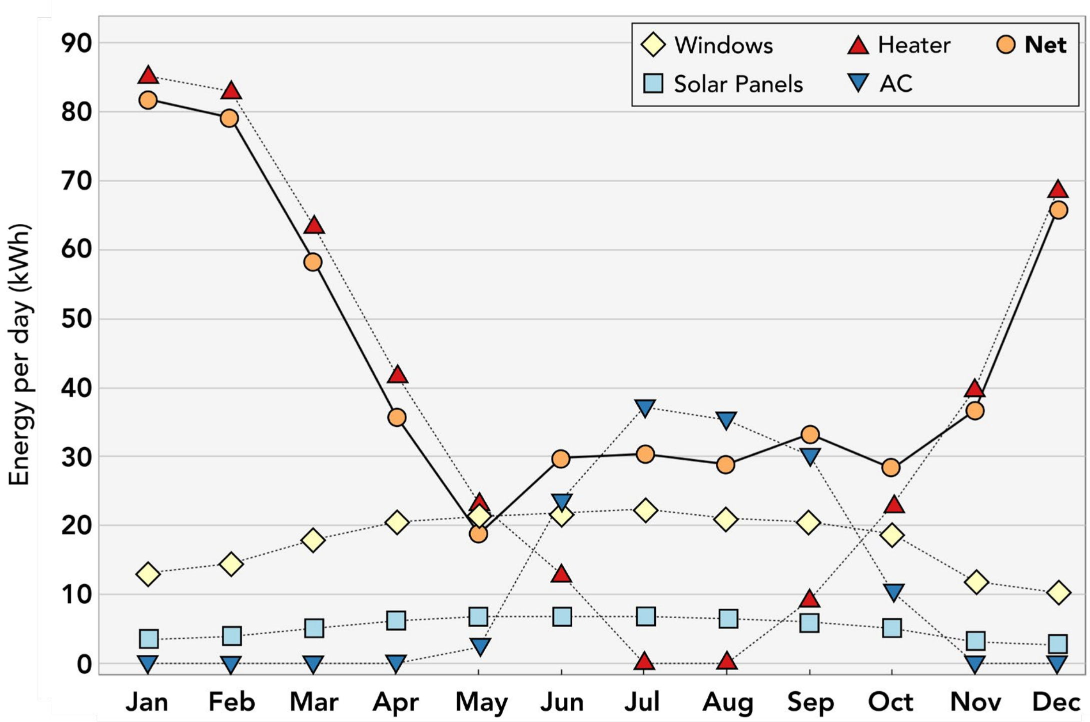


Figure 2.
The *Aladdin* built-in annual energy analysis tool showing energy use (in kWh) for various components of a modeled building as a function of time (in months). The figure has been modified from the *Aladdin* output to improve readability by increasing the marker and font sizes and by using colorblind safe colors (electronic version only).

material classification. While it is a CAD software, presently *Aladdin* does not easily allow fabrication, for example, by sending CAD designs to a 3D printer (though it supports printing out 2D pieces for assembling into 3D structures). Nevertheless, students can still use the software to learn about material classification. Students can explore how changing material properties (e.g., thermal insulation of building walls) may affect the overall building design. *Aladdin* allows students to set either the U-value or R-value for one or more walls of a building (see Figure 3). The U-value is the overall heat coefficient of a material and has units of $W/m^2 \cdot °C$. In the case of a hot summer day or a cold winter night, an ideal house should have low U-values for its walls to minimize thermal energy transferring through them. A low U-value will keep the inside of the building insulated, thus allowing it to be cooler inside in the summer and warmer in the winter. Alternatively, instead of setting the U-value, students can set the R-value. The R-value is a measure of the resistance to heat conduction and has units of $h \cdot ft^2 \cdot °F/BTU$. As part of their building design, students can explore setting different insulation values (either U- or R-values), they can look up typical insulation values for real building construction materials, and they can explore the consequences of setting different insulation values for different walls to factor for solar irradiance.

Quantitative analysis involves a number of skills such as computational thinking, data collection, analysis and communication, system analytics, modeling and simulation, and computational tools. By the nature of the CAD software, *Aladdin* is ideal for teaching all of these skills, but here we will particularly focus on how it can help teach students to use computational tools. *Aladdin* allows students to model buildings in a specific location (e.g., Indianapolis, Indiana). Students can use the heliodon feature to visually study the Sun's path through the sky as a function of time (see Figure 4). In the case of Indianapolis, since the city is located nearly 40 degrees north of the equator, students will notice that the Sun's path is lower in the sky in the winter and higher in the summer. They can,

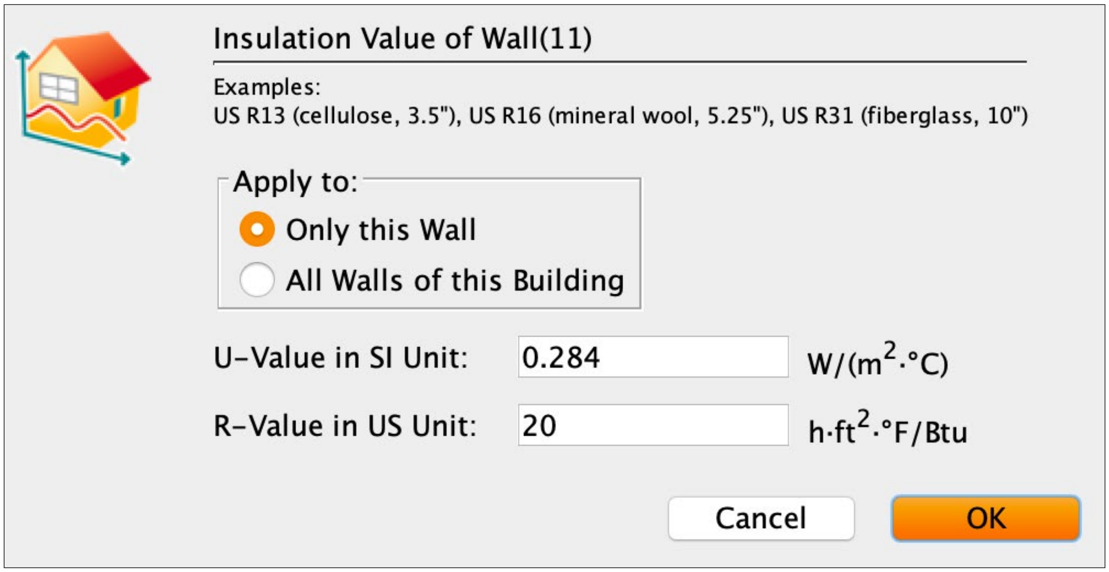


Figure 3.
Wall insulation can be modified for buildings in *Aladdin*

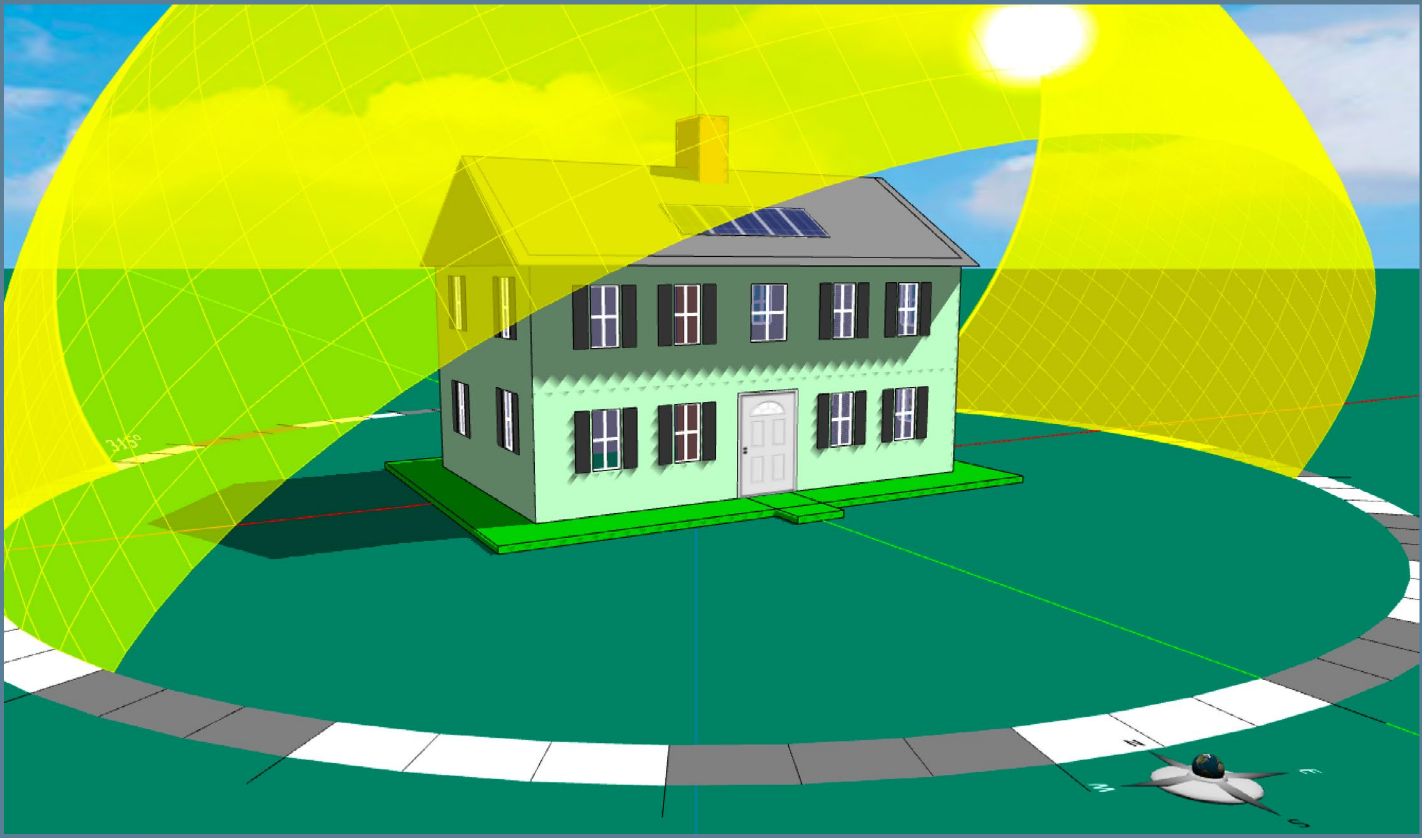


Figure 4.
Heliodon feature in *Aladdin* allows students to analyze energy use based on the Sun's path across the sky

for example, then think about how their building designs can take advantage of the Sun's path to maintain a certain temperature throughout the year.

The final component of *Engineering Practice* is *professionalism,* which involves a number of skills such as professional ethics, workplace behavior/operations, honoring intellectual property, the role of society in technological development, engineering-related careers, and technological impacts. Since *Aladdin* allows students to model buildings and to analyze them for their energy efficiency, the software naturally lends itself to a discussion about technological impacts, particularly impacts on the environment. Constructing and operating buildings produces significant amounts of carbon dioxide emissions. In 2017, buildings accounted for 39% of the world's carbon dioxide emissions (Abergel, Dean, Dulac, & Hamilton, 2018). Given that buildings are a significant contributor to climate change, we need to both make current buildings more sustainable and improve future building designs. *Aladdin* can help teach our youth to be mindful of the impact that buildings have on the environment and to work towards mitigating those negative effects.

Engineering Knowledge

Engineering Knowledge involves engineering sciences, engineering mathematics, and engineering technical applications. We will focus here on engineering sciences and engineering technical applications.

Engineering sciences include statics, mechanics of materials, dynamics, fluid mechanics, mass transfer and separation, chemical reaction and catalysis, circuit theory, thermodynamics, and heat. *Aladdin* can help students learn concepts in both thermodynamics and heat. A lesson on the first law of thermodynamics would be a good introduction to students using *Aladdin.* Students would then use the software with the knowledge that maintaining a comfortable temperature inside a building (i.e., no change in its internal energy) means that the building needs to have no net heat (assuming of course, there is no thermodynamic work done on the building). Students can use the heat flux visualization tool in *Aladdin* (see Figure 5) to understand how certain parts of a building have higher heat fluxes (windows in this particular case) and can think about ways in which thermal energy exchange between the inside of a building and the outside environment can be minimized.

Engineering technical applications include concepts such as mechanical design, structural analysis, hydrologic systems, geotechnics, environmental considerations, and electrical power. Given that *Aladdin* allows students to easily add solar panels onto their model buildings, it is a convenient place to teach students about electrical power generation. This is also a relevant topic to students since we, as a society, will likely be using more solar power for our electrical power generation in the coming years and decades. When a student places a solar panel, they will have a number of options to alter properties such as the model of the solar panel (e.g., ASP-

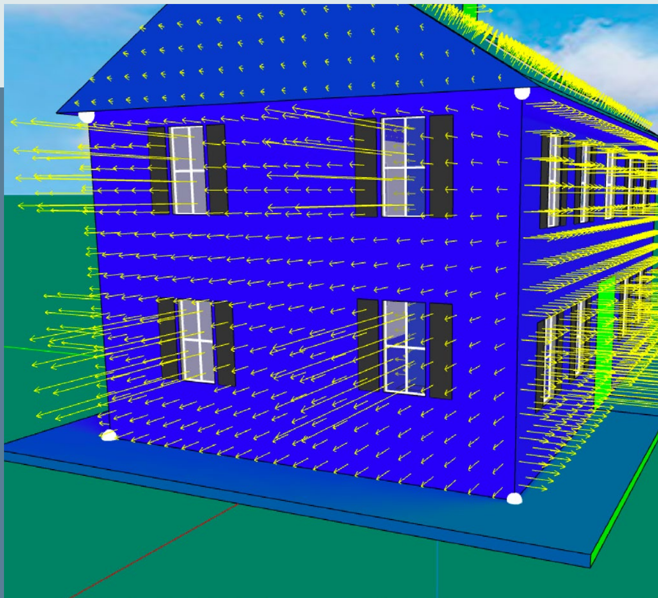


Figure 5.
Heat flux vectors demonstrating more energy loss through windows than walls of the building

400M, CS6X-330M-FG, and FS-275), size, cell type (e.g., polycrystalline, monocrystalline, and thin film), cell efficiency, and inverter efficiency (see Figure 6). Cell efficiency is defined as the fraction of incident solar energy that is converted by the cell to electrical energy. While solar energy is freely available, students may be interested to learn that a contemporary limiting factor for solar energy production is cell efficiency. Even today, the most efficient solar cells tend to be under 40% efficient (Green et al., 2020). While certain solar panel parameters are limited by current technology, students can explore ways to alter the number, size, and orientation of solar panels to increase electrical power production.

Conclusions

With the publication of the *Framework for P-12 Engineering Learning*, engineering will hopefully become more prominent and equitable across secondary education in the coming years. As this occurs, teachers will need effective tools to help them teach engineering concepts to students in an authentic manner. Here we demonstrate how a freely available, open-source CAD program can serve that purpose. By doing so, we hope that we have provided some examples and ideas for teachers to empower engineering learning within their classrooms in authentic and rigorous ways. In addition, this tool may provide options for teachers to continue their instruction virtually in times of interruption, such as during the COVID-19 pandemic.

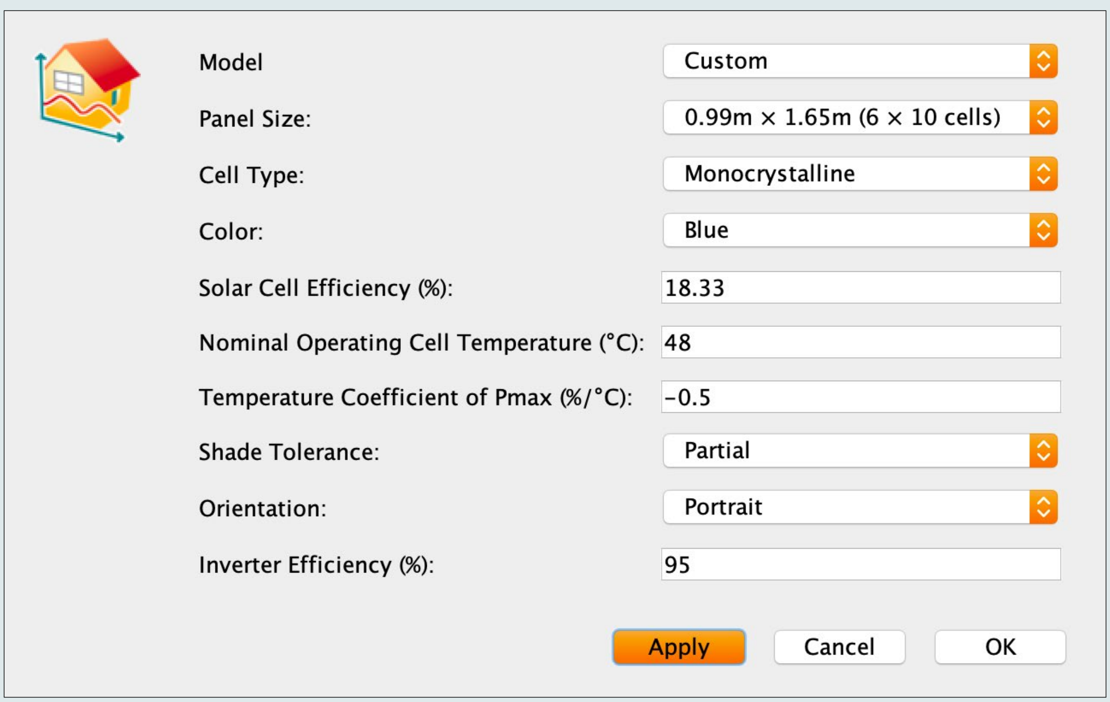


Figure 6.
Options to change solar panel parameters in *Aladdin*

Acknowledgments

We thank Charles Xie for developing *Aladdin* and Cynthia A. Brewer (Penn State) for the Color Brewer tool (https://colorbrewer2.org) that helped us select colorblind-safe colors for Figure 2. The research reported in this paper was supported in part by the U.S. National Science Foundation (NSF) under the award DRL #1503436. This content is solely the responsibility of the authors and does not necessarily represent the official views of the NSF.

References

Abergel, T., Dean, B., Dulac, J., & Hamilton, I. (2018). *2018 Global Status Report: Towards a Zero-Emission, Efficient, and Resilient Buildings and Construction Sector.* Global Alliance for Buildings and Construction. www.worldgbc.org/sites/default/files/2018%20GlobalABC%20Global%20Status%20Report.pdf

Advancing Excellence in P-12 Engineering Education & American Society of Engineering Education (2020). *Framework for P-12 engineering learning: A defined and cohesive educational foundation for P-12 engineering.* American Society of Engineering Education. https://doi.org/10.18260/1-100-1153-1.

Change the Equation. (2016). Left to chance: U.S. middle schoolers lack in-depth experience with technology and engineering. *Vital Signs.* www.ecs.org/wp-content/uploads/TEL-Report_0.pdf

Chao, J., Xie, C., Massicotte, J., Schimpf, C., Lockwood, J., Huang, X., & Beaulieu, C. (2018). Solarize Your School. *The Science Teacher, 86*(4), 40-47. www.jstor.org/stable/26611994

Dasgupta, C., Magana, A. J., & Vieira, C. (2019). Investigating the affordances of a CAD enabled learning environment for promoting integrated STEM learning. *Computers & Education, 129,* 122-142. https://doi.org/10.1016/j.compedu.2018.10.014

Goldstein, M., Loy, B., & Purzer, Ş. (2017). Designing a sustainable neighborhood. *Science Scope, 41*(1), 32. www.nsta.org/science-scope/science-scope-september-2017/designing-sustainable-neighborhood-interdisciplinary

Goldstein, M. H., Omar, S. A., Purzer, S., & Adams, R. S. (2018). Comparing two approaches to engineering design in the 7th grade science classroom. *International Journal of Education in Mathematics, Science and Technology, 6*(4), 381-397. www.ijemst.org/index.php/ijemst/article/view/280

Green, M. A., Dunlop, E. D., Hohl-Ebinger, J., Yoshita, M., Kopidakis, N., & Ho-Baillie, A. W. (2020). Solar cell efficiency tables (Version 55). *Progress in Photovoltaics: Research and Applications, 28*(1), 3-15. https://doi.org/10.1002/pip.3228

International Technology and Engineering Educators Association (ITEA/ITEEA). (2000/2002/2007). *Standards for technological literacy: Content for the study of technology.* Reston, VA: Author.

International Technology and Engineering Educators Association (ITEEA). (2020). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education.* www.iteea.org/STEL.aspx.

Magana, A.J., Chiu, J., Seah, Y.Y., Bywater, J.P., Schimpf, C., Karabiyik, T., Rebello, S., & Xie, C. (2021). Classroom orchestration of computer simulations for science and engineering learning: a multiple-case study approach. *International Journal of Science Education.* https://doi.org/10.1080/09500693.2021.1902589

Miaoulis, I. (2010). K-12 engineering: the missing core discipline. In Grasso D., Burkins M.B. (eds) *Holistic Engineering Education.* Springer, New York, NY. https://doi.org/10.1007/978-1-4419-1393-7_4.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: The National Academies Press. https://doi.org/10.17226/13165

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academies Press. www.nextgenscience.org/

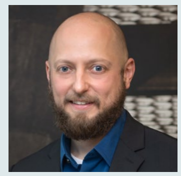
Reed, P. A. (2018). Reflections on STEM, standards, and disciplinary focus. *Technology and Engineering Teacher, 77*(7), 16-20.

Seah, Y. Y., & Magana, A. J. (2019). Exploring students' experimentation strategies in engineering design using an educational CAD tool. *Journal of Science Education and Technology, 28*(3), 195-208. https://doi.org/10.1007/s10956-018-9757-x

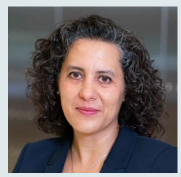
Vieira, C., Seah, Y. Y., & Magana, A. J. (2018). Students' experimentation strategies in design: Is process data enough?. *Computer Applications in Engineering Education, 26*(5), 1903-1914. https://doi.org/10.1002/cae.22025

Xie, C, Schimpf, C, Chao, J, Nourian, S, & Massicotte, J. (2018). Learning and teaching engineering design through modeling and simulation on a CAD platform. *Computer Applications in Engineering Education, 26,* 824-840. https://doi.org/10.1002/cae.21920

Viranga Perera, Ph.D., *is a postdoctoral researcher at Purdue University (West Lafayette, IN). He can be reached at viranga@purdue.edu.*

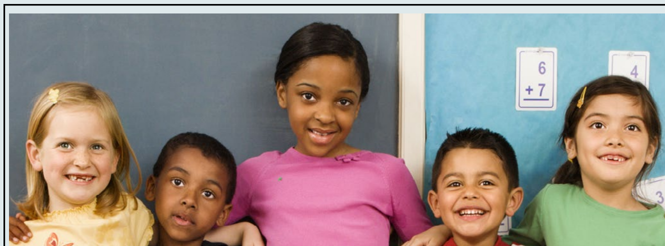


Greg J. Strimel, Ph.D., *is an assistant professor of technology leadership and innovation at Purdue University (West Lafayette, IN). He can be reached at gstrimel@purdue.edu.*



Alejandra J. Magana, Ph.D., *is the W.C. Furnas Professor in Enterprise Excellence at Purdue University (West Lafayette, IN). She can be reached at admagana@purdue.edu.*

This is a refereed article.



classroom challenge

children's book design challenge

by Harry T. Roman

Introduction

There is great interest in technology-themed books for the young reader. You should challenge your students to create such books to help develop their written communication skills (i.e., the ability to bring across simple concepts in a clear, concise manner); and to learn how listening to the market or audience for a new product is important to the design of that product. These are 21st century skills workers will need to successfully compete in a global economy.

Getting Started

What kinds of technology books are out there already for the young reader? Your students need to research the field. Check out websites and bookstores. There are probably books that discuss such popular and timely technology subjects like:

- Electricity from the sun
- Robots
- Wind power
- Electric cars

There might even be books that discuss:

- Inventions
- Space flight
- Computers
- Climate change

Take a hard look at how these books are designed, how the content is presented, what graphics and illustrations are used, the age level of the books, and any special projects or materials for the reader to do on their own.

Perhaps a survey of lower-grade students at your school might reveal what interest there is in various technology subjects. Why not design a survey for younger students to fill out and tell you what technologies they are interested in? What would they like to know about the technologies of interest? How would they like to see the information presented?

This process is similar to what companies do to determine if there is a need for new products and/services, and what those might be. They are generally referred to as market surveys. Analyze the results of your in-school surveys and select the technologies of greatest interest so your students can attempt some book designs.

The Designs

Encourage your students and teams to keep these things in mind:

- What is the age level of the reader you are designing for?
- Should the book design be a hardbound or paperback edition; or perhaps an electronically accessible product for a variety of devices like PCs, and hand-held portals?
- What aspects of the technology to be discussed is to be emphasized to the young reader:
    - Cost of the technology?
    - Maturity of it?
    - Benefits it brings to users and the world?
    - Other?
- What book length is suitable for the attention span of young readers?
- How much should this book cost?
- Would your students want to show how this technology is being used today, perhaps even there in your school?

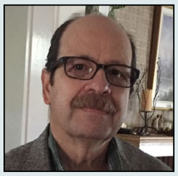
As your students and teams begin the writing and development of the books, provide feedback from the intended readers…let some younger students read drafts of the book and offer comments. This is a powerful way to keep the writers and book designers on track with their work.

Have teachers look the draft text over as well to make sure grammar, composition, and writing style are correct and consistent. If the books are being created via student teams, then perhaps various team members should play important roles (on a rotating basis) as copyrighter, editor, proofreader, etc…just like in a book publishing company.

How and where will the graphics be introduced—using stock art or hand-drawn figures? Can someone from your school's art department help out here?

Might it be appropriate to have quotations from experts in technology fields included in the text?

Once your students have a chance to live the bookmaking process, chances are they will never see a book the same way again!



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.*


Use STEM Skills to Change Lives
Inspire Student Innovation
Impactful Design-Thinking Project
ITEEA
Ready-Made Lesson Plans + Slides
Win ITEEA Awards
Sign-Up TODAY!
iteea
REaCH
challenge
An Innovative Adaptive & Assistive Technology Challenge
for Middle School, High School, and College STEM Programs
www.ReachChallenge.org