



TECHNOLOGY AND ENGINEERING EDUCATION



Bringing STEM to Life

IDEAS FOR SECONDARY INSTRUCTION

Experiences of Incorporating
Virtual Modeling in Technology
and Engineering Classrooms

ELEMENTARY STEM IN ACTION

Computational Thinking Friends

INTERNATIONAL PERSPECTIVES

Landscaping Korean STEM Education
as Teachers and Researchers in the
Field of Technology and Engineering
Education

Preregistration Opens in Early September!

ITEEA's 86th Annual Conference in Memphis, TN: March 6-9, 2024



Technology and Engineering: The Soul of STEM

All educators should strive to teach all students – including those with different strengths, backgrounds, and interests – to authentically apply STEM concepts and knowledge with hands-on technology and engineering education experiences! ITEEA's 2024 Conference will help you do just that; featuring sessions that range from "back to basics" to exploring emerging technologies, educators will leave with turnkey "Monday morning" lessons for their classroom. Join us as we use technology and engineering education to connect with students' souls and bring STEM to life!

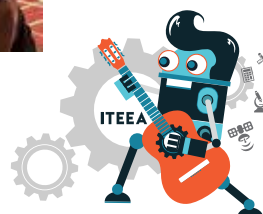


Why attend ITEEA's 2024 Conference?

- Learn from the knowledge, research, and ideas shared by like-minded professionals.
- Boost your network.
- Stay updated on the newest products and trends.
- Enjoy all that Memphis has to offer!

There is still time to apply for the 2024 STEM Showcase!

Scan the QR code to learn more!



MEMPHIS
MARCH 6-9, 2024

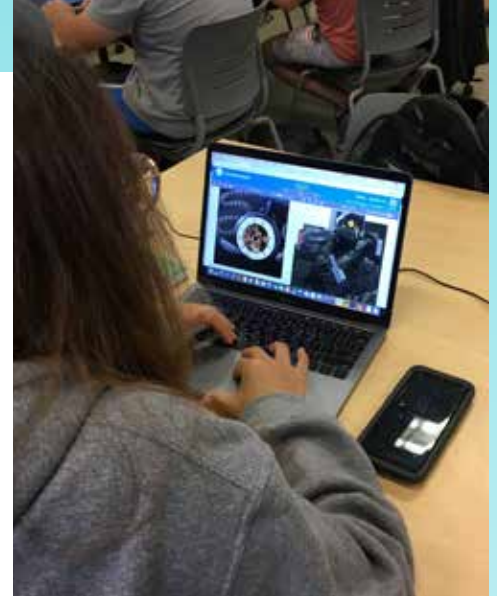
Preregistration Opens in Early September!
For the latest conference information, go to
www.iteea.org/ITEEA2024.aspx

Contents

- 4 EDITORIAL**
Welcome to the premiere issue of *Technology and Engineering Education: Bringing STEM to Life*
BY THOMAS ROBERTS, CATHRINE MAIORCA, AND VIRGINIA R. JONES, PHD, DTE
- 6 PRESIDENT'S MESSAGE**
BY CHARLIE MCLAUGHLIN, DTE
- 7 BRINGING STEM TO LIFE**
Lessons from Dilbert: Clarifying Design Expectations: Learning Inspiration and Consensus through Evaluation
As educators, how might we promote student evaluation skills so that students can evaluate their own work as they progress through the design process?
BY SCOTT R. BARTHOLOMEW, NATHAN MENTZER, DTE, AND ANDREW JACKSON
- 14 PREPARING FUTURE T&E TEACHERS**
Models for Integrating Research into Tech Ed Projects
This article describes the evolution of a senior capstone course in Technology Education to integrate and increase research practices.
BY TAMECIA R. JONES

- 21 IDEAS FOR SECONDARY INSTRUCTION**
Experiences of Incorporating Virtual Modeling in Technology and Engineering Classrooms
A look at how virtual modeling has impacted classroom experiences from the perspective of secondary technology and engineering education teachers.
BY ERIK SCHETTIG
- 27 BUILDING A STEM TEACHING TOOLKIT**
Growing Grit through Challenge
Grit is important for success in both K-12 STEM classrooms and also the STEM workforce. This article explores how grit is grown through social, mental, and physical challenge in a middle school STEM classroom in Northwest Indiana.
BY CARRIE HUTTON AND TRACY MIS
- 31 ELEMENTARY STEM IN ACTION**
Computational Thinking Friends
This article focuses on four of the most commonly included elements of computational thinking: abstraction, decomposition, algorithmic thinking, and pattern recognition.
BY JESSICA YAUNEY, SCOTT R. BARTHOLOMEW, VERONICA WUTHRICH, AND EMERSON ELYA

- 40 INTERNATIONAL PERSPECTIVES**
Landscaping Korean STEM Education as Teachers and Researchers in the Field of Technology and Engineering Education
An examination of how convergence education policy in Korea began and developed, and what challenges it faced from the standpoint of teachers and researchers in the field of Technology Education.
BY HYUKSOO KWON AND YUBIN LEE
- 46 TEACHER HIGHLIGHT**
Ira E. Compton, III
Zach Glennon



TECHNOLOGY AND ENGINEERING EDUCATION



Bringing STEM to Life

EDITORIAL
THOMAS ROBERTS, PHD
Editor-in-Chief
Associate Professor
Bowling Green State University

EDITORIAL
KATHLEEN B. DE LA PAZ
Director of Communications
ITEEA

ASSOCIATE EDITORS

SHARON BOWERS
Senior STEM Ed Specialist
National Institute of Aerospace

KUEN-YI LIN, PHD, DTE
Professor/Associate Dean
National Taiwan Normal University

AARON STRAUS
Creative Engineering Coordinator
University of Pittsburgh

KEVIN SUTTON, EDD, DTE
Assistant Professor
Appalachian State University

KIMBERLY BRADSHAW, DTE
Principal
Green Valley Elementary School (VA)

CATHRINE MAIORCA, PHD
Assistant Professor
Oklahoma State University

GREG STRIMEL, PHD, DTE
Associate Professor
Purdue University

BLAIRE THRASHER, EDS, DTE
Engineering and Technology Teacher
East Coweta Middle School (GA)

VIRGINIA R. JONES, PHD, DTE
Adjunct Professor
Old Dominion University

JOAN HARPER-NEELY, DTE
STEM Ed Specialist
National Institute of Aerospace

EUISUK SUNG, PHD
Assistant Professor
New York City College of Technology



ITEEA.ORG

Technology and Engineering Education is a peer-reviewed practitioner journal for educators and educational leaders who are building high-quality STEM learning experiences for each and every student.



Thomas Roberts, PhD is Editor-in-Chief of *Technology and Engineering Education* and an associate professor at Bowling Green State University. He can be reached via email at otrober@bgsu.edu.



Cathrine Maiorca, PhD is an assistant professor at Oklahoma State University and Associate Editor of *Technology and Engineering Education*. She can be reached via email at cat.maiorca@okstate.edu.



Virginia R. Jones, PhD, DTE, is an adjunct professor at Old Dominion University and Associate Editor of *Technology and Engineering Education*. She can be reached via email at vjones@iteea.org.

EDITORIAL

Welcome

to the premiere issue of *Technology and Engineering Education: Bringing STEM to Life*.

BY THOMAS ROBERTS,
CATHRINE MAIORCA, AND
VIRGINIA R. JONES, DTE

As an organization, ITEEA took time over the last year to reimagine its publications. The task seemed very large, but started with a simple question: how can we meet our readers' needs in the most efficient way possible? Over the course of six months, a team reviewed responses to ITEEA's communications survey, talked to each of ITEEA's councils, and looked at what other STEM organizations do. The task force made the recommendation to the board to change ITEEA's journals by combining *Technology and Engineering Teacher* and *The Elementary STEM Journal* into one larger peer-reviewed practitioner journal, *Technology and Engineering Education*. This issue is the first product in making that change.

Teachers and students consistently share positive views of integrated STEM education, specifically in increasing student engagement and understanding when content is applied in real-world settings (Roberts & Roberts, 2023). High-quality integrated STEM learning experiences have open-ended, real-world prompts that encourage students to leverage the content knowledge of

individual STEM disciplines and provide the opportunity to think critically and creatively to design solutions to problems that are meaningful and relevant. Through participating in these activities, students develop productive dispositions toward integrated STEM and the individual STEM disciplines, critical- and creative-thinking skills, and empathy for others, empowering them to make changes in their world (Jackson et al., 2021). However, significant barriers to implementing high-quality integrated STEM learning experiences remain. As Chris Emdin (2022) explained, "to improve the conditions of STEM learning in the US, we must first acknowledge and sit with the disaster [the system] has created. Without reckoning with our mismanagement of students' dreams and potential, we cannot improve STEM" (p. 127). Improving STEM systemically would mean properly funding schools and STEM programs, providing teachers with professional development, and deemphasizing standardized testing and scripted curricula. While this is a daunting list that will require collective action, we can all take action to reimagine how we approach STEM.

Just as we worked to reimagine this journal, we challenge you to think about one small change you want to make in your sphere of influence this year. Industry leaders can look for schools to partner with to provide resources or opportunities for real-world connections for students. State and provincial education leaders could look for ways to support their STEM teachers. For those

looking for a curriculum to support STEM teachers, consider becoming a [consortium state for Engineering byDesign™](#). This not only provides a standards-based curriculum to help teachers but includes professional development to support teachers in their implementation. As a system leader, your sphere of influence is large and can remove some barriers many teachers face to implementing STEM.

What changes could district and building leaders make to better support implementing high-quality integrated STEM learning experiences? Maybe there are opportunities to get creative with scheduling so that students have more access to STEM. The days before holidays can be great opportunities for integrated STEM activities throughout the school. Another small change could be exploring [group membership to ITEEA](#) so that more people can access member resources such as the OnDemand Learning Library or registration discounts to the [2024 ITEEA Conference](#) in Memphis, TN. Dedicated time and professional development opportunities are things district and building leaders can help shift to make a positive impact on the STEM culture.

For teachers, consider trying a new teaching practice to promote integrated STEM. If you're new to teaching STEM, it can seem overwhelming. A small idea could be attempting to build items using recycled materials that students

can help collect. Or maybe try to focus on giving students open-ended tasks to unleash their creativity and problem-solving abilities. Other teachers may decide to focus on how students can collaborate and communicate when participating in STEM learning experiences. Communication goes beyond working well together to include explaining their reasoning behind design choices, using data to explain how effective their design was, and using varied media to communicate the overall effectiveness of their product. Yet, another change could be to introduce students to a variety of important STEM tools. This can range from straightedges, compasses, and spring scales to screwdrivers, handsaws, and power tools. Having a clear focus on tools helps students understand what tool can be used in specific contexts so that they can strategically choose which tools to use to complete tasks.

Making a change to a system is difficult. The current system does not value Technology and Engineering Education, provide adequate resources for public schools, and actively ignores children's innate brilliance and creativity by subjecting them to relentless standardized testing and scripted curricula. That will not change overnight. Making a conscious effort to make one small adjustment in our practice is a step in the right direction. Emdin (2021) reminds us, "Children must be given

the space to think, dream, and work in order for them to learn. Their work is to question, discover, and dream. Our job as educators is to provide them with the contexts that make their experience productive (p. 123)." As we begin this new school year, we challenge you to pick one thing you want to try in your approach to integrated STEM education this year. Tag ITEEA (Facebook: ITEEA STEM, Twitter @iteea) on social media and use the hashtag #ReimagineTeachingSTEM to share your ideas. The individual with the most liked post on Facebook or Twitter by October 31, 2023, will win a \$25 gift card from ITEEA.

References

- Emdin, C. (2021). STEM, STEAM, make, dream: Reimagining the culture of science, technology, engineering, and mathematics. *International Center for Leadership in Education*.
- Jackson, C., Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Roberts, T., Yost, C., and, Fowler, A. (2021). Equity-oriented conceptual framework for K-12 STEM literacy. *International Journal of STEM Education*. <https://doi.org/10.1186/s40594-021-00294-z>
- Roberts, T., & Roberts, A. (2023). Promises and perils of STEM education: synthesizing teacher, student, and research perceptions. In Tierney, R.J., Rizvi, F., Erkican, K. (Eds.), *International Encyclopedia of Education*, vol. 11. <https://dx.doi.org/10.1016/B978-0-12-818630-5.13043-X>



PRESIDENT'S MESSAGE

Charlie McLaughlin, PhD, DTE serves as ITEEA President (2023-24) and is a Professor of Technology Education and Chair of the Department of Educational Studies at Rhode Island College in Providence, RI. He can be reached at cmclaughlin@iteea.org.

Welcome to the first issue of ITEEA's rebranded journal, *Technology and Engineering Education: Bringing STEM to Life*. We believe this new publication will meet the needs of not only Technology and Engineering practitioners, but other communities invested in supporting integrated STEM education. Incorporating great ideas from many contributors strengthens our profession in so many ways. The new structure of *Technology and Engineering Education (TEE)* promotes a novel approach to informing the ITEEA membership about important developments and research in our field of study and the innovative work that occurs in our labs, makerspaces, and classrooms. Please let us know what you think of the publication.

During the months after our very successful conference in Minneapolis, the Executive Committee and Board of Directors worked to review and revise our guiding documents. We renewed our commitment to make the Strategic Plan a living document by updating sections and creating a sixth goal related to our obligations to recruitment and retention. In the near future, we will be calling on our members to assist with the development of new resources and identify best practices to attract and retain a diverse pool of Technology and Engineering teacher candidates. The Board of Directors, at its June meeting also approved revisions to

ITEEA's Statement for Diversity, Equity, Inclusion, and Sense of Belonging (DEIB). These modified documents can be found on our website: www.iteea.org.

One of our significant decisions was to create a new committee and a new task force to improve our position in the future. The new Standards Committee will provide oversight for necessary revisions and updates to *Standards for Technological and Engineering Literacy (STEL)*. They will research best practices for STEL implementation and direct the development of supporting STEL resources. All of this work is necessary to make known the power that STEL can have informing curriculum decisions and providing teachers and others with the tools for assessment while fostering an innovative learning environment.

The Task Force on Membership/Recruitment/Retention was deemed necessary as teacher candidate pools and even established teacher populations are slowly diminishing. This is a time of change in Technology and Engineering Education, as it is in other disciplines. We have faced challenges for years—foremost is the inconsistent flow of potential teaching candidates into Technology and Engineering Education. This task force will be comprised of a cross-section of our membership, including our student members who

can provide us with valuable insights on why they remain or leave the organization after graduation. We will also depend on the comments from veteran TEE teachers so that we can all promote Technology and Engineering Education in a better, more positive, and more effective manner.

We cannot leave this important work to a task force alone! Therefore, my simple request to ITEEA members is to identify and mentor students in your classes who show a passion for Technology and Engineering/STEM. Explain to them the importance of this profession and describe the fulfillment that you enjoy as you go about your teaching duties each and every day. You can also take ownership of the profession by working to encourage active members to renew their memberships and encourage non-members to sign up and join this exceptional organization. A focus on empowering our members will provide us with the important discussions and significant problem solving needed from an engaged membership to keep ITEEA sustainable into the future.

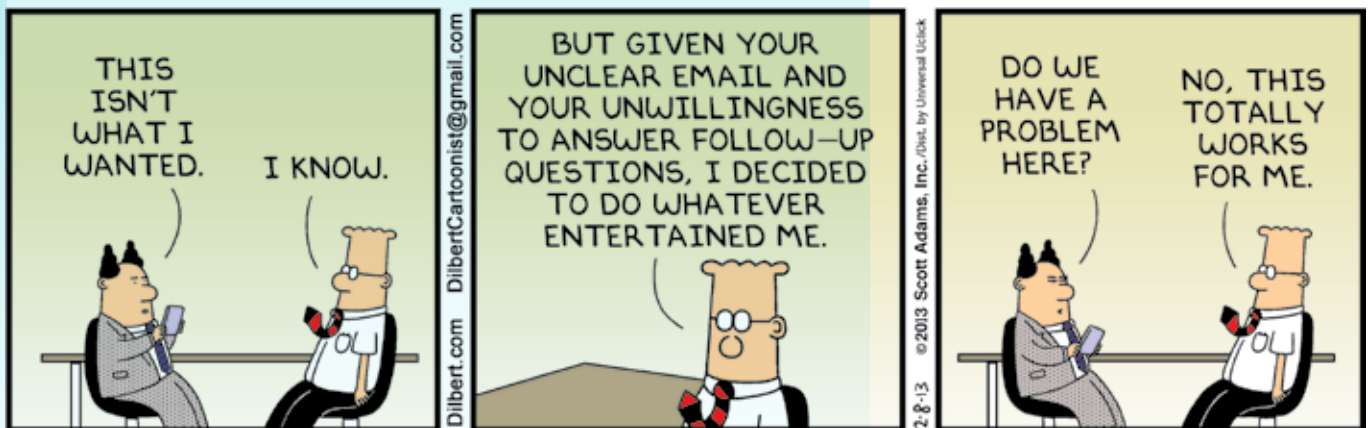
Together, we will be most successful when we work collaboratively as a unified membership on activities that strengthen our organization and demonstrate our value to the world around us.

I wish you all success and fulfillment in the school year.

Lessons from Dilbert: Clarifying Design Expectations

Introduction

Have you ever asked someone to do something only to find out later that they did something completely different? Communication problems (e.g., misunderstandings) are one of the most common issues plaguing the workplace and classrooms (Nowak, *n.d.*). As Technology and Engineering Educators this is something we have seen often—both in our classrooms and in those we have visited—especially when it comes to open-ended design settings, which are often “messy” and ill-defined (Westerlund & Wetter-Edman, 2017). In many such instances, we have provided our students with an intentionally open-ended design challenge—hoping to be inspired by their creativity, ingenuity, and progression through a design process—only to find that students missed the mark and didn’t really understand what we were hoping they would do. In these instances, the students turn in their work (e.g., design portfolio, prototype, etc.) and it becomes very clear that a communication disconnect has occurred. However, at this point, what are we to do as the teacher? We can’t start



Learning Inspiration and Consensus through Evaluation

BY SCOTT R. BARTHOLOMEW, NATHAN
MENTZER, DTE, AND ANDREW JACKSON

Figure 1. Dilbert Cartoon (dilbert.com)
DILBERT © 2013 Scott Adams, Inc. Used By
permission of ANDREWS MCMEEL
SYNDICATION. All rights reserved.

the assignment over—it would take too much time. We shouldn’t fail the whole class of students for missing the mark—communication goes both ways. So, we do the best we can to provide feedback and grades to the students. As captured beautifully in the Dilbert cartoon above (Figure 1), we are often more willing to simply move on in light of a communication failure than we are to address, fix, and work through the problem (Markman, 2017).

Design in Technology and Engineering Education—The Challenge is Challenging!

Standards for Technological and Engineering Literacy (International Technology and Engineering Educators Association, 2020) identifies *Design* as one of eight standards driving our field; design is at the core of the *STEL* practices of creativity, critical thinking, optimism, making and doing, systems thinking, collaboration, attention to ethics, and communication. As we engage students in learning design—whether it be through a prescribed curriculum (e.g., ITEEA’s Engineering byDesign™) or other approaches—a hallmark of Technology and Engineering Education classrooms is that students are actively engaged in the design process. Students are typically challenged to *do* design work from problem identification to solution presentation, all in an open-ended and ill-defined setting. By definition, this is a messy, complex space with no right answer. But there is a process (i.e., the engineering design process) and students have the potential to develop world-changing solutions (for example, a *Pennsylvania teen developed a solution to eliminate blind spots in cars to improve pedestrian safety*; see Harmata, 2019). Still, the open-ended and ill-defined nature of the design learning experiences

makes it hard for teachers to lay out clear expectations and guidance for students without over-constraining student thinking or having the miscommunications described earlier. *As educators, how can we better communicate expectations at the start of each design challenge?*

Design challenges can overwhelm and paralyze students who struggle to see how the challenge might be solved. Students may feel they could never develop a solution to the problem because it is too challenging, and, as a result, may not even try. However, as teachers, we know that students are able to develop solutions and we often may even have a “library” in mind of many previous creative solutions. *As educators, how might we foster design self-efficacy in students?*

Over the years, Technology and Engineering Education (TEE) teachers become experienced at recognizing good design work and can identify it when they see it. However, even with a solution in mind, students don’t have this luxury and are often left to wonder what their products and processes should look like. With all of these questions, some students can shut down if they feel they are not able to be successful: What is valuable? What is not? Which direction should I take and how should I represent my design in my portfolio? Should I be taking risks in developing ideas that are innovative or be more cautious about making sure the product works by using well established materials and processes? Should I focus on documentation, product form, function, or all of these?

As teachers we often explain our expectations as we introduce the design brief. While students might actually be listening, students may have a hard time internalizing these expectations without context. If students don’t (or can’t) internalize how their work will be evaluated,

what is important (and not), and what “good” looks like, they will struggle to generate good work or sometimes exhaust their efforts on the wrong aspects of the project. *As educators, how might we promote student evaluation skills so that students can evaluate their own work as they progress through the design process?*

Learning by Evaluating

To address these concerns related to design education, the authors are piloting a design primer called *Learning by Evaluating*. The concept of Learning by Evaluating (LbE) arose from work in assessment—specifically, assessment using a technique referred to as *adaptive comparative judgment* (ACJ). A full description of ACJ, its underpinnings, and the associated findings is beyond this piece, but the reader is encouraged to look at Pollitt (2012) and Bartholomew (2018, 2022) for a more complete description. It is important that we highlight one key finding of the ACJ literature: the power of comparisons. Research over the years has consistently shown that humans are more comfortable and reliable when making comparative decisions than when making subjective decisions. For example, there’s a reason that an optometrist shows you pairs of different prescriptions and asks you to choose the clearest of the two—if they simply showed you all the options at one time and asked which lens was the right one, your ability to decide would be severely hampered, in both ease and reliability. We highlight this aspect of ACJ because there is power in paired comparisons above and beyond the benefits that may come from simply viewing examples of previous work (such as in a gallery walk). As authors, this connection between ACJ and LbE and the power of paired comparisons was almost accidental—while studying methods for improving assessment techniques of



Figure 2. A student using ACJ to evaluate peer design work.

teachers, students were engaged in the practice of evaluating their peers' work in a paired fashion (through ACJ; see Figure 2).

Originally, students were engaged in these evaluations as a means of investigating how their evaluations compared with those completed by the teacher; however, we quickly noticed that this practice of asking students to evaluate peer work was influencing them. Students began to notice the details in their peers' work (good and bad), they were developing the ability to discern between "good" and "better," and they were picking up on the vernacular used in design (e.g., describing subtle differences in their peers' ability to "identify criteria and constraints" or "produce a functional prototype"). These benefits were strengthened as students were asked to verbalize (or write out) their own thinking while they evaluated these consecutive pairs of peer work and selected the one they perceived as "better." The authors' research ([Bartholomew et al., 2022](#)) identified four main benefits of engaging students in this

evaluation experience *as an intentionally placed primer for learning in a design setting*, these include:

1. Students are exposed to previously completed work, helping them "set the bar" and clarify expectations around the assignment.
2. Students identify positive and negative qualities that they can later use in their own designing.
3. Students learn the "language of the field" as they use design-specific terminology to describe why one item is "better" than another.
4. Students solidify their own understanding of design elements as they verbalize (or write) these down in their justifications for choosing one item over another.

Building on these findings, funding was applied for and received from the National Science Foundation to test this instructional approach further with K-12 students (NSF Grant #2101235). Specifically, the authors have been working with teachers and students in the greater Atlanta area (Georgia, USA) enrolled in an introductory high school design class (*EbD Foundations of Technology*). In these classes, LbE has been situated as a primer for design learning in a variety of settings, projects, and classrooms—we are continuing to explore what works, or doesn't, and why. Some of the preliminary findings, observations, and experiences are shared in hopes that more classroom teachers can implement LbE with their own students.

Learning by Evaluating—How To

Three main pedagogical elements of incorporating LbE as a primer in the learning process are suggested:

1. Introducing and orienting students
2. Engaging students in a series of comparisons

3. Leading a classroom debrief
Each will be discussed in context of the Engineering byDesign *Foundations of Technology* Unit 5 preliminary challenge: Park Design with Community Connection. In this challenge, students demonstrate their understanding of design while using CAD software to model a community park.

STEP 1. INTRODUCING AND ORIENTING STUDENTS.

Instead of other work that emphasizes assessment at the end of a design process, we propose situating LbE at the beginning of a design challenge, just after providing the students with the design brief and prior to students beginning any design work. The first element of LbE is to introduce and orient students as preparation for them to engage in a series of comparisons. The teacher might ask a few questions (perhaps hypothetically at this point) such as what makes a good community park? What does our community need in a park? What are key features of a community park? How might we best communicate our design intentions to share our park design? After sharing a few questions to prompt students to wonder how their park might look and how they might engage in designing their park, the teacher can show students two park designs side by side and ask which is better (Figure 3 as a potential example). Some students might identify the park on the top because it is more colorful or the park on the bottom because it has more green space.

STEP 2. ENGAGING STUDENTS IN A SERIES OF COMPARISONS.

After a teacher-led discussion on the qualities of different parks and some whole-group classroom comparisons (e.g., using Figure 3), the teacher can engage the students individually in a series of comparisons. Students are provided with access to several pairs of park designs and asked to evaluate them by identifying, of the



Figure 3. Two images of a park for discussion (Whiting, 2021).

pair, which is best. Student decisions should be guided by a predetermined criteria (i.e., called a holistic statement or prompt) from which they determine which of the two designs is better. Example criterion could include ideas such as:

1. Which is more “family-friendly?”
2. Which is more attractive?
3. Which is safer?
4. Which provides better parent supervision ability?
5. Which could support a wider age group?
6. Which might be easier to maintain?
7. Which fits our community better?
8. Which is more exciting?

After each comparison, students are asked: “why”? This provides them with an opportunity to justify each decision of one over the other with evidence and reasoning. Because there is not a right answer in these

questions or between the examples provided, students are challenged to think deeply about what matters and explain why.

STEP 3. LEADING A CLASSROOM DEBRIEF.

After the students have had a chance to individually consider what makes a “good” park for a community, the teacher can facilitate a classroom discussion to both elicit and solidify the concepts noticed by the students. We suggest returning to the original questions posed hypothetically in Step 1 (i.e., What makes a good community park? What does our community need in a park? What are key features of a community park? How might we best communicate our design intentions to share our park design?). At this point, students can verbalize, and internalize, key elements of existing design work that might serve to inspire them creatively while also helping them recognize “good” design work. With this solidified understanding of their value structure, what matters in design, we hypothesize that their design experience will be more informed and thoughtful.

We also anticipate that, in some cases, the class and the teacher may have discrepancies in their values that are revealed by the comparisons and discussion. These differences are not necessarily “right” or “wrong”—often they are simply an expression of a different understanding, background, and “lens” through which the design challenge is viewed. For example, there may be students in the class who thought the park shown on the bottom in Figure 3 was better. However, perhaps the teacher thought they had been emphasizing an ADA-accessible park for which the grassy field may not be compliant. Alternatively, some students may have identified the park on the top as better, while the teacher was envisioning a community gathering place at the park for children (and adults)

of all ages. These differences in perceptions of “needs” and “emphasis area” are valuable and positive—they provide opportunities for classroom discussion and the solidification of design criteria and constraints. While TEE teachers typically specify expectations in a design brief, students may or may not be able to operationalize what these mean in practice and the teacher might not be aware of this miscommunication. By engaging in a discussion about which is better and why, the students and teacher are able to establish a clearer understanding in preparation for design work.

Ok Cool—I Want To Try It—Which Button Do I Push?

Three tools are suggested to bring this comparative experience to your classroom on Monday morning: Google Slides, No More Marking, and RM Compare. Each approach has benefits and challenges. Which might be best for you?

GOOGLE SLIDES:

At the simplest level, the teacher might put together a slide show where each slide is numbered and has two images (student interface shown in Figure 4). With a label for each image on the slides, A or B, students can write down (on paper or electronically) which is better, A or B, and why. While this approach is quick and easy, it yields no analytics on student responses, nor does it automate the capturing of student decisions and/or rationales.

NO MORE MARKING:

No More Marking is a website that facilitates comparative judgment for schools with free accounts for educators (at www.nomoremarking.com/). The student interface is shown in Figure 5. The advantage of this tool is that the interface facilitates the paired comparisons, and the teacher is provided with a ranked order of the results (includ-



Figure 4. Google slideshow student interface.

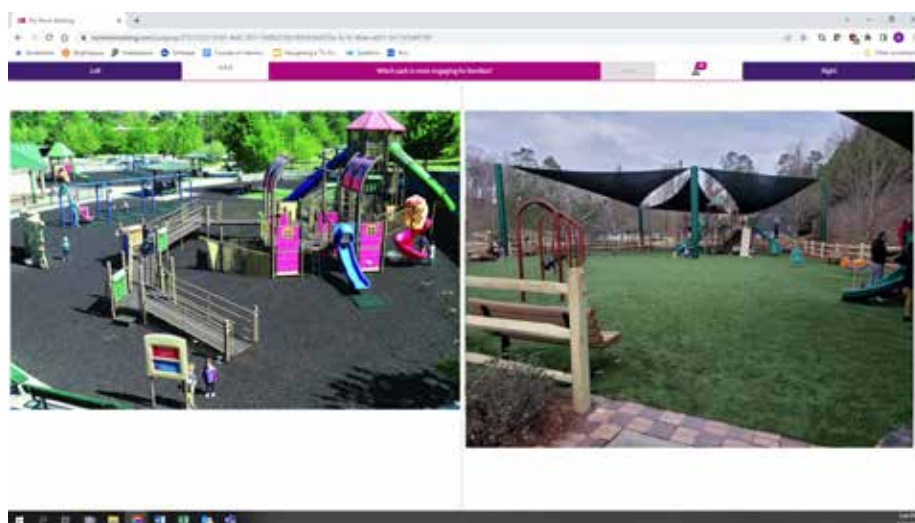


Figure 5. No More Marking student interface.

ing student comments), which may be informative for the debriefing discussion to identify which items were considered best and worst by students. Comparison items are limited to PDFs and need to be oriented in “portrait” page layout. Note that the system is not password-protected, which means the login is easy, but anyone with whom you share the link can access the contents of the session.

To set up a session, teachers should create a free account and then select “Create a Custom Task.” In the “General” settings, the task can be named, the prompt for the judges (students) can be posted, and instructions for the judges (students)

can be entered in the field named “Judge info.” Toggle “use codes” to “no.” The rest of the settings on this page can remain as the default. Be sure to use the “update” button at the bottom of the page to save your settings. Next, click on “1 c. Scan Completed Assessment and Upload” and select or drag and drop PDF files for students to compare. Then, click on “2 a. Run a judging session” and estimate the number of judgments you would like each student to make. Note that the “candidates” are your items to judge (PDFs you just uploaded), and the “judges” are the number of students you have in class. Experiment with the number of “candidate judgments” (“how many times will

each item be judged?”) until you get a reasonable number of judgments per judge (“how many times will each student be prompted to compare a pair of items?”). Hit the “adjust” button to update. When ready, copy the link provided and share with students! Students can select the top middle banner (the prompt text) to leave comments about each item explaining their decision and then select the left or right side of the banner to indicate their choice of which is better.

After students engage, the teacher can click on “3 a. Check your results.” “Refresh task” first and view the rank order. Results can then be sorted by scaled score to see the rank order with the scale value being a relative measure of how different each item was from the others. The “Infit” measure of an item indicates the extent to which judges (students) are consistent in their decisions comparing items where lower numbers indicate more agreement between judges on that item. For additional information, the teacher can navigate to “2 a. Run judging session” and “refresh task” to see who judged, how much time judgments took, and judge (student) “infit.” Infit for a judge is a measure of how consistent that student is with others, where 0-1 is consistent (this student agrees with the majority) and a higher number is less consistent. Controversial items might be a great place to start the debrief discussion: What can be seen in each image that informs our design? Students with higher infit scores (meaning they don’t agree with their peers) might be a great place to either reteach (if they don’t understand the expectations) or learn unique insights for the class (as they might be “thinking outside the box”)! Use the “My Tasks” (and then select “custom tasks”) button to return to your dashboard.

RM COMPARE:

RM Education offers a software interface called “Compare,” for which the student interface is shown in Figure 6. This interface is custom tailored to facilitate adaptive comparative judgment and provides a well-developed user experience including a mobile-friendly platform. It requires a login to facilitate secure access for students and teachers. The interface offers a variety of analytics for teachers to rigorously interrogate student decision data. A limited free version is offered at <https://compare.rm.com>, with a paid subscription available. To get started, log into your account and select “Create New Session” and name the session. In the “Overview,” “Settings,” “Basic” tab, the session can be named and described, and the holistic statement (prompt for students) can be entered (don’t forget to “save changes”). Under the “Feedback” tab, student comments explaining their decisions can be enabled at the comparison level or the item level. In the “Judging” tab, students can be permitted to see results and upload their own items for comparison. Next, in the “Add Judges” Tab, judges (students) can be invited by email, reused from a previous session, or uploaded from a CSV file (which could be exported from your LMS software). In the “Add Items” tab, webpages, images, PDFs, videos, or YouTube videos (note RM Help for YouTube video link formatting) can be uploaded for evaluation. When ready, “Run Session.”

After students make comparisons, the teacher can review a variety of data including an overview in the form of a report. From the “Reports” tab, choose “Show Report” to access a rank order with reliability (“how confident are we in the results of this session?”) and parameter values (“how did each different item compare to the others?”). “Judge Misfits” shows visually and numerically the extent to which each judge agreed

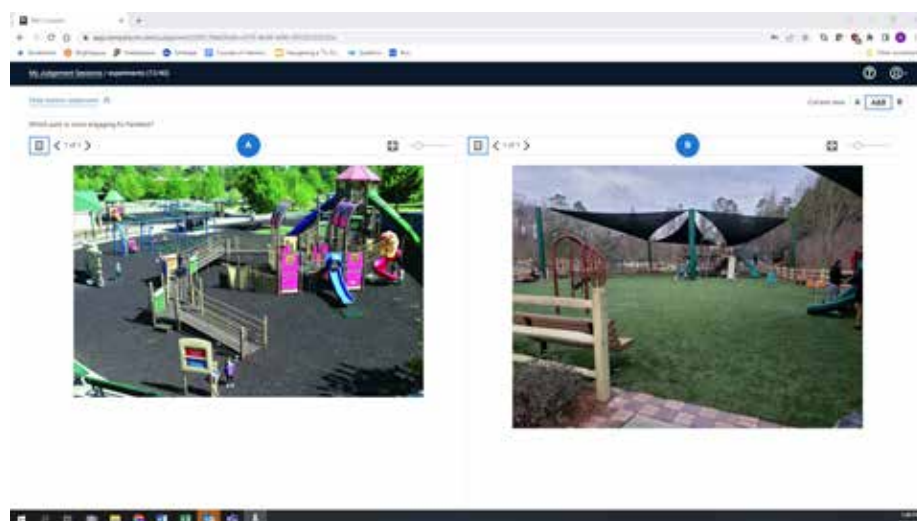


Figure 6. RM Compare student interface.

“
As educators,
how can
we better
communicate
expectations at
the start of each
design challenge?
”

with the others (lower numbers indicate stronger agreement). “Item Misfits” indicate the extent to which judges (students) agreed on individual items with lower numbers, indicating stronger consensus. With these data, teachers know which items the class thought were better, why, and if any students rated items significantly differently than other students or if any items were controversial.

Conclusion

As authors and TEE teachers, the authors have been experimenting with the LbE approach since 2016 in

a variety of elementary, middle, high school, and university level courses. Positive findings across grade levels have shown the potential for using LbE to improve design experiences for students. However, we noted two specific challenges while working with the teachers and students. One involves selecting the right items for students to compare, coupled with the right criterion statement, and requires some effort. This effort can be mitigated in part by using student work from a previous semester, but to be precise, what needs to be communicated to students requires deliberate (not Dilbert) choices about which items explicitly illuminate the features that might address student misunderstandings. For example, a teacher who notices that students are struggling with the identification of criteria and constraints will need to carefully select examples for comparison that highlight both positive and negative examples of this identification. This collection process for paired comparisons can be intense in terms of effort and time required for successful completion.

Another challenge uncovered in teacher discussions is the worry that students might simply copy what they see on the screen in the paired

comparisons for their project. In essence, the students may think they are being shown the “right” answer and their job is to duplicate it, which is not a good example of engaging in the design process or fostering creativity. Helping students to overcome this temptation will likely require teacher intervention and explicit direction (e.g., during the debrief section of LbE). Moreover, by seeing a variety of “good” designs, and even variety in the characteristics of those designs, we think students can be encouraged in their own process.

Despite the challenges associated with LbE, overall, the required time and effort to implement LbE in the classroom is minimal. Following the first year of investigation within Grade 9 *Foundations of Technology* under the NSF grant, two main benefits to the approach were noted:

First, this approach supports the teacher and students in converging on a shared understanding of expectations, helping to answer the question, “What does a good one look like?” This clarifying experience can help avoid the *Dilbert* miscommunication trap outlined above. A shared understanding of “good” helps all in design education settings.

Secondly, this approach can also support divergent thinking. Specifically, LbE is useful for fostering creativity in students in that, as they view pairs of previous work, their own thinking, creativity, and understanding of possibilities are expanded. In this way LbE is helpful in answering the question, “What *could* a good one look like?” Further, exposing students to a variety of ideas may be helpful in overcoming design fixation—a problem commonly encountered with students.

TEE teachers are encouraged to consider opportunities for LbE in

their own classrooms using one of the three approaches outlined above. Clarifying expectations and avoiding *Dilbert*-like experiences in classrooms will make the learning experience better for teachers and students.

Note: This material is based upon work supported by the National Science Foundation under Grant 2101235. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

Bartholomew, S., Mentzer, N., Jones, M. D., Sherman, D., & Baniya, S. (2022). Learning by evaluating (LbE) through adaptive comparative judgment. *International Journal of Technology and Design Education*, 32, 1191-1205. <https://doi.org/10.1007/s10798-020-09639-1>

Bartholomew, S., Strimel, G. S., & Yoshikawa, E. (2018). Using adaptive comparative judgment for student formative feedback and learning during a middle school open-ended design challenge. *International Journal of Technology & Design Education*.

Harmata, C. (2019). Teen Wins \$25,000 for Inventing Unique New Solution to Cars’ Blind Spots. *People.Com: Human Interest*. <https://people.com/human-interest/teen-invented-solution-to-eliminate-cars-blind-spots/>

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

Markman, A. (2017). “Poor communication” is often a symptom of a

different problem. *Harvard Business Review: Organizational Culture*. [https://hbr.org/2017/02/poor-communication-is-often-a-symp-tom-of-a-different-problem](https://hbr.org/2017/02/poor-communication-is-often-a-symptom-of-a-different-problem)

Nowak, M. (n.d.). *Top 7 Communication Problems in the Workplace*. Retrieved June 15, 2022, from <https://mitefcee.org/top-7-communication-problems-in-the-workplace/>

Pollitt, A. (2012). The method of adaptive comparative judgment. *Assessment in Education: Principles, Policy & Practice*, 19(3), 281-300.

Westerlund, B., & Wetter-Edman, K. (2017). *Dealing with wicked problems, in messy contexts, through prototyping*. 20(sup1), S886-S899.

Whiting, T. (2021). Top 13 playgrounds in Atlanta. *Atlanta Parent*. www.atlantaparent.com/top-13-playgrounds/



Scott R. Bartholomew, PhD is an assistant professor of Technology and Engineering Studies at Brigham Young University,

Provo, UT. He can be reached at scottbartholomew@byu.edu.



Nathan Mentzer, PhD, DTE is an associate professor of Engineering & Technology Teacher Education at Purdue University. He can be

reached at nmentzer@purdue.edu.



Andrew Jackson, PhD is an assistant professor in Workforce Education at the University of Georgia. His research focuses on

the design process, including how to help students and teachers in design-based learning. He can be reached at andrewjackson@uga.edu.

Models for Integrating Research into Tech Ed Projects

The goal for the course project is to accomplish as many of the *STEL* Benchmarks as possible while supporting student agency and creativity.

BY TAMECIA R. JONES

Introduction

"I hate research, but this class made it make sense, like it had a purpose. I never realized research went into the design of everything. That kind of research I can do." This article describes the evolution of a senior capstone course in Technology Education to integrate and increase research practices. A southeastern university capstone course for Technology Education students went through many iterations due to instructor changes. Some instructors favored research, while others favored development. In one effort to improve the research rigor of the course, an older version of the course required students to write a research paper that would have been synonymous with a final thesis or research proposal. The next session of the course supported individualized research projects. In the fall of 2018, an instructor attempted to balance research and development in a course revision that would change the research lens toward development. Since 2018, the course has been taught five times and had two adaptations due to the COVID-19 pandemic and university responses to course delivery. The pandemic forced in-person classes to go virtual, requiring the class to

go online for two and a half semesters. As a result, the model for courses changed. As we re-enter traditional in-person class meetings, there are now three methods for integrating research skills into senior capstone courses in Technology Education. These methods are thematic-inspired, skill-inspired, and content-inspired, as described below.

Context

This required undergraduate course is at a university that licenses technology education teachers and provides service courses in graphics and modeling to design and engineering majors. There is a digital fabrication makerspace and a traditional manufacturing workshop through which students are able to prototype and build projects. The digital makerspace has multiple 3D printers, a laser cutter, and a vinyl cutter. The manufacturing workshop is equipped with a planer, table saw, miter saw, circular table saw, drill press, lathe, drills, jigs, sanders, and other hand tools. Students also have access to multiple makerspaces across campus at university libraries.

By the time students get to the capstone course, they will have introductory, mid-level, and advanced courses including, but not limited to,

desktop publishing, digital media, robotics, materials, lab management, making and manufacturing processes, and design thinking. Students have become proficient in modeling software and had the opportunity for coursework involving AutoCAD, SolidWorks, the Adobe Creative Suite, Tinkercad, Revit, and electronics. Students pursuing teacher licensure will have taken pedagogy and methods classes. Most students enter the course with experience researching for papers in humanities courses or scientific research projects, but research for the purpose of development is a skill they can use in future studies or careers (Petrella & Jung, 2008). This kind of research involves critical review of information and data analysis that helps students integrate theory and practice while deepening inquiry (Healey & Jenkins, 2009).

Course Goals and Relationship to *STEL*

The goal for the course project is to accomplish as many of the *STEL* Benchmarks (Table 1) (International Technology and Engineering Educators Association, 2020) as possible while supporting student agency and creativity. Each project was crafted with these intentions and to facilitate building of student portfolios

for internships, graduate school, or resumes for future employment. Each course model uses rubrics as assessment methods for project milestones and the final design and assesses research skills as competencies.

Because of foundational coursework in materials, modeling, and manufacturing, students have had many projects that were fixed or narrow. Many of the projects have also been group projects. Therefore, they have had more practice doing standards 7AA, 7CC, 7DD, and 2T but less practice doing standards 1Q, 1R, 2X, and 7Z. The capstone course project is an individual project in which students can show both experience in some skills and development of new skills.

Model 1: Thematic Research-Informed Iterative Design

In the thematic research-informed iterative design, students developed and practiced research skills as they conducted research around a particular theme. Figure 1 shows the organization of topics, integration of research skill practice, and design schedule. Many themes can

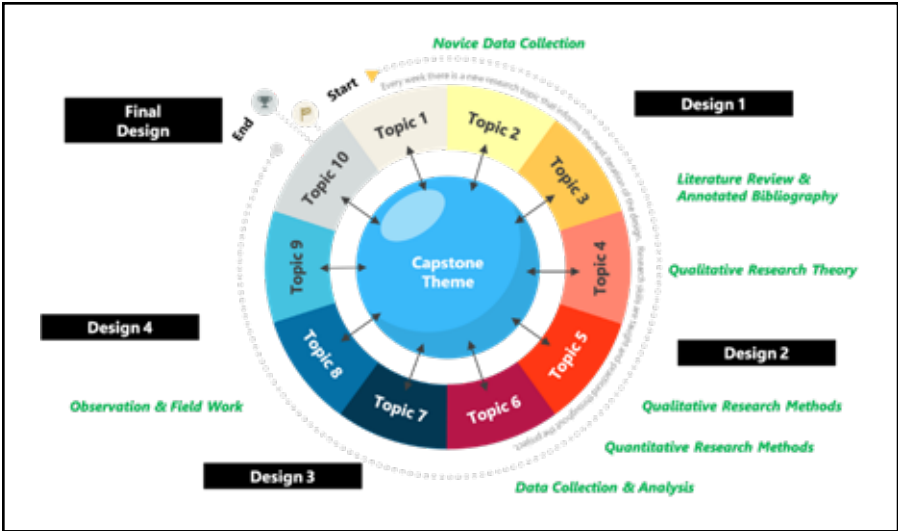


Figure 1. Theme-based research model timeline and topical breakdown. Source: Author.

be broken down to include specific content, theory, policy, inclusion, safety, materials, and supplies topics. When paired with research skills through a complementary textbook or research method activities, students are introduced to the discrete skills involved in research. The two textbooks that inspired the activities were *How to Do Research: 15 Labs for the Social & Behavioral Sciences* (Gualtney & Peach, 2016) and *Research Methods for Education*

(Privitera & Ahlgrim-Delzell, 2019). These research skills were introduced via labs in class, assignments, and group activities.

In this course iteration, the chosen theme was playgrounds. The development and design of playgrounds involves research (1Q) into policy, safety, equipment, materials, injuries, disabilities, play, and learning. The final project for the course was to design and construct a playground with three features for three different activities that met ADA minimums and was scaled down to fit a 10" by 10" square (1R, 2X). This meant that students would model (2T) with software multiple iterations toward a final design, that could be 3D printed or made with tools and materials. There was no budget minimum or maximum and students were free to select materials or purchase parts with instructor approval. Students conducted peer reviews and received instructor feedback on design notebooks at each iteration, spaced two to three weeks apart within a 14-week semester. Students could also express their creativity or personal interests in sustainability or recycled materials, interactivity, learning, or accessibility. Figure 2 shows a final, scaled project made from a combination of materi-

STEL BENCHMARK	
1Q	Conduct research to inform intentional inventions and innovations that address specific needs and wants.
1R	Develop a plan that incorporates knowledge from science, mathematics, and other disciplines to design or improve a technological product or system.
2T	Demonstrate the use of conceptual, graphical, virtual, mathematical, and physical modeling to identify conflicting considerations before the entire system is developed and to aid in design decision making.
2X	Cite examples of the criteria and constraints of a product or system and how they affect final design.
7Y	Optimize a design by addressing desired qualities within criteria and constraints.
7Z	Apply principles of human-centered design.
7AA	Illustrate principles, elements, and factors of design.
7CC	Apply a broad range of design skills to their design process.
7DD	Apply a broad range of making skills to their design process.

Table 1. STEL Benchmarks Spotlighted for the Course.



Figure 2. Student playground models, Course, University. Photo taken by author.

als. Figure 3 shows the course scope and sequence.

The research skills introduced and practiced included literature review for annotated bibliographies, qualitative data coding and analysis, quantitative data collection and analysis, site observations, memo-ing, and interviews. Field trips were taken to conduct observations and have first-person user experience, and interviews of peers and

relatives provided data collection and analysis practice. In this manner, students were shown how research informs design.

Model 2: Skill-Inspired Iterative Design

During the first full academic year of the pandemic, the normal in-person class was shifted from hybrid to a virtual only delivery after beginning the semester as a hybrid with rotating groups for in-person meetings. Students were given three options for projects under the same theme: “Virtual (Yet Hybrid) PE” for elementary kids. Students were allowed to choose from three options: a bowling set, golf course, or musical chairs. The goal of the project was for elementary kids to be able to play in their respective homes but also have some connection and interaction with their classmates. Since bowling and golf are sports that have both individual and team components, this seemed to be a fit for that moment. As an option for younger kids, a musical chairs option was added. The bonus challenge was to send scores to a “class” so that it would feel like students were playing together because they can see everyone’s scores (or status

in musical chairs) and discourage cheating. The instructor provided initial golf clubs and toy bowling sets, which could be modified. These projects reflected the design of a system with interactions between multiple parts, and the instructor provided a suggested project timeline for each project option. Students worked individually in their homes and had supplies shipped to them. If they needed 3D printing, they made arrangements with campus facilities or emailed files to the instructor who printed at home or on campus and set up hands-free delivery protocols. The projects were divided into two-week milestones that students could complete in the most appropriate order for their circumstances. The criteria and constraints for the project are shown in Table 2.

Students were informed that there were no specific skills mandated to learn, but that the skills they learn would be based on their project goals and implementation. If they could design an object that was not electronic or did not require programming, a Rube Goldberg-inspired product was allowed and encouraged. If they needed to build something that used electronics

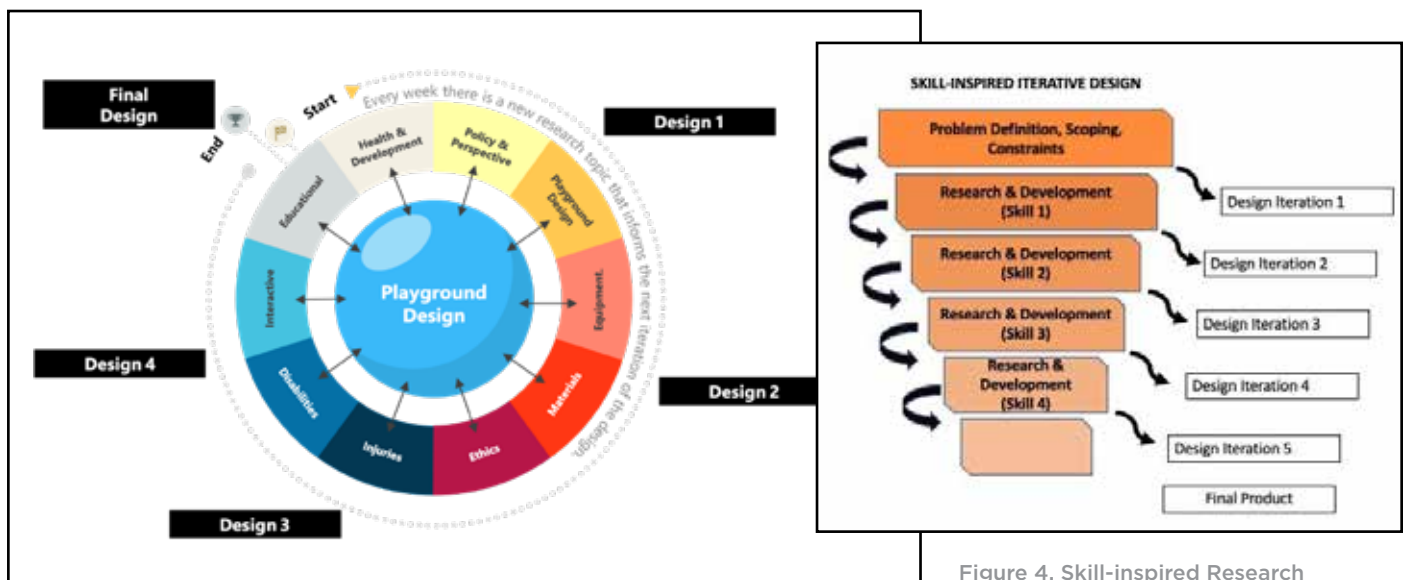


Figure 3. Playground Design Course Timeline. Source: Author.

Figure 4. Skill-inspired Research Design Model Overview and Artifact Schedule. Source: Author.

PROJECT	BOWLING BALL THAT KEEPS SCORE	GOLF CLUB THAT KEEPS SCORE	VIRTUAL MUSICAL CHAIRS
Constraints	1. Must have a physical ball and pins* 2. Must identify sensors or mechanism by which pins will be identified and have a status of standing or knocked down.	1. Must have a physical golf club and a hole* 2. Must determine sensors/mechanism by which strokes will be identified and have a status of putt, ball, and hole.	1. Design something that can be put on a chair at a home but does not change the chair. 2. Music is controlled remotely
BONUS CHALLENGE	The score is sent to a “virtual” class so everyone can see the others’ scores and no cheating is possible.		Sends a signal to the teacher that the student sits down.
	* You can buy a toy version to alter or make it. • All code must be commented on and wiring documented with schematics. • All graphics must be original or altered substantially and renamed. • Prototypes can be made at home or in the lab.		

Table 2 Summary of Skill-based Project Descriptions.

or programming, they may have to learn parallel and series circuits, switches, sensors, and program an Arduino. Often those skills were wiring, IR or Bluetooth sensors, IF/THEN statements, FOR loops, and nesting commands. In this manner, the students were not taking an explicit robotics, mechatronics, or programming course, but they could learn basics from instructor-led topical sessions and additional research.

The research involved in the skill-inspired iterative design meant students had to research and select sensors that helped them accomplish their design plan and then develop the skills necessary to construct their design. Students conducted analysis of quality of sensors, accuracy, and failure rates. They collected data in design journals and made design decisions based on testing results and revisions to the systems involved in the project.

Because the students had a variety of background skills and diverse project plans and timelines, the instructor added self-assessment opportunities to the assessment rubrics to support students’ project management and metacognition. Students would rate themselves

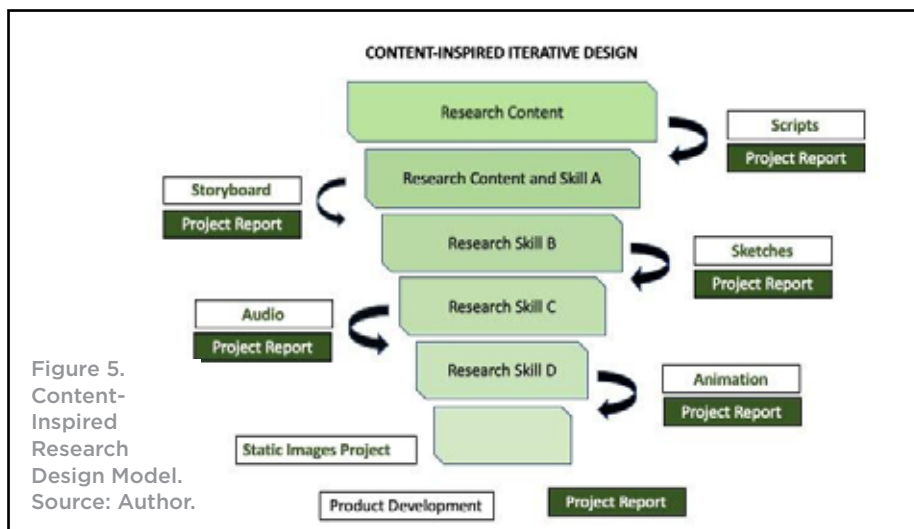
against the rubric and provide context about their two-week progress and its relation to overall project goals. Peer reviews were conducted virtually, synchronously, and asynchronously and students offered feedback and recommendations for improvements based on successes and challenges. Since this course was completely virtual, Flipgrid was the platform used to facilitate peer reviews online. Online peer assessment provided more opportunity for feedback from multiple peers and provided solutions to challenges and encouragement (Lu & Law, 2011).

Model 3: Content-Inspired Iterative Design

One semester during the COVID-19 pandemic was completely virtual. The project for this semester was a pivot towards more multimedia-based projects. Students had no access to the prototyping spaces and student projects were impacted by shipping and supply chain issues during the in person-turned-virtual semester. The dependency had to shift from physical equipment and hardware towards software and media equipment. Students had access to university licenses for some software used in courses, so the instructor went

with a completely graphics-based project. This semester’s project challenge was to develop an animation and static images artifact around a particular content. Students were to select a topic within a theme and research content that they would then have to use multimedia skills to teach K-12 students via animation. The technology skills they would develop included scripting, storyboarding, graphics, audio, and editing towards animation (Figure 5).

This animation had no minimum or maximum time limit and would be published on a course YouTube channel. To keep students engaging their graphics and making skills, they had to make a static images artifact to accompany the animation. The static images artifact allowed students freedom and flexibility to be creative and externalize their understanding (Moran & John-Steiner, 2003). The artifact also facilitated production of a tangible object that could be printed and would alleviate the requirement that products be developed using tools in the shop. There was no requirement that students’ projects had to be professionally printed, so they could make images or generate the artifact by



hand with supplies they could acquire or purchase.

The topic for the semester was common childhood illnesses or injuries since there was a trend to teach about health and science in response to the pandemic to improve public health literacy. Students chose topics such as asthma, allergies, braces, eyeglasses, diabetes, leukemia and chemotherapy, and broken bones and x-ray machines. They researched biological and anatomical concepts, cellular processes, and treatment options. Then they chose software (free, subscription-based, university-provided) and researched techniques to accomplish their vision. Such examples of static images artifact included board games, flash cards, brochures, comic books, puzzles, and models with holograms.

For assessment, the instructor provided templates for project reports and rubrics for project components. Students submitted project reports and presented every two to three weeks for peer feedback. They also had project reflection rubrics for project components (animation, audio, sketches, etc.) to give them self-assessment opportunities (Figure 9). Students estimated and provided a rationale for their score,

providing a chance for nuance and explanation that might not be documented in project reports. Each stage of the project had its own rubric, allowing students to progress at different rates for different aspects of the project.

Application for Middle and High School Teachers

In each of these methods, students had their own research and devel-

opment journey. There was a common set of research skills that they learned and practiced. Though this was an undergraduate capstone course, middle and high school teachers can use similar models for class projects. These projects were conducted over a semester of 14 weeks where students met for 110 minutes twice a week, so those with block schedules could have compatible timeframes. Undergrads self-reported working for approximately three to 10 hours per week outside of class, according to university expectations for three-credit courses and their personal technology or skill goals, so project work time ranged from 300 to 750 minutes per week. For middle and high school teachers who have instructional time every day, the projects can be broken down into subunits where discrete research and development skills are taught in class. Table 3 shows minutes of instruction for different project lengths and meeting times.

Teachers have a few options for how these can be deployed in their class-

Factor	0	5	10	Your Estimated Score	Your Score rationale (or N/A if not applicable to your project).
Background	No background images have been developed or uploaded as layers.	Some background images have been uploaded.	All background images have been uploaded.		
Images	No images have been uploaded into main animation.	Some images have been uploaded and/or edited.	All images have been created and edited into the animation.		
Transitions	No transitions are complete.	Some transitions are smooth and complete.	All transitions are smooth and complete.		
Completion	None of the animation (sound + moving images) has been created.	Half of the animation has been created and edited.	The animation is complete.		
Organization	There is no description or evidence of an organization process for the project.	There seems to be an organized process but it is not documented.	There is a documented organization process in one spot (table or screenshots of file hierarchy is ok) with filenames, flowcharts, or tables indicating relationships. This is included in project report deliverables section.		

Figure 6. Rubric for Animation Reflection. Source: Author.

PROJECT LENGTH	SEMI-WEEKLY (MIN)	DAILY (MIN)
Block (14 weeks)	120	60
Year-long	45	60
Quarter (8 weeks)	45	90
Trimester (10 weeks)	40	75

Table 3. Potential Project Instructional Time Plan.

rooms. If they want to make projects like these individual end-of-year or portfolio projects, they can document individual skills acquisition and will see student-level competencies evolve, but they will have to manage and assess more projects. If teachers want students to work in groups, there will be fewer projects to manage, but teachers will have to make smaller assignments to ensure that each individual student within the groups practices the skills. Teaching and supporting peer review will give each student the opportunity to brainstorm ideas, present alternative solutions, reflect, and offer critique without prominent voices silencing others (Falchikov, 2003; Topping, 2018). During the hybrid and virtual course deliveries, using Flipgrid for video submissions and commenting opened the door for shy students to display their thinking and get celebrated by peers. Flipgrid also provided an archive so students could revisit peer feedback asynchronously.

SOFTWARE

The undergraduate students have had courses in SolidWorks and the Adobe Suite, but middle and high school kids may have to start with Tinkercad as a free entry-level browser-based 3D modeling software. Cloud-based modeling and computer-aided design (CAD) software may be most efficient for classroom teachers because it will not require particular hardware requirements and operating systems and only require an internet connection (Junk & Spannbauer, 2018). If teachers want to use other software,

they will need to consult school and district IT to get costs for site licenses or educational discounts and see what technology requirements are necessary to support the software. SketchUp has moved to a subscription model but is free with a G Suite or Microsoft education account.

COST

The undergraduates did not have a course textbook, so money that would have been spent on a textbook was shifted to their projected maximum project budget of approximately \$50, depending on design. Students building the playground rarely spent more than \$20 for materials. Students who chose the golf club, bowling, or musical chairs project spent approximately \$25-40 for an Arduino Uno and the cost of circuit sensors and parts unless they purchased an Arduino or ELEGOO Uno project kit (\$60-120) or had a micro-controller from a previous course. Students using the Adobe Creative Suite for animation had software costs of \$20 per month unless they chose another route via free software for their project.

There are a few ways to reduce project costs. Teachers can reduce project costs with bulk orders of PLA 3D filament, which averages 20 to 30 dollars a roll. Ten rolls of filament (approximately \$300-\$500) should last for a significant amount of time if physical projects are scaled to fit on 10" by 10" squares. Teachers can also purchase Legos® to have durable, non-consumable supplies. Golf clubs were acquired from Goodwill or consignment shops for one dollar each. Used bowling pins can

be purchased from bowling alleys. For class sizes up to 25 students, that averages about \$25 per project unless students deconstruct or alter the golf clubs or bowling pins.

STEL STANDARDS APPLIED TO MIDDLE AND HIGH SCHOOL

The STEL standards for Grades 6-8 and 9-12 are included in Table 4. Middle school students will apply the design process (7Q) and refine design solutions that address criteria and constraints (7R) as they move through revisions to their iterations. As they research, they will discover human factors in design and create solutions to problems (7S). They will evaluate strengths and weaknesses of different design solutions (7U) when they conduct peer reviews and assess design quality (7T). As they sketch and model using software, select materials, and make using workshop equipment or 3D printing, they will determine benefits and opportunities associated with different approaches to design (7P) and improve skills necessary to design successfully (7V).

High school students will apply all of the middle school standards and expand them. They will apply a broader range of design and making skills to their process (7CC & 7DD) because they will have had more practice with different software and equipment.

Conclusion

Students often fail to understand the impact of research on everyday life and have underutilized skills that impact them as lifelong learners. Courses that typically involve making may not explicitly teach how research impacts design. This article describes three models for developing research skills while practicing and expanding making skills in technology education classes. The examples given complemented course delivery and access to software and lab or

STEL 7 DESIGN IN TECHNOLOGY AND ENGINEERING EDUCATION

6-8	7P. Illustrate the benefits and opportunities associated with different approaches to design.
6-8	7Q. Apply the technology and engineering design process.
6-8	7R. Refine design solutions to address criteria and constraints.
6-8	7S. Create solutions to problems by identifying and applying human factors in design.
6-8	7T. Assess design quality based upon established principles and elements of design.
6-8	7U. Evaluate the strengths and weaknesses of different design solutions.
6-8	7V. Improve essential skills necessary to successfully design.
9-12	7W. Determine the best approach by evaluating the purpose of the design.
9-12	7X. Document trade-offs in the technology and engineering design process to produce the optimal design.
9-12	7Y. Optimize a design by addressing desired qualities within criteria and constraints.
9-12	7Z. Apply principles of human-centered design.
9-12	7AA. Illustrate principles, elements, and factors of design.
9-12	7BB. Implement the best possible solution to a design.
9-12	7CC. Apply a broad range of design skills to their design process.
9-12	7DD. Apply a broad range of making skills to their design process.

Table 4. STEL 7 Design in Technology and Engineering Education Standards Connection.

workshop spaces available during the pandemic. Middle and high school teachers can change project scope and scale based on middle or high school grade level and available software and equipment resources. These project challenges can be very engaging for students of all ages, from middle school through university. On final presentation day, a student reflected, “The research part was more fun than I expected. I made something I could never have imagined.”

References

- Falchikov, N. (2003). Involving students in assessment. *Psychology Learning and Teaching*, 3(2), 102-108.
- Gualtney, J. F., & Peach, H. D. (2016). *How to do research: 15 labs for the social & behavioral sciences* (1st ed.). SAGE Publications.
- Healey, M., & Jenkins, A. (2009). *Developing undergraduate research and inquiry*. Higher Education Academy (now Advance HE).
- International Technology and Engineering Educators Association. (2020). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education*. www.iteea.org/STEL
- Junk, S., & Spannbauer, D. (2018). Use of Cloud-Based Computer Aided Design Software in Design Education. 17th International Conference on Information Technology Based Higher Education and Training (ITHET),
- Lu, J., & Law, N. (2011). Online peer assessment: effects of cognitive and affective feedback. *Instructional Science*, 40(2), 257-275. <https://doi.org/10.1007/s11251-011-9177-2>
- Moran, S., & John-Steiner, V. (2003). Creativity in the making: Vygotsky's contemporary contribution to the dialectic of development and creativity. In R. K. Sawyer, V. John-Steiner, S. Moran, R. J. Sternberg, D. H. Feldman, H. Gardner, J. Nakamura, & M. Csikszentmihalyi (Eds.), *Creativity and development*. Oxford University Press.
- Petrella, J. K., & Jung, A. P. (2008). Undergraduate Research: Importance, Benefits, and Challenges. *International Journal of Exercise Science*, 1(3), 91-95.
- Privitera, G. J., & Ahlgrim-Delzell, L. (2019). *Research Methods for Education*. SAGE.
- Topping, K. (2018). *Using peer assessment to inspire reflection and learning*. Routledge.



Tamecia R. Jones, PhD, is an Assistant Professor at North Carolina State University in the STEM Education Department. Jones

studies assessment in K12 formal and informal spaces and develops technology and research methods that expand capture of engineering knowledge. She can be reached at trjones8@ncsu.edu.

Experiences of Incorporating Virtual Modeling in Technology and Engineering Classrooms

BY ERIK SCHETTIG

Virtual modeling applications have increased in education settings to demonstrate complex concepts (Perets et al., 2020; Kumar & Shumar, 2017). Five secondary technology and engineering educator experiences were recorded and thematically analyzed. Reflecting on the successes and challenges of teachers using virtual modeling in the classroom enables the development of innovations in student learning and teacher professional development programs.

Virtual modeling allows users to utilize interactive digital tools, such as interactive digital simulations, computer-aided design (CAD), and digital renderings, to simulate and test ideas (Kumar & Shumar, 2017). The impacts of virtual modeling include an increase in spatial visualization skills and STEM content knowledge, leading to an increase in self-efficacy in STEM applications (Shu & Huang, 2021). Virtual modeling applications have grown due to technology improvements and have become a strong focus within STEM education, including technology and engineering curricula, pushing a need to possess

knowledge of digital environments and tools (Perets et al., 2020).

Virtual Modeling in STEL

Standards for Technological and Engineering Literacy (STEL) provides a model supporting the development of technological and engineering literacy to enhance STEM education (ITEEA, 2020). Virtual modeling tools align closely with grade band benchmarks of *STEL*, such as 2T,

“Demonstrate the use of conceptual, graphical, virtual, mathematical, and physical modeling to identify conflicting considerations before the entire system is developed and to aid in design decision making.” (ITEEA, 2020) Virtual modeling aligns with *STEL* through technology and engineering education projects such as CAD bridge design, electric vehicle simulation, and CNC router operating software (see figure 1).

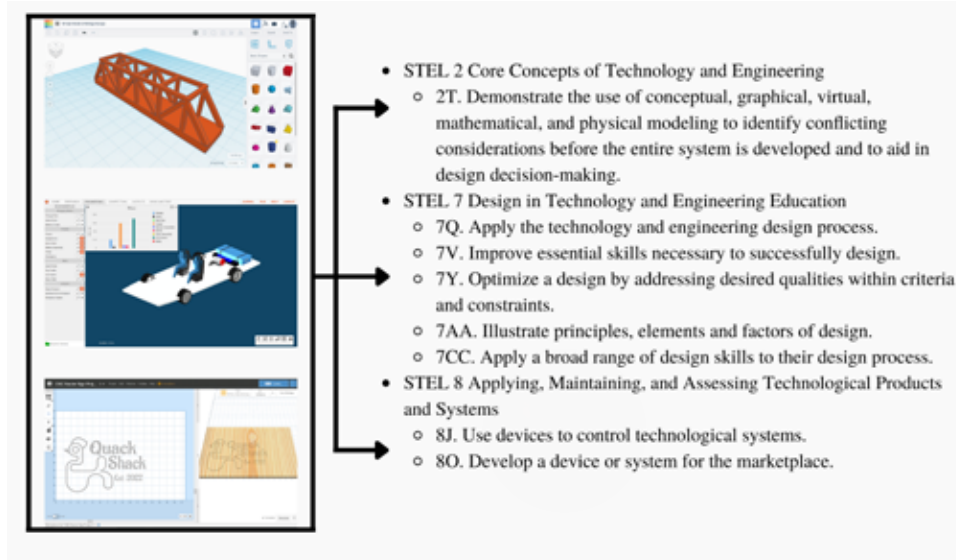


Figure 1. Examples of Virtual Modeling Projects with Associated Standards for Technological and Engineering Literacy.

Virtual Modeling and STEM Skills

Student preparation for a STEM workforce depends on early exposure to tools that support the development of technological and engineering literacy (ITEEA, 2020). Tools include 2D and 3D modeling software used in the classroom, which involves the virtual modeling of complex STEM concepts that can positively impact students' content knowledge of STEM subjects (Urban & Falvo, 2016). An increased understanding of STEM content knowledge leads to academic success, which can increase STEM self-efficacy (Roberts et al., 2018; Whalen & Shelley, 2010). STEM self-efficacy contributes to promoting persistence in STEM degree programs. When used to present multiple perspectives or representations of STEM content, virtual modeling positively impacts the spatial visualization of the learner (Fatemah, 2020). Spatial visualization is the mental manipulation of 2D and 3D designs and is a vital skill that contributes to success in STEM fields and can improve through training (Sorby, 2009). When teachers provide early opportunities through virtual modeling, they provide students with experience developing skills that can increase preparedness in a STEM workforce (Van Laar et al., 2020). These experiences are not achievable without associated challenges that need attention during implementation.

Challenges of Virtual Modeling in Classroom

A commonly reported challenge is that teachers must develop a sense of proficiency with the software to effectively apply it in the classroom setting (Marklund, B. B., & Taylor, A. A., 2016). A lack of teacher proficiency in virtual modeling software in a classroom leads to low student proficiency in using the tool in and beyond the classroom (Marklund,

B. B., & Taylor, A. A., 2016). Another challenge is assuring that software supports classroom content and objectives (Marklund, B. B., & Taylor, A. A., 2016). While students may enjoy the experience of applied software in a classroom, their experience will not strongly impact their learning of course content if there is inefficient relation to objectives or standards (Marklund, B. B., & Taylor, A. A., 2016). There is a need for components such as computers, power, input devices, and output devices to run virtual modeling software in the classroom. Regardless of how great the software may be, it will not be advantageous to the classroom if adequate devices or funding are lacking. This study gained input on teachers' experiences incorporating virtual modeling to understand how to navigate such obstacles. The study's research question is: How has virtual modeling impacted classroom experiences from the perspective of secondary technology and engineering education teachers?

Methodology

Through a multiple case study approach using semi-structured interviews, this study gained the perspectives of teachers' experiences applying virtual modeling projects to students. Teacher accounts came from a purposeful sample of five middle and high school teachers

who instruct at least one course on technology, engineering, and design education. Teachers received a list of interview questions, as shown in Table 1, before the discussion. They were not asked the questions in succession during the interview so that a natural conversation could occur. After the interviews, an analysis of transcripts of the recorded interviews was conducted, leading to the coding and development of themes.

Results

After analyzing the interview transcripts, as detailed in Figure 2, five themes emerged as common among the teacher interviews: (1) positive student engagements, (2) promoting STEM skills, (3) accommodating to classroom needs, (4) challenges, and (5) resources.

Discussion

POSITIVE STUDENT ENGAGEMENT:

Teachers identified that, during virtual modeling projects, students remained engaged in the lesson because they could instantly observe the impacts of their design changes. The instant gratification of designing, testing, and improving their design maintained students' engagement in exploring different avenues of expressing creativity, communicating the impacts of design decisions, and experiencing the effects of applied problem-solv-

Explain why and how you have used virtual modeling in your classroom.
Why did you choose to use virtual modeling versus traditional modeling methods?
What were some challenges in using virtual modeling in your learning environment, and how did you navigate such challenges?
What do you identify as being positive and negative elements of incorporating virtual modeling into a learning environment?
What skills and resources do you see necessary for you (teacher) and students to effectively incorporate virtual modeling technology into a classroom effectively?

Table 1. Interview Questions Presented to Participating Teachers.

Positive Student Engagement	• Opportunities to demonstrate student creativity. • Increased capability to communicate an idea that would be difficult to do physically. • Students have more fun and take projects further when using virtual modeling. • Virtual modeling aided students in developing soft skills. • If a student were struggling, another student would step in and demonstrate or help. • Has the capability to meet students' learning needs. Reading aloud or translating languages. • Allows for the practice of troubleshooting and designing with instant results. • Provides multiple ways to engage students in problem-solving. • Students can collaborate and each student is responsible for a major part of the virtual modeling.
Promoting STEM skills	• Students practice the real-world application of the engineering design process and tools. • Teachers witnessed students practicing collaboration and communication techniques. • Teachers use virtual modeling to practice documenting problem-solving. • Students can test and improve their design solutions. • Virtual modeling is supported by industry micro certification. • Students can use virtual modeling to become certified in applications.
Accommodating Classroom Needs:	• Virtual modeling enables a simpler method of demonstrating complex concepts. • When discussing complex technology and engineering concepts, virtual modeling enabled teachers to demonstrate to students to clarify their understanding. • Virtual modeling is accommodating to a wide range of standards and classroom needs. • Very accommodating to learning students' needs. • Students can complete projects with reduced stress of being at the same level or ability as peers. • Virtual modeling reinforces concepts learned in the technology and engineering classroom.
Challenges	• Companies may charge an annual licensing fee. Costly software can be a barrier. • Teachers and students need access to adequate equipment, permissions, and approvals. • Virtual modeling should challenge students, but the overall experience should not be overwhelming or negative. • Incorporating virtual modeling into the classroom requires teachers to practice from students' perspectives to understand possible challenges. • Schools should have one-on-one computing capabilities. • Proficiency requires time, professional development, and previous knowledge. • Proficiency is needed in teachers and students. • Virtual modeling software needs to meet the range of abilities in each classroom.
Resources	• STEM partnerships, grant opportunities, industry partnerships, and organizational funding. • Higher education institutions enable teachers to access software or can identify types of virtual modeling to use in the classroom. • Corporate partnerships can provide virtual simulations and content to better prepare students for the automated manufacturing industry. • Flexibility in time and tools allowed teachers to overcome challenges. • It is important that teachers make or locate and use pre-made tutorials for students to use at their own pace while using the virtual modeling software.

Figure 2. Identified Themes of Incorporating Virtual Modeling in a Technology and Engineering Classroom.

ing approaches. Additional positive student engagement occurred when students developed an increased understanding of STEM concepts through teachers' application of digital renderings and demonstrations generated through virtual modeling.

Success in STEM involves increasing one's content knowledge, self-efficacy, and ability to apply related skills (Roberts et al., 2018; Whalen & Shelley, 2010). As identified in responses from the interviews, engagement occurs through peer support, where students help each other accomplish various steps in the application of virtual modeling. Teachers identified that several times, students would answer each other's questions on how to change a setting in software

or use a particular tool. The use of instructional guides in the form of videos, text, or images, engaged students in utilizing resources as needed for success in real-world applications of STEM tools.

PROMOTE STEM SKILLS:

Positive student engagement in technology and engineering education courses promotes the development of technological and engineering literacy. Industries place so much value on literacy development that they sponsor virtual modeling software and hardware installation into educational environments and offer associated certifications to prepare future workforces.

Teachers communicated that they employed virtual modeling in their

classrooms to enable students to practice communication and collaboration skills along with problem solving and design processes. Since virtual modeling extends students' capabilities, it also allows them to think critically with reduced limitations to modeling their ideas, as shown in Figure 3, which demonstrates virtual modeling in the design of an electric vehicle model and the communication needed to wire the associated circuit. From all of these STEM skill experiences, students can gain knowledge of applied technology and engineering standards and therefore gain early STEM experiences and establish a STEM identity.

With the ability to design through the digital rendering of ideas, students can view their solutions from multiple perspectives, positively impacting their spatial visualization skills. Spatial visualization skills are a strong predictor of success in technology and engineering courses and careers, which can be enhanced early in education through virtual modeling. Responses from teachers during the interviews reinforced that virtual modeling supports the promotion of STEM skills.

ACCOMMODATING CLASSROOM NEEDS:

Teachers could incorporate virtual modeling into their classrooms and *STEL* because of the range of content virtual modeling accommodates. Since tools in the classroom must be associated with course objectives, it is beneficial that virtual modeling meets a wide range of educational objectives. With increasingly intuitive virtual modeling software, it has become simpler to use such tools in classrooms. There is an ease of use in incorporating virtual modeling in classrooms because some students have familiarity with how to use computer tools. Financial barriers decrease when using low-cost virtual modeling software that does not require high-end ma-

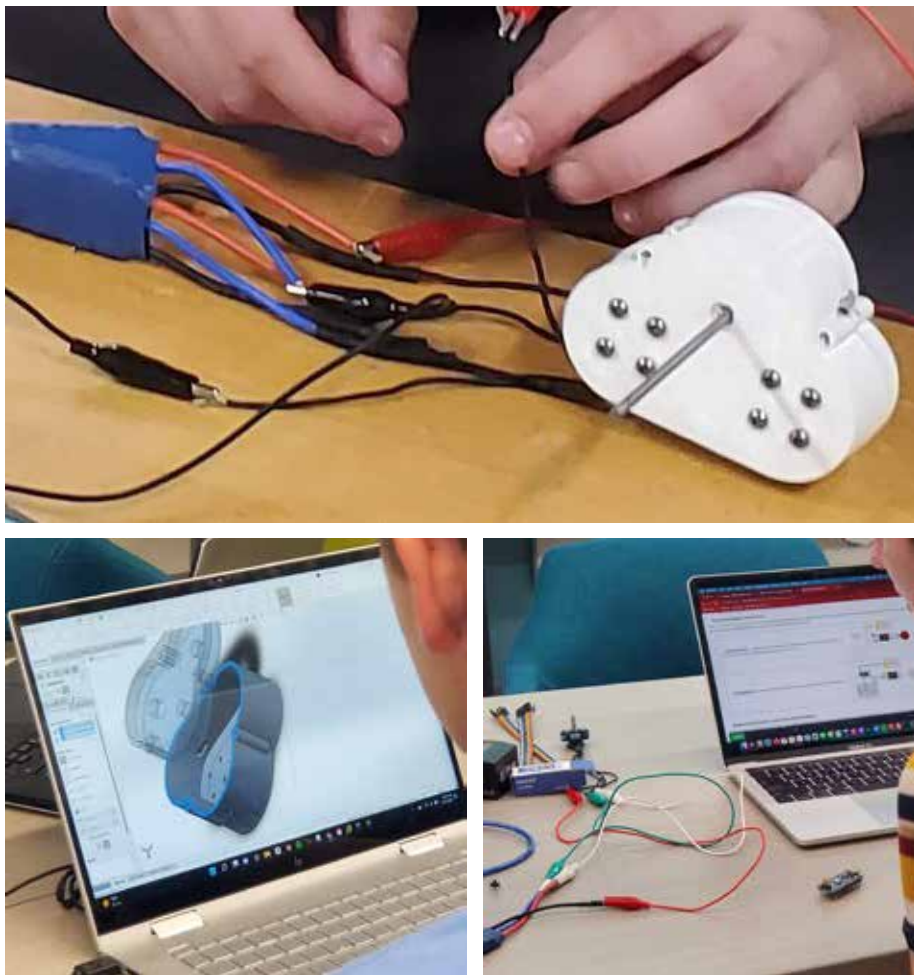


Figure 3. Students Design an Electric Vehicle Prototype Using Virtual Modeling Tools.

chines. Examples are software such as TinkerCad, Google Sketchup, and West Point Bridge Design. These are free-to-use and available online; some can function on already-available devices such as Chromebooks.

As identified by teachers, virtual modeling reduces barriers such as time, material availability, and funding. A highlight was how teachers could safely and quickly demonstrate complex events, such as chemical reactions, through virtual modeling to clarify understanding. One teacher stated, “Using a simulation, I can have students adjust light type and direction to observe the effect it has on a solar panel.” Virtual modeling in the classroom reduces time and costs in setting up complex, expensive demonstrations.

As identified in *STEL*, extending students’ capabilities is a crucial objective in technology and engineering education (ITEEA, 2020). Students participating in these courses function at different levels of capabilities, and the use of virtual modeling allows teachers to meet the diverse needs of students. Virtual modeling software can align with various levels of ability, from novice to expert. Since several guided resources exist, as identified in all interviews, students can engage with the lesson at their level and pace using the guides and tutorials as references. A teacher highlighted that “the software can read to the student and can translate to multiple languages when describing the simulation.”

Challenges

Teachers highlighted challenges they experienced when incorporating virtual modeling into their classrooms. A strongly highlighted challenge by previous studies and teacher interviews assured that students had access to hardware and software. A teacher stated, “no matter how great the software is, it cannot be used in the classroom if there is not the right equipment.” Schools struggle to provide even essential tools to classrooms, including computers. Not all virtual modeling requires high-end machines, but essential components include a computer, input devices, output devices, power, and possibly network connectivity.

Without these system components, virtual modeling is not able to have an impact on the classroom. Obtaining such equipment or permissions can be challenging due to funding, product availability, or administrative approval. Even when schools can provide the equipment, it can be challenging to ensure each student has a device for one-on-one computing since such practice can provide an in-depth virtual modeling experience. Teachers use free or reduced-cost software to increase the incorporation of virtual modeling tools into technology and engineering education classes since several education programs face constrained budgets.

The achievement of proficiency is a common issue in integrating STEM software, as supported in teacher interviews (Marklund, B. B., & Taylor, A. A., 2016). All teachers had to set aside time to gain proficiency and ensure student success in using the software. Several teachers have to do this training in their own time in addition to their current duties. It may be a solution to offer or fund more professional development opportunities through various platforms using virtual modeling

“When teachers provide early opportunities through virtual modeling, they provide students with experience developing skills that can increase preparedness in a STEM workforce.”

tools. Incentives for participating in such professional development can include paying teachers during summers to complete online or in-person professional development on virtual modeling in their curricula or providing licensure renewal credit.

As students were engaged in virtual modeling in the classroom, it was essential to challenge them in a problem-based learning experience. However, teachers shared that requesting too much of students' use of virtual modeling can overwhelm them. “If students struggle too much with the software, they will not remain engaged and, therefore, not benefit from the lesson,” a teacher stated. When introducing new software to students, they can become overwhelmed with just learning the basics. Because of this, some teachers found it challenging to make a problem-based project too difficult or not difficult enough. Flexibility or differentiation in what students had to produce enabled teachers to overcome this challenge or project complexity.

An additional challenge was having to manage students working at var-

ious levels. While it is excellent that virtual modeling accommodates a diverse range of needs in students, it can pose a challenge when students need the attention of various levels. Teachers identified tutorials, on-line videos, and guides, as well as a peer-support system as solutions to this challenge.

Resources

It was identified in each interview that teachers heavily relied on resources that came in a variety of formats. The number of tutorials and guides on virtual modeling in educational and professional settings has grown as the software used in the classroom has increased. Each teacher said they used tutorial guides for students to follow while working with virtual modeling tools. These tutorials were either made by the teacher, shared by a colleague, or found online and came as pictures, text, and video. Tutorials enabled students to practice elements of self-regulated learning by using the guides when they ran into an obstacle, had to learn a new task, or refreshed their memory on how to accomplish a task.

Other vital resources that teachers relied upon in the classroom were the students. Each teacher identified how they witnessed multiple instances where a student would have a question or be struggling with a task and another student would be able to resolve the situation without the teacher having to draw attention from another student. A teacher said, “I love that while I was helping a student and saw a hand raised across the room, their friend or neighbor would jump up and say I had that same problem and then go help them.” This collaboration not only helped the teachers but also supported the development of peer support and communication skills.

The ability of flexibility and perseverance was a resource identified in in-

terviews because changes will occur due to unexpected technical errors or other challenges. Teachers stated that test-running equipment in the classroom reduces the chances of such challenges occurring. As with technology and engineering courses, such challenges can act as educational opportunities for students to learn adaptability and the application of resources.

Bringing outside perspectives into the classroom is of great importance for student development. Teachers can partner with universities, community organizations, or industries to obtain funding, project ideas, guest speakers, equipment, or general support to reinforce their use of virtual modeling in the classroom. Most teachers discussed partnering with universities or companies through a research experience for teachers (RET) program, where they learned about current virtual modeling tools and practices. As identified by teachers, additional partnerships can occur in the form of program sponsorship or management from external sources. These learning resources for teachers can provide access to equipment and ideas they can incorporate into the classroom and establish a stronger self-efficacy in their practices in a technology and engineering education environment.

FUTURE RESEARCH AND PRODUCT DEVELOPMENT:

The experiences and perspectives of teachers applying virtual modeling can act as information resources in developing professional development and curricula for technology and engineering courses. Understanding that teachers have a limited budget encourages using free or reduced-cost software that can run on basic machines yet still provide positive student engagement while promoting STEM skills. Partnerships through universities, community organizations, and industries can

provide virtual modeling resources. Providing intuitive software while covering various topics encourages teachers to use industry-related tools in their curricula. Knowledge of the associated challenges that teachers may experience can enable preparation in reducing such stresses. Preparation steps include providing professional development opportunities that promote proficiency with virtual modeling tools. First-hand experiences through professional development can increase teachers' associated content knowledge and self-efficacy of STEM tools that can ultimately transfer to student success in STEM applications.

Conclusion

Described experiences of how virtual modeling has impacted the technology and engineering classroom from five middle and high school educators resulted from semi-structured interviews. Insight from these perspectives provided knowledge associated with virtual modeling and acted as a resource for future program development and research. Five themes of what teachers considered to be the largest impacts in the application of virtual modeling in the classroom were (1) positive student engagement, (2) promoting STEM skills, (3) accommodation of classroom needs, (4) an awareness of challenges, and (5) accessing resources. Knowledge of these themes enables future programs, teachers, and curricula to be aware of virtual modeling's impacts in a STEM education setting. As technology trans-

forms in physical and digital formats, technology and engineering classrooms must model the real-world applications of such tools.

References

Fatemah, A., Rasool, S., & Habib, U. (2020). Interactive 3D visualization of chemical structure diagrams embedded in text to aid spatial learning process of students. *Journal of Chemical Education*, 97(4), 992-1000. <https://doi.org/10.1021/acs.jchemed.9b00690>

International Technology and Engineering Education Association (ITEEA). (2020). *Standards for technological and engineering literacy*, Reston, VA: Author.

Kumar, V., & Sharma, D. (2017). Cloud computing as a catalyst in STEM education. *International Journal of Information and Communication Technology Education*, 13(2), 38-51. <https://doi.org/10.4018/ijicte.2017040104>

Marklund, B. B., & Taylor, A. A. (2016). Educational games in practice: The challenges involved in conducting a game-based curriculum. *Electronic Journal of E-Learning*, 14(2), 122-135. Doi:1479-4403

Roberts, T., Jackson, C., Mohr-Schroeder, M., Bush, S. B., Maiorca, C., Cavalcanti, M., Schroeder, D. C., Delaney, A., Putnam, L., & Cremeans, C. (2018). Students' perceptions of STEM learning after participating in a summer informal learning experi-

ence. *International Journal of STEM Education*, 5(1), 1-14. <http://dx.doi.org/10.1186/s40594-018-0133-4>

Shu, Y., & Huang, T. C. (2021). Identifying the potential roles of virtual reality and STEM in maker education. *The Journal of Educational Research*, 114(2), 108-118. <https://doi.org/10.1080/00220671.2021.1887067>

Urban, M. J., & Falvo, D. A. (Eds.). (2016). Improving K-12 STEM education outcomes through technological integration. *IGI Global*. <http://doi:10.4018/978-1-4666-9616-7>

van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2020). Determinants of 21st-century skills and 21st-century digital skills for workers: A systematic literature review. *SAGE Open*, 10(1), 215824401990017. <https://doi.org/10.1177/2158244019900176>

Whalen, D. F., & Shelley, Mack C., II. (2010). Academic success for STEM and non-STEM majors. *Journal of STEM Education: Innovations and Research*, 11(1), 45-60.



Erik Schettig is a lecturer in the Technology, Engineering, and Design Education program area at NC State University.

His main research interest is teacher education within the technology, engineering, and design education field and developing engaging STEM curricula and professional development experiences. He can be reached at ejschett@ncsu.edu.

Growing Grit Through Challenge

BY CARRIE HUTTON AND TRACY MIS

There have been significant and intentional efforts to address the quality and quantity of science, technology, engineering, and mathematics (STEM) instruction in K-12 classrooms for over 25 years (Kelley & Knowles, 2016; Thibaut et al., 2018). STEM careers are high pay, high growth clusters that contribute to the economy, quality of life for all citizens, and national security, making STEM education a national priority as a way to fill workforce vacancies and provide equitable career opportunities for all students. It is important that the available jobs of today and tomorrow in STEM fields are filled with qualified personnel. It is also important that all students have the opportunity to pursue STEM careers if their interests and skills align with those clusters (Hall & Miro, 2016).

Students decide during their early K-12 experience where their interests lie and whether or not they are “good” at STEM subjects. It is important to introduce elementary school students to integrated problem solving approaches because they help develop interest in STEM and provide a foundation for the sustainability of STEM interest through the K-12 circuit (Sanders,



2009; Kloser et al., 2018). Elementary school classrooms are also ideal settings to nurture curiosity and allow students to explore the world around them, further developing necessary skills for STEM careers. Middle school classes should strengthen students' academic core and establish supportive and safe learning environments (Indiana Department of Education, 2013). Risk and failure are fundamental to advancement and breakthrough thinking (Marshall et al., 2011). Middle school teachers should continue to help students develop interest and self-confidence in STEM. High school STEM courses should begin to help students narrow their focus to specific career clusters while bridging the divide between student

interest and the skills and knowledge required to pursue a STEM major in college (Valla & Williams, 2012).

Grit is a term that has become inextricably linked with rigorous STEM education. Grit is also closely linked with a growth mindset. Hacısalihoglu et al., (2020) stated, “Growth mindset refers to the students' belief in improving their own academic success with a combination of effective study strategies and effort” (p. 1). In order to develop a growth mindset, students must have grit, which is defined as the ability to keep trying after failure (Hacısalihoglu et al., 2020; Bazalais et al., 2016).

Fortunately, grit is a characteristic that can be learned and practiced. Bazalais (2016) stated that grit “entails working strenuously toward

challenges, maintaining effort and interest over years despite failure, adversity, and plateaus in progress” (p. 34). Learning by doing is a commonly accepted best practice in STEM classrooms and often includes risk and sometimes failure. When students learn how to fail and then get back up through challenges, they build grit. When grit leads to success, it gives students an intellectual level of self-satisfaction, which may lead to intrinsic reward, thus gratifying students through grit. Grit is an important skill for STEM careers particularly since workers are often required to solve problems that did not previously exist. This article will explore how grit is grown through social, mental, and physical challenge in a middle school STEM classroom in Northwest Indiana.

An appropriate level of challenge is required to help students develop and practice grit. Because the appropriate level of challenge is different for each student, it is often beneficial to allow them to create their own challenges. The goal is to get students to rely less on someone else pushing them, so they find the motivation to challenge themselves and build grit in the process. The middle school classroom teacher dis-

cussed in this case study has 25 years of experience. Based on observations made during their career, the following practices contribute to developing an optimal level of challenge:

- High expectations from the teacher.
- Time constraints for projects in order to create a sense of urgency.
- Rubrics that make it difficult to earn an A or B on a project.
- The requirement to work in groups and select group leadership roles.
- Providing students with opportunities to fail and then guiding them toward success through reflection.
- Providing students opportunities to go beyond the basic task and create their own level of challenge.
- Providing high levels of differentiation for the product, scoring, and methods of instruction.

Norms regarding challenge and grit are established on the first day of school. The discussion begins with how challenge and grit are related and defined. The discussion is balanced, and the teacher and students work together to establish a common understanding. Students

“Grit can be developed and cultivated during the K-12 education circuit through challenging assignments and projects.”

often begin with the concept that a challenging class can be attributed to a demanding teacher who assigns a great deal of work and difficult tests. That simply isn’t the case in a productive and safe STEM learning environment. The ultimate goal of immediately establishing a common understanding of challenge is to help students buy into the idea that they should challenge themselves instead of waiting for someone else to push them.

The teacher in this case study further cements the concept of challenge and the development of grit in their classroom by presenting icebreaker examples and tasks that are quick, difficult, open-ended and push students out of their comfort zone. For example, students are asked to give a verbal explanation to the class about the proper technique to make a paper snowflake. Another example is to give students several random items to design and construct a pencil for a person with a broken thumb. A third example is to give students a basic task with a near-impossible time frame in which to complete it. After students complete each activity, they are applauded, celebrated, and receive a pat on the back because they accepted the challenge. Challenges and struggles are discussed openly and often and viewed as a badge of honor. If a student stated, “that was easy” the





response is “how, then, can we take this to the next level through iteration and push ourselves”?

Another way to promote challenge and the development of grit is to provide students with opportunities to create and demonstrate their own level of challenge. Since not every student defines challenge the same way, it is important to offer a menu of possibilities. A “self-evaluation” critique leading to future iterations of improvement is one way students can define their own challenge. Speaking publicly in front of the class or instructing peers on how to approach a task is another way students can demonstrate a self-challenge. Students can also experiment with relevant technology beyond what is given in class. Lastly, students are encouraged to go beyond the level of 80% on assignments in order to earn a grade of A or B.

Project Lead the Way curriculum includes a Pull Toy project (PLTW, 2022). The project requires students to use the engineering design process to design, build, and test a pull toy that employs at least three mechanisms. The goal is to learn about mechanical systems, which relate to several Technological and Engineering Literacy Standards including “Design in Technology and Engineering Education” and “Core Concepts of Technology and Engi-

neering” (International Technology and Engineering Educators Association (ITEEA), (2020). The classroom in this case study structures the Pull Toy project as a tiered project. Students work to meet the challenge level predetermined by the teacher. Projects that earn a grade of A or B have a level of difficulty that only a very limited number of students could achieve. The high-average student ideally achieves 80%. Along with the tiered aspect of the assignment, there is also a “Grit” score. Extra points for grit are earned by not giving up and working to solve the problem themselves.

“Go Beyond” (GB) points are also used to incentivize students to earn scores higher than 80%. GB points are awarded to students who go outside of their comfort zone in order to “enhance” their projects. Some examples of enhancement include presenting their final product, instructing the class on a task they have mastered in an effort to help others, and creating an added challenge using practices associated with the technological and engineering literacy standards such as systems thinking, creativity, making and doing, critical thinking, collaboration, and communication (ITEEA, 2020). GB points allow students to create their own challenges, giving them ownership in how they develop grit.

The classroom teacher in this case study works tirelessly to provide students with examples, instructional videos, helpful hints on troubleshooting and to ward off issues that may arise during the course of each project. They are also careful to avoid providing too much support because it removes situations where students should struggle and figure things out on their own. When teachers become like overprotective parents who remove obstacles and chances to fail, they negate opportunities for students to build resilience and grit. Students need opportunities to fail in safe learning environments.

A survey was administered to students at the end of the course in this case study. When students were asked what they felt their biggest accomplishment was during the term, their responses fell into two categories. The first was being able to use their imagination and create freely, which led to an increased amount of time and effort invested in the task. The second was the feeling of success and accomplishment when they overcame a difficult task. When students were asked what would make the class more challenging, their responses fell into three categories. The first was to require more work and provide less time to do it. The second was to provide less support, allowing students to fail and figure things out on their own. The third was to be sure assignments were presented in a way that Google could not answer. Students know that if they can Google an answer, it is not a challenge.

The survey responses seem counter-intuitive, but they support the best practice of inquiry-based learning in STEM classrooms. They also support the development of grit through challenge. Grit is an essential characteristic in K-12 STEM classrooms, but more importantly in STEM careers. When students experience a setback

or failure, instead of attributing it to a lack of innate ability they need to have the resilience, determination, and grit to persevere until they succeed, even if that means changing course (van Aalderen-Smeets et al., 2019). Partnering with students to define challenges was an effective way to help students in this case study grow their grit.

References

- Bazelais, P., Lemay, D. J., Doleck, T. (2016). How does grit impact college students' academic achievement in science? *European Journal of Science and Mathematics Education*, 4(1), 33-43.
- Hacisalihoglu, G., Stephens, D., Stephens, S., Johnson, L., & Edington, M. (2020). Enhancing undergraduate student success in STEM fields through growth-mindset and grit. *Education Sciences*, 10(279).
- Hall, A., & Miro, D. (2016). A study of student engagement in project-based learning across multiple approaches to STEM education programs. *School Science & Mathematics*, 116(6), 310-319. <https://doi.org/10.1111/ssm.12182>
- Indiana Department of Education (2013). *Indiana's science, technology, engineering, and mathematics (STEM) initiative plan*. Retrieved from <http://www.doe.in.gov/sites/default/files/ccr/indiana-frame-work-stem-educationv2.pdf>
- 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
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3.
- Kloser, M., Wilsey, M., Twohy, K. E., Immonen, A. D., Navotas, A. C. (2018). We do STEM: Unsettled conceptions of STEM education in middle school S.T.E.M. classrooms. *School Science and Mathematics*, 18, 335-337.
- Marshall, S. P., McGee, G. W., McLaren, E., & Veal, C. C. (2011). Discovering and developing diverse STEM talent: Enabling academically talented urban youth to flourish. *Gifted Child Today*, 34(1), 16-24. doi: 10.1177/107621751103400107
- Project Lead the Way. (2022). PLTW gateway - middle school STEM curriculum (6-8). <https://www.pltw.org/our-programs/pltw-gateway>
- Sanders, M. (2009). Integrative STEM Education: A Primer. *The Technology Teacher*, 68(4), 20-26. Retrieved from <https://vtechworks.lib.vt.edu/bitstream/handle/10919/51616/STEM-mania.pdf?sequence=1>
- Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., De Cock, M., Hellinckx, L., Knipprath, H., Langie, G., Struyven, K., Van de Velde, D., Van Petegem, P., & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, 3(1).
- Valla, J. M., & Williams, W. M. (2012). Increasing achievement and higher education representation of underrepresented groups in science, technology, engineering, and mathematics fields: A review of current K-12 intervention programs. *Journal of Women Minorities in Science and Engineering*, 18(1), 21-53. doi:10.1615/JWomenMinor-ScienEng.2012002908.
- van Aalderen-Smeets, S. I., Walma van der Molen, J.H., & Xenidou-Dervou, I. (2019). Implicit STEM ability beliefs predict secondary school students' STEM self-efficacy beliefs and their intention to opt for a STEM field career. *Journal of Research in Science Teaching*, 56(4), p. 465-485.



Carrie Hutton, Ed.D., is the Mathematics Program Director at Calumet College of St. Joseph, located in Whiting, IN, where she also teaches

mathematics courses. Previously, Dr. Hutton taught dual credit engineering classes at local high schools. She is a commissioner for the Human Relations Commission in Hammond, IN. She can be reached at chutton@ccsj.edu.



Tracy Mis has taught middle school math, science, or Project Lead The Way for over 20 years. She is passionate about working with

students to inspire and develop a STEM mindset. She can be reached at tamis659@gmail.com



ELEMENTARY STEM IN ACTION

Computational Thinking Friends

By exposing students to computational thinking and helping them to strengthen these skills at a young age, they can be better prepared to thrive in an increasingly complex world.

BY JESSICA YAUNEY, SCOTT R. BARTHOLOMEW, VERONICA WUTHRICH, AND EMERSON ELYA

Computational Thinking

Computational thinking is a problem-solving approach that involves breaking down complex problems into smaller, more manageable parts and using systematic, algorithmic processes to develop solutions. It is a way of thinking that is essential for anyone who wants to work with computers and it is becoming increasingly important beyond computer science, including business, medicine, and science (Wing, 2006). Computa-

tional thinking has been called the “thought process of the future” (Papert & Resnick, 1996), and it is seen as a critical skill for students in the 21st century. This can help them develop a better understanding of the world around them and prepare them for a future in which technology will play an even more central role. Computational thinking is not just about developing computer programs, but it is a way of thinking that can be applied to any field (Grover & Pea, 2012).

According to Wing (2006), computational thinking involves abstraction, decomposition, algorithmic thinking, pattern recognition, data representation and manipulation, automation, and evaluation. However, there is a large amount of variety in how computational thinking is defined and categorized (Shute et al., 2017). This article focuses on four of the most commonly included elements of computational thinking: abstraction, decomposition, algorithmic thinking, and pattern recognition. By using these elements in combination, problem solvers can develop the skills necessary to tackle complex problems.

Friends Who Help Us

Educational mascots are used in a wide range of educational contexts to teach children concepts in a relatable and fun way. Smokey the Bear is one of the most recognizable examples. He has been used since 1944 to promote wildfire prevention (Ballard et al., 2012). A similar example is McGruff, the crime dog used by the National Crime Prevention Council to increase crime aware-

ness and personal safety since 1980. Before these iconic mascots, books used similar concepts with Clifford the Big Red Dog (1963), Paddington Bear (1958), Corduroy (1968), and Black Beauty (1877). More recently the same phenomenon has been used on social media with “will power” representing Johnson City Power Board (Caufield, 2011) and @water having over 500,000 followers (@Water, n.d.).

As the authors searched for a way to bring computational thinking into the elementary classroom, they designed computational thinking friends to help students learn about, remember, and apply computational-thinking skills. Below is an introduction to each of the four friends they created: Abs the Abstraction Detective, Al Gordo the Algorithmic Thinking Chef, Pat the Pattern Recognition Cat, and Deco the Decomposition Zombie.

Abs the Abstraction Detective

Abstraction in computational thinking refers to the process of isolating the essential features of a problem and ignoring the non-essential details. The goal of abstraction is to simplify complex systems and make them easier to understand, analyze, and solve. Students are encouraged to “zoom in” on the most pertinent aspects of a problem with Abs the Abstraction Detective. She always has her magnifying glass to help her find the essential features. Students



were assisted in their debugging process by remembering to zoom in to “find out what was the problem with” their project. Students even used their learning with Abs to help them summarize and identify the climax in their literacy activities.



Deco the Decomposition Zombie

Decomposition is a fundamental aspect of computational thinking that involves breaking down complex problems into smaller, more manageable parts. The goal of decomposition is to simplify complex problems and make them easier to understand, analyze, and solve. By decomposing a problem, problem solvers can identify and isolate specific subproblems, and then develop solutions to those subproblems, which can then be combined to form a complete solution to the original problem. Students enjoy learning about breaking down or decomposing with their friend Deco the Decomposition Zombie who may be falling apart themselves but is great at taking problems apart and putting them back together. Students reflected on the value of computational thinking and decomposition saying things like “there were times like when the night light had a really big code and it was kind of hard to try to put it all together. But then when I broke it up and took it one step at a time it got easier. That’s awesome.”

Al Gordo the Algorithmic Thinking Chef

Algorithmic thinking involves organizing a complex activity into smaller steps and using those steps to create a solution. Algorithmic thinking is designed to help develop systematic, repeatable, and automated processes for solving problems. One of the most common types of algorithms that students are familiar with is a recipe (Rankin et al., 2019; Lineberry et al., 2020). Students understand the step-by-step nature of cooking and thus our computational thinking friend for algorithmic thinking is a chef named Al Gordo. Students can combine what they learned about zooming in from Abs and breaking down problems with Deco with what they learn from Al Gordo to identify and formalize the algorithms needed to solve their problems. One student reflected that “the computer is like really interesting, and I mean like you could just tell a person to do this, and they just usually do it but with the computer you have to put all these specific codes together to make sure that the computer knows what you want it to do [...] kind of like Al Gordo.”



Pat the Pattern Recognition Cat

Pattern recognition is a key aspect of computational thinking that involves identifying patterns, trends, and relationships in data and systems. By recognizing patterns, problem solvers can develop more



effective solutions to problems. Pat the Pattern Recognition Cat is the computational thinking friend who helps students in this case identify patterns like the spots or stripes on some of our favorite big cats. Pattern recognition can be used to identify similarities and differences in data and it can be applied to a wide range of applications. Stu-

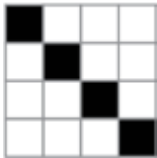
dents can use abstraction to identify phenomena, pattern recognition to identify how the phenomena functions, and then algorithmic thinking to generalize the solution. Students were able to use pattern recognition while building step counters to identify that with “the step counter [...] every time you shake it or take a step it goes up by two.”

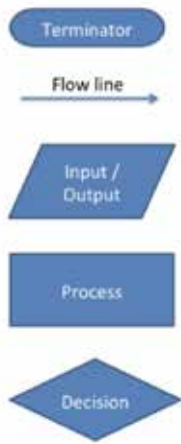
Conclusion

Computational thinking is an essential skill that is most easily exercised in STEM fields but can also play a role in other areas. According to Bell and Lunt (2011), computational thinking provides individuals with a structured and systematic approach crucial for addressing complex problems in STEM fields. Computational thinking is particularly useful in data analysis, modeling, and simulation

and can be used to understand and solve complex problems in fields from biology to engineering and finance (Margolis & Fischer, 2002). While computational thinking skills can be used in the activities you already complete in your class, additional activities that directly reinforce computational thinking skills are provided in Table 1 as suggestions. A lesson plan is also included in Tables 2 through 5 and can be used to introduce our computational thinking friends. By exposing students to computational thinking and helping them to strengthen these skills at a young age, they can be better prepared to succeed not only in computer science and engineering classes in secondary education but can also be better prepared to thrive in an increasingly complex world.

Table 1. Examples of Computational-Thinking Activities

COMPUTATIONAL THINKING SKILL	ACTIVITY NAME	DESCRIPTION
Algorithmic Thinking	Peanut Butter and Jelly Sandwich	The concept most often introduced with this activity is that computers do exactly what they are told and nothing more. Students are asked to write instructions for how to make a peanut butter and jelly sandwich and then are able to watch the funny results as their teacher or parent follows their instructions, e.g., forgetting to take the bread out of the bag before putting peanut butter on it. static.zerorobotics.mit.edu/docs/team-activities/ProgrammingPeanutButterAndJelly.pdf
Algorithmic Thinking and Abstraction	Graph Paper Programming 	Students are invited to draw pixel art on graph paper by using the following instruction “language” for movement and drawing:  You can extend this activity by adding color to the “language.” Then students can be introduced to Image Representation and how a set of rules are followed so that all images can be broken down into instructions that use binary. code.org/curriculum/course2/1/Teacher

Algorithmic Thinking and Decomposition	Flowcharts	Students can be prompted to create a flowchart to provide instructions for any task from making friends or playing a board game to getting home from school or fixing a light. This process requires students to break down larger tasks into its parts. Students can swap algorithms with a partner or work in a group to improve their algorithms. 
Abstraction	Think Outside the Box	Thinking abstractly is a difficult concept for many young children to grasp, so one of the easiest ways to teach them is by comparing abstraction to “thinking outside the box.” I draw a box filled with nine dots and give my class the following rules:  - You must draw four straight lines that connect all dots. - You can’t lift the marker once you start. - I remind them to think outside of the box. Then I have the students come up to the whiteboard and try to solve the puzzle. Once a handful have tried, I share the solution.
Pattern Recognition and Abstraction	Sphero Indi	These robot cars detect color tiles that they pass over and complete the instruction that the color is tied to. For example, pink cards tell the car to turn left. By playing with the cards and the cars, students can recognize the patterns and determine an abstract set of rules. https://sphero.com/pages/sphero-indi
Decomposition and Pattern Recognition	Gauss	Ask students to determine the sum of the numbers between 1 & 100 in 30 seconds. When they can’t, you can walk them through decomposing the problem into a series of easier problems and recognizing the pattern: 200 + 1? 199 + 2? 198 + 3? letstalkscience.ca/educational-resources/backgrounders/gauss-summation
Pattern Recognition and Algorithmic Thinking	Coin Sorting	When presented with a pile of coins, prompt students to select one and provide a plan for how they will gather only those coins. Students will identify color, size, and/or other attributes to help them identify the proper coins. www.stem.family/2018/04/24/sorting-coins-with-a-pattern-game/

Decomposition	Dance Moves	Students can break down the elements of a dance move in order to learn a new step or teach someone else how to do the step. The lawnmower, sprinkler, shopping cart, or thriller can be fun moves to start with. You can let students suggest or even make up other dance moves to try.
Decomposition, Abstraction, Pattern Recognition, and Algorithmic Thinking	Digital Storyboards	Students are invited to design a visual representation of a scene they are familiar with from media that takes advantage of electrical and coded components to control lights, movement, and sound with the help of micro:bits. (Bartholomew & Yaune, 2022)
Decomposition, Abstraction, Pattern Recognition, and Algorithmic Thinking	Micro:Bit Challenges	Micro:Bits or other similar hardware devices allow students to create programs to control physical components like servos or lights. An extremely wide range of activities can be created ranging from a beating heart to walkie-talkies. https://microbit.org/projects/

Table 2. Lesson Overview

Grade Level	Grades 1-5
Lesson Title	Computational Thinking Friends
Big Idea	Computational thinking fosters problem-solving skills and logical reasoning in young children, helping them think more critically and systematically. Learning computational thinking at an early age lays the foundation for future technological literacy and helps students develop skills that are essential for success in a rapidly evolving digital world.
Enduring Understandings	- Abstraction, Decomposition, Algorithmic Thinking, and Pattern Recognition are important computational-thinking skills that can be supported in early elementary school. - By introducing these skills through a helpful friend, students are more likely to remember and apply them.
Purpose of Lesson	In the lesson, students are invited to strengthen their computational-thinking skills. Students learn about and work with friends who help them remember specific aspects of computational thinking.
Instructional Time	30 minutes or more depending on activities implemented
Learning Objectives	- Students will be able to identify abstraction, decomposition, algorithmic thinking, and pattern recognition as elements of computational thinking. - Students will be able to provide examples in which each of these skills was useful in problem solving.
Standards-Based Assessment	- Formative assessment » Student understanding can be checked by asking students to narrate their process during computational thinking activities. - Summative assessment » Students can be asked to recount a way computational thinking helped them in the activities or to imagine a way it could have been helpful.
Lab/Classroom Safety and Conduct	- All of the described activities pose limited risk to students. - For classes where students have nut allergies, peanut butter can be replaced with sunflower butter.
Technologies and Other Material Resources	Different activities have different resources and technologies. Links are provided following each example activity.

Table 3. Lesson Standards

FRAMEWORK FOR P-12 ENGINEERING LEARNING	
Engineering Habits of Mind	Creativity: Students strengthen their pattern recognition skills, allowing them to identify new patterns or relationships or imagine new ways of doing things. Systems Thinking: Computational-thinking skills allow students to recognize and solve problems in systematic ways. Algorithmic thinking is heavily important within systems thinking.
Engineering Practice	Quantitative Analysis: Computational thinking including abstraction and pattern recognition assists students in analyzing and drawing conclusions from data.
Engineering Knowledge	Engineering Mathematics: Computational thinking skills are embedded in and necessary to be successful mathematicians.
STANDARDS FOR TECHNOLOGICAL AND ENGINEERING LITERACY (STEL)	
Standards	• PreK-2 Grade Band » Core Concepts of Technology and Engineering (2A, 2D) • 3-5 Grade Band » Core Concepts of Technology and Engineering (2F) » Applying, Maintaining, and Assessing Technological Products and Systems (8D)
Practices	• Critical Thinking • Systems Thinking
Contexts	• Computation, Automation, Artificial Intelligence, and Robotics • Information and Communication
NEXT GENERATION SCIENCE STANDARDS (NGSS)	
Practices	Using Mathematical and Computational Thinking
	Analyzing and Interpreting Data
COMMON CORE MATHEMATICS STANDARDS (CCSS MATH) FOR MATHEMATICAL PRACTICES	
CCSS.MATH.PRACTICE.MP1 Make sense of problems and persevere in solving them.	Mathematically proficient students start by explaining to themselves the meaning of a problem and looking for entry points to its solution. They analyze givens, constraints, relationships, and goals. They make conjectures about the form and meaning of the solution and plan a solution pathway rather than simply jumping into a solution attempt. They consider analogous problems and try special cases and simpler forms of the original problem in order to gain insight into its solution. They monitor and evaluate their progress and change course if necessary.
CCSS.MATH.PRACTICE.MP2 Reason abstractly and quantitatively	Mathematically proficient students bring two complementary abilities to bear on problems involving quantitative relationships: the ability to decontextualize—to abstract a given situation and represent it symbolically and manipulate the representing symbols as if they have a life of their own, without necessarily attending to their referents—and the ability to contextualize, to pause as needed during the manipulation process in order to probe into the referents for the symbols involved.

Table 4. 6E Lesson Plan

ENGAGE

The purpose of the ENGAGE phase is to pique student interest and get them personally involved in the lesson, while pre-assessing prior understanding.

There are many engaging ways to begin discussing computational thinking but one of the most popular is the Peanut Butter and Jelly Sandwich. If allergies are of concern any nut butter can be used. If students are already familiar with this activity, then you can select one of the options provided in the Explore section.

Invite students to independently write instructions for how to make a peanut butter and jelly sandwich. (10 min)

Allow 2-3 students to volunteer their instructions to be tested. Follow their instructions precisely. Here are some common mistakes in student code. (10 min)

- Forgetting to instruct you to get the supplies.
- Forgetting to instruct you to open containers including bread and jars.
- Not specifying how much peanut butter/jelly.
- Not specifying where to put the peanut butter/jelly.
- Not specifying how to orient the bread before putting them together.

EXPLORE

The purpose of the EXPLORE phase is to provide students with the opportunity to construct their own understanding of the topic.

Providing students an opportunity to apply the lessons they just saw in a similar context can be useful.

The Coin Sorting, Dance Moves, Graph Paper Programming, Gauss, and Flowchart activities given above can be selected. Invite students to work collaboratively to complete one of the tasks. (15 min)

EXPLAIN

The purpose of the EXPLAIN phase is to provide students with an opportunity to explain and refine what they have learned so far and determine what it means.

Introduce students to the Computational Thinking Friends. Discuss each of the skills they teach us and point out an example of that skill's usefulness in the Explore task that was just completed. (15 min)

ENGINEER

The purpose of the Engineer phase is to provide students with an opportunity to develop greater depth of understanding about the problem topic by applying concepts, practices, and attitudes. They use concepts learned about the natural world and apply them to the man-made (designed) world.

Digital Storyboards can be designed and built to use Micro:bits to illustrate a scene from a student's favorite media (movie, book, television, etc.).

Teachers can decide to provide students with blank illustrations to add electrical components to or allow students to draw their own illustrations. Students identify locations for lights (10 min/60 min).

Students connect the lights to a Micro:bit. Students select and implement code that determines the behavior of lights and the Micro:bit (30 min).

ENRICH

The purpose of the ENRICH phase is to provide students with an opportunity to explore in more depth what they have learned and to transfer concepts to more complex problems.

As students just barely began using micro:bits with their Digital Storyboards, they can expand their knowledge of coding by completing challenges using Micro:bits. A single activity can be selected and completed in 20 minutes or students can explore many options over multiple hours. Here is a list of sample ideas:

- Digital Dice
- Water Reminder
- Stop Light
- Hand Wash Timer
- Catapult
- Jeopardy Buzzer
- Thermometer
- Night Light
- Musical Instrument
- Step Counter
- Beating Heart
- Show Your Emotions
- Walkie Talkies

EVALUATE

The purpose of the EVALUATION phase is for both students and teachers to determine how much learning and understanding have taken place.

In our experience, the topic of computational thinking is so complex that the most effective evaluation method is to interview or discuss each of the computational thinking areas with students. As this is usually not possible due to time and resources an alternative is provided.

Students can be prompted to write an introduction to their assigned computational thinking friend. They can be prompted to include how that friend helped them complete the computational thinking activities they completed in this unit. These introductions can be in the form of slideshows, portraits, or speeches.

POTENTIAL FOLLOW-UP ACTIVITIES

Computer Programming is one of the most common and clear applications of computational thinking. It can be extended into an entire course. There are many options for programming ranging from Hour of Code and Scratch to Spheros and Micro:bits.

Table 5. Vocabulary List

Computational Thinking	A way of thinking like a computer to solve problems.
Abstraction	Simplifying complex ideas by focusing on the most important parts and ignoring the details that aren't necessary.
Algorithmic Thinking	A way of thinking about problems that involve breaking them down into smaller, more manageable steps that can be solved using a set of instructions.
Algorithm	A set of instructions or steps that tell a computer or person how to solve a problem or complete a task.
Pattern Recognition	The ability to identify similarities or patterns in data, images, or ideas.
Decomposition	Breaking a problem down into smaller, more manageable parts or steps.

References

Ballard, H. L., Evans, E., Sturtevant, V. E., & Jakes, P. (2012). The evolution of Smokey Bear: Environmental education about wildfire for youth. *The Journal of Environmental Education*, 43(4), 227-240. <https://doi.org/10.1080/00958964.2011.644352>

Bartholomew, S. & Yauney, J. Digital Storyboards. *The Joint Conference of the 108th Mississippi Valley Technology Teacher Education Conference and the 59th Southeastern Technology Education Conference* Clarion Hotel, Nashville Downtown Stadium, Nashville, TN November 17-18, 2022.

Bell, P., & Lunt, T. (2011). The importance of computational thinking in K-12 education. *ACM Inroads*, 2(1), 40-43.

Caufield, K. (2011). Analyzing the effects of brand mascots on social media: Johnson City Power Board case study. *East Tennessee State University*.

Grover, S., & Pea, R. (2012). Computational thinking in K-12. *Educational Researcher*, 42(1), 38-43. <https://doi.org/10.3102/0013189X12463051>

Lineberry, Litany, Lee, S., & Ghimire, A. Dance-A-Bit: Integrating Dance with Teaching Algorithmic Thinking. *ASEE Annual Conference Proceedings*, (2020). Retrieved from <https://par.nsf.gov/biblio/10184802>.

Margolis, J., & Fischer, M. (2002). *Unlocking the clubhouse: Women in computing*. Cambridge, MA: MIT Press.

Papert, S., & Resnick, M. (1996). *The children's machine: Rethinking school in the age of the computer*. New York: Basic Books.

Rankin, Y. A., Thomas, J. O., & Irish, I. (2019). Food for Thought. *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*. <https://doi.org/10.1145/3287324.3287484>

Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. *Educational Research Review*, 22, 142-158. <https://doi.org/10.1016/j.edurev.2017.09.003>

Wing, J. (2006). Computational thinking. *Communications of the ACM*, 49(3), 33-35. @water. (n.d.). Instagram. Retrieved February 10, 2023, from <https://www.instagram.com/water/>



Jessica Yauney is a graduate student in the School of Technology at Brigham Young University and a former computer

science high school teacher. Her research centers on computer science secondary education. She can be reached at jessica.yauney@gmail.com.



Scott R. Bartholomew, PhD is an assistant professor of Technology and Engineering Studies at Brigham Young University and a

former Technology and Engineering middle school teacher. His research centers on the use of adaptive comparative judgment for student learning, STEM teacher professional development, PBL curriculum, and open-ended design assessment. He can be reached at scottbartholomew@byu.edu.

Veronica Wuthrich is an undergraduate student in Technology and Engineering Studies with a Technical Emphasis at Brigham Young University. Her research centers on coding attitudes in elementary school children. She can be reached at ronald115vw@gmail.com.



Emerson Elya is an undergraduate student in Technology and Engineering Studies with a Teaching Emphasis at Brigham Young

University. Her research centers on coding attitudes in elementary school children and adaptive comparative judgment for student learning. She can be reached at emers02@byu.edu.

Landscaping Korean STEM Education as Teachers and Researchers in the Field of Technology and Engineering Education

BY HYUKSOO KWON
AND YUBIN LEE

Introduction

In terms of the rapid development of science and technology, the future society will be very different from the present, and great attention is being paid to anticipating and preparing for it. Many countries around the world are interested in innovative development in the field of science and technology and are making great economic investments and educational efforts. On the other hand, school education should focus on helping students develop core competencies required by this future society and preparing them to demonstrate their full competencies in the future society. As part of these efforts, many countries have started STEM education policies and are actively and diversely implementing policies at the national level.

In Korea, STEM Education began in 2011 as the term STEAM education and is now being used as a term called convergence education. Korean STEM Education is relatively well realized as an education policy as Korea has a strong national curriculum and various practical strategies to match. However, this policy created many challenges and difficulties

for teachers and researchers. To solve these issues, research has been conducted to revise and supplement the convergence education policy every year. This manuscript examines how convergence education policy in Korea began and developed, and what challenges it faced from the standpoint of teachers and researchers in the field of Technology Education. In other words, this paper consists of an overall introduction to convergence education in Korea and the current status and reflection on convergence education from the standpoint of Technology Education.

Based on the results of recent research on convergence education policy in Korea, the authors intend to describe recent trends of convergence education in Korea from the beginning by actively utilizing the results of interviews with teachers and data from several government projects in which the authors participated. All teachers interviewed were given pseudonyms.

Launching Korean STEM Education

Around the world, STEM Education has been introduced and developed

to suit individual education systems and national circumstances. Similarly, since development and innovation in the STEM field is an indicator of national competitiveness, many countries have been interested in STEM Education and have promoted various educational policies (Kwon & Park, 2021). STEM education must be an educational policy that is attracting attention in terms of students' benefits through the convergence among subjects in schools (e.g., students' academic achievement, learning motivation, attitude, interest in career, etc.) and preparation for future education (Kang, 2019). Based on the results of these accumulated studies and social needs, each country started its STEM education policy.

In Korea, an educational policy called STEAM Education was announced in 2011 by combining elements of STEM Education and Arts, which had already been announced in other countries. Specifically, when defining STEAM Education, Kang (2019) added the term integrated in front and defined it as follows.

Integrated STEAM education in South Korea is an approach to

preparing a quality STEM workforce and literate citizens for highly technology-based society by integrating science, technology, engineering, arts, and mathematics in education (p. 2).

In this definition, the concept of Arts includes fine arts, liberal arts, language arts, etc., and targets all subjects in the school. However, since the term STEAM itself is too reminiscent of a specific subject, STEAM Education has a tendency and narrowness to focus on a specific subject within the national curriculum.

Interview with Mathematics Teacher Suhak (pseudonym): *“I was really looking forward to it after the announcement of the policy that STEAM is an attempt at convergence between subjects at school, but I was a little upset to see that STEAM gives more opportunities only to science teachers in our district.”*

Interview with technology teacher Hyukshin: *“There are T and E in STEAM education, right? As a technology teacher, I heard that there are various projects and training for STEAM teachers, so I was very excited. However, in the early days, science teachers took precedence, and official documents and information only went to the science department. I was really upset.”*

Developing Korean Convergence Education

After the STEAM Education policy was initiated by the STEAM Education vitalization plan announced in 2011, the Korean government focused on providing a foundation for fostering human resources equipped with both scientific and technological knowledge and artistic sensibility. In addition, keeping in mind the confusion and intolerance of the term STEAM, the term convergence talent education was selected and used for

a short time through a national policy title contest. STEAM education is a convergence education to improve students' convergence thinking and problem-solving ability and strategies such as operating research and leading schools by region and supporting teacher research groups were used to vitalize STEAM Education. In addition, the Korean government promoted a lot of budget and detailed policies to vitalize STEAM Education based on “strengthening knowledge information and convergence education” as a national task (Lim, Kwon, 2020). Afterwards, Korea will develop a revised national curriculum in 2015 that emphasizes fostering creative convergence-type talents with upright character through core competencies required by future society (MOE, 2015). In 2017, while establishing a mid- to long-term plan for convergence talent education (2018-2022), teachers and students strengthened their STEAM Education capabilities and focused on spreading STEAM Education to the field.

However, recently, the Korean government prepared for future education through the Comprehensive Plan for Convergence Education (2020-2024) and focused on laying the groundwork for convergence education, which changes the paradigm of learning based on educational achievements so far, to settle down and spread in schools (MOE, 2020). Figure 1 shows the vision and promotion strategy that are the basis for proceeding with convergence education policy.

The Korean government prepares for future education through convergence education and wants to change classes (students, teachers), classrooms (space, technology/tools), and local society (collaboration, culture). First, the strategy for changing the class was to actively introduce learner-centered teaching

“For convergence classes to take place properly in schools, it is necessary to create a self-sustaining collaborative culture in which teachers of various subjects cooperate to research, develop, and share convergence education contents.”

methods such as flipped class and PBL to students, and to strengthen the expertise of convergence education through various training systems and teacher convergence learning community support for teachers. As a strategy to change the classroom, the main promotion strategy is to create a convergence-type future learning space and to secure and spread a place for convergence education that can be shared in various places by preparing a foundation for convergence education using advanced technology. As a strategy to be together with the local community, there is a convergence education culture that connects and cooperates with schools and local communities through the establishment of convergence education experience centers for each region and spreads a convergence education culture of empathy and consideration.

Key Challenges of Korean Technology Education toward Convergence Education

At the beginning of the introduction of STEAM education, many tech-

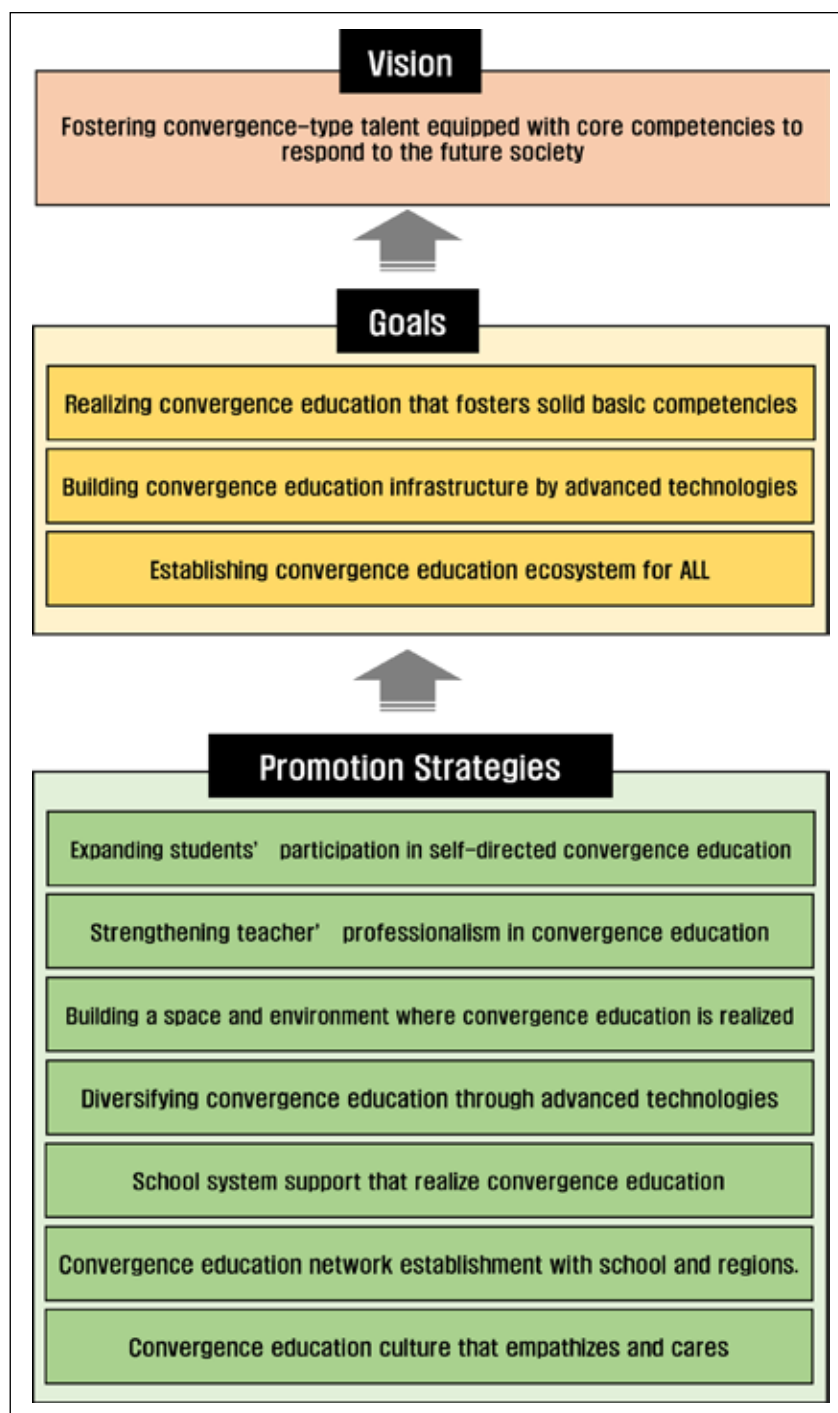


Figure 1. Vision and Implementation Strategy of the Comprehensive Plan for Convergence Education in Korea (MOE, 2020).

nology teachers and researchers expected greater interest in and awareness of Technology Education as people in charge of T (technology) and E (engineering). As a result, although many people have succeeded in knowing what T is, the lack of identity of technology in the national curriculum was still there. There is no independent subject called technology in Korea, and the current status of technology subjects in the 2015 revised curriculum, which is the current curriculum, is shown in Table 1.

As shown in Table 1, technology as an independent subject does not exist in the current curriculum (MOE, 2015). From elementary school to high school, technology constitutes roughly half the amount along with home economics (Lee, Ham & Kwon, 2020). However, in elementary school, information and agriculture are included in the technology area, but there are very few parts that can be linked with middle school purely in relation to technology. Overall, in the national curriculum, technology is not recognized as technology and engineering because of its subject name, and it is always fighting against incorrect perceptions and misconceptions due to the identity of the subject. However, it is true that through the STEAM education policy, other subject communities in many schools have shown many questions and concerns about the existence of T and E. Also, they are asking a lot of questions such as “Who can teach Engineering at

SCHOOL GRADE	ELEMENTARY SCHOOL	MIDDLE SCHOOL	HIGH SCHOOL
Subject Name	Practical Arts	Technology and Home Economics	Technology and Home Economics (General Selective) General Engineering (Career Selective) General Intellectual Property (Career Selective)

Table 1. Technology Related Subjects in the 2015 Revised National Curriculum.

school while showing interest in Engineering?” Korea’s national curriculum clearly states that technology teachers can teach engineering general subjects in high schools, but technology teachers cannot teach engineering subjects in schools due to the shortage of technology teachers in high schools. High school curriculum has presented enough needs for including engineering classes, but the supply of teachers is not enough (Lee & Kwon, 2021).

Interview with the Leader of Technology Teachers: *“As the president of the Korean Technology Teachers Association, the most unpleasant thing is that the value and importance of technology education is not highlighted due to structural problems such as subject names. Even if only the problem of subject name, such as Technology and Home Economics, could be separated and recognized as technology, I think that many of the misperceptions and identity problems of Technology Education would be resolved.”*

Thanks to the slightly improved awareness of technology, the Korean educational community paid attention to the values of technology and

engineering through many exemplary technology teachers, and this provided a good opportunity to publicize Technology Education well through convergence education.

Positioning Technology and Engineering within Korean Convergence Education

KOREA TECHNOLOGY TEACHERS’ ASSOCIATION INCLUDES ENGINEERING!

To take the place of Technology and Engineering in convergence education, many technology teachers and groups carried out their own cultural movement of Technology Education with passion. As an active expression that technology teachers can teach engineering, the Korea Technology Teachers Association (KTTA) changed its official name to the Korea Technology Engineering Teachers Association (KTETA). The KTETA made great efforts for the position of Technology and Engineering in convergence education.

In particular, the government secured a position as a technology teacher by protesting giving opportunities to participate mainly to science, mathematics, and information teachers in the government’s promotion plans

such as teacher research groups and professional development or trainings. As a result of the 39 executive committee members’ votes, 38 voted in favor of including Engineering in the group’s name.

KOREAN CONVERGENCE EDUCATION CASE 1: STUDENT-DIRECTED PROJECT

While implementing the convergence education policy, the Korean government tried to promote project-type education in which students can choose their own learning topics and learning processes. An excellent example of a student-led project in the comprehensive plan established by the government is the technology class at Yeongdeungpo High School. There, the technology class is based on problem-based learning, where students select a problem-solving topic and design, produce, and evaluate it as a team project (Figure 2). In convergence education, many educational communities have considerable interest in student-led projects of technology classes and are showing great interest in the effects through them.

Interview with Science Teacher Tamgu: *“One of the new things I learned through convergence*

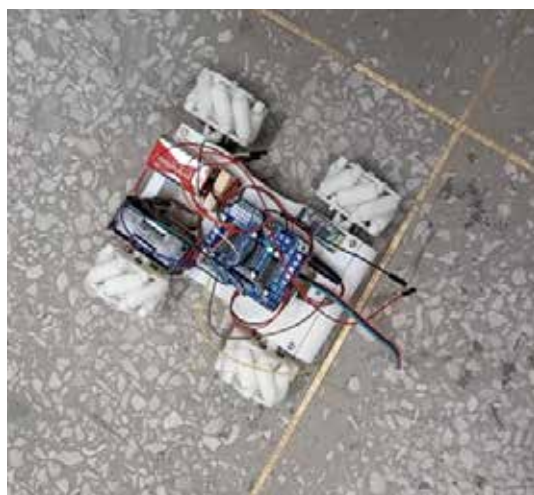


Figure 2. Semester Final Product in Yeongdeungpo High School. Building a self-driving car (left) and building RC car hacking and racing rail (right).



Figure 3. Teachers' Professional Learning Community. Using the class design card (left) and positively influencing others by sharing collaborative convergence class design outputs (right).

education is my understanding of technology teachers. Before, I was not interested in school life at all, but I found out that technology teachers have always been doing student-led activities and projects, and it was good to share advice about convergence education class activities with technology teachers."

The whole process of learning is to create a page for each group using the internet site, record the process in detail in the cloud, and finally announce it. This class can be said to be an excellent class example in high school and an essential class of technology.

KOREAN CONVERGENCE EDUCATION CASE 1: TEACHERS' PROFESSIONAL LEARNING COMMUNITY

For convergence classes to take place properly in schools, it is necessary to create a self-sustaining collaborative culture in which teachers of various subjects cooperate to research, develop, and share convergence education contents. As a practical strategy for convergence education, the Korean government is expanding and supporting the

operation of self-sustaining convergence learning communities among teachers. In the case of the Cheongju Solbat Middle School learning community, which is cited as an excellent case in the Comprehensive Plan for Convergence Education, technology teachers were the focus, and in their classes design, execution, and sharing were spontaneously created. Since 2016, this middle school has been implementing convergence project classes to cultivate future core competencies (Figure 3). As an expert and technology teacher of convergence education, the performance and composition of leading the community of convergence education teachers in a school for four years are very excellent and worthy of being an example, so they are dealt with in depth in the comprehensive plan for convergence education.

Wrap Up and Discussion

New talents are required according to social changes in the era of the 4th industrial revolution, and accordingly, the demand for changes to the existing traditional education

method is growing. Increasingly, the importance of learning and the role of school education in fostering interest have been emphasized, and the ability to discover and solve problems based on convergent thinking rather than fragmented knowledge is also emphasized. Amid these changes, many countries around the world have introduced STEM education policies, and Korea has also implemented STEAM education for the same purpose. For a broader convergence education for all, the term convergence education is used rather than STEAM. Through the introduction and growth of convergence education, from the standpoint of technology education, there was an advantage that it could receive interest and attention from other subjects, but the problem of the identity of Technology Education and the situation that was still concentrated in a specific subject was a big issue.

Nevertheless, in the recent comprehensive plan for convergence education by the Korean government, the representative case among the cases for each action plan was the practice



Summer professional development in KTETA.

of technology teachers. Specifically, as an example of a teaching method for convergence education, the case of student-led project learning or PBL class was selected, and the philosophical practice of the technology teacher was outstanding. In addition, convergence education was a good example as a community of class design, practice, and sharing led by technology teachers as an example of a school-level teacher community. Lastly, the Technology Teachers Association recently changed to the Korean Technology and Engineering Teachers Association by adding engineering to its name. The steady practice of technology teachers and the active driving force of the KTETA provided a good opportunity to position T and E in convergence education amidst difficulties and challenges. Korean Technology Education groups should concentrate on advertising the values and benefits of Technology Education through Technology and Engineering cultural movement.

Acknowledgement

The author would like to express special thanks to the Korean Technology

and Engineering Teachers' Association (KTETA) and Seokyoung Kwon, Juhyun Kim, and Dong Kuk Lee for sharing data and photos.

References

Ministry of Education (MOE)(2015). The 2015 Revised National Curriculum.

Ministry of Education (MOE)(2020). A comprehensive plan for convergence education that changes the paradigm of learning 2020-2024.

Kang, N. (2019). A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea. *Asia-Pacific Science Education*, 5(6).

Lee, H., Ham, H. & Kwon, H. (2020). Research trends of integrative technology education in South Korea: a literature review of journal papers. *International Journal of Technology and Design Education*, 791-804.

Lim, Y. & Kwon, H. (2020). Research trends and issues of social studies

related STEAM education. *Social Studies Education*, 59(3), 209-222.

Kwon, H. & Park, B. (2021). Issues in International STEM Education Research: A Meta-Comprehensive Approach. *Journal of Science Education*, 45(1), 11-22.

Lee, Y. & Kwon, H. (2021). Transition of high school technology education in Republic of Korea. *Journal of Technology and Engineering Education*, 51(1/2), 29-44.



Hyuksoo Kwon, PhD, is a Professor at Kongju National University, Chungcheongnam-do, Republic of Korea. He can be reached via

email at hskwon@kongju.ac.kr.



Yubin Lee is a technology education teacher at Jusan Middle School, Daecheon, Republic of Korea.

Ira E. Compton, III

MS Technology and Engineering Teacher CTE
Williston Middle School
North Dakota



TEACHER HIGHLIGHT

Ira Compton grew up in a smaller North Dakota Farming Community. He was shaped by great mentors in Boy Scouts, sports, and church, as well as by his parents. He is an avid hunter and enjoys his friends and his community of teachers.

How would you describe your Technology and Engineering teaching philosophy?

Theory lessons that are established with the students bring out more successful lab projects and life learning past middle school.

Do you have a favorite “success story”?

When students approach me after middle school and tell me I made a difference in their young lives.

If you could pass on any wisdom to your students, what would you share?

A good work ethic is needed throughout your life. Stay focused, move forward, and make it happen!

What’s the best advice you’ve been given about teaching Technology and Engineering?

Build a relationship with your classes and teach to their level and at a pace set for them by the CTE teacher.

What’s the most challenging aspect of teaching Technology and Engineering?

Teaching middle schoolers spatial reasoning and design features that are layered by standards.

If you could take the students on a field trip to anywhere in the world, where would you take them?

To the Toyota Motors Headquarters where students can learn about managing vehicle design and good quality control.

What career would you choose if you were not a Technology and Engineering teacher?

Social work or manager at a hardware store like Ace.

What do you consider to be your “superpower”?

Structure in planning and learning what works and what does not with teens.

What does being an ITEEA Teacher Excellence Award winner mean to you?

I have improved and want to keep learning as a teacher.

Zach Glennon

Technology Education Teacher
Moultonborough Academy
New Hampshire

Zach works with middle and high school students as their Tech Ed teacher and as a theatre co-advvisor. He was born and raised in New Hampshire and enjoys spending time outdoors. He is an avid board game player.

How would you describe your Technology and Engineering teaching philosophy?

Problem solving is all about learning how to fail and to try again in a different way until success can be found.

Do you have a favorite “success story”?

My favorite success story is that my students were tasked with creating five large dragon heads for *She Kills Monsters*. They had to design, plan, and execute the project. They started to do it one way and had to try again a couple of times to make their designs work. The students were challenged by their own designs. They tried, learned, and then succeeded after several attempts to complete their dragon heads.

If you could pass on any wisdom to your students, what would you share?

It is okay to fail, you just need to keep trying until you succeed.

What’s the best advice you’ve been given about teaching Technology and Engineering?

Play to your strengths and have as much fun with the projects as the kids do.

What’s the most challenging aspect of teaching Technology and Engineering?

Helping students understand that it is okay to fail. That they just need to get up and try again.

If you could take the students on a field trip to anywhere in the world, where would you take them?

If I could take students anywhere in the world, I would take them to an out of state championship robotics competition. There students could see first-hand problem-solving solutions in real time during the matches, while also being able to check out the problem solving that is going on in the pits to fix the robot or what they did to get their robot to that point.

What career would you choose if you were not a Technology and Engineering teacher?

If I were not a technology and engineering teacher, I would be a production manager for a regional theatre.

What do you consider to be your “superpower”?

Adapting to multiple curveballs that are thrown at me.

What does being an ITEEA Program Excellence Award winner mean to you?

Being an ITEEA Program Excellence Award winner means, to me, that the program is being recognized for the flexibility of the school and students to try something new, and that the new thing is working for everyone involved.

ITEEA's Now Offers Annual Global Design Challenges for Elementary and Secondary STEM Students! Deadline: December 15, 2023

In 2008, the U.S. National Academy of Engineering (NAE) identified 14 Grand Challenges for Engineering in the 21st Century, which were designed to cause students and educators to think about solutions to the big challenges affecting all of our lives. It's now time for your students to get in on the action and show the world that they can solve big STEM design problems as well.

The Process: STEM students from around the world will work in small design teams to solve a GDC outlined below. They will be required to document the process with a simple portfolio that describes the problem-solving processes undertaken, the products developed, results of product testing, as well as the final product presentation. Photos and descriptions of proposed solutions will be posted on ITEEA social media accounts and ultimately, the winning teams can present their solution during the ITEEA Conference in Memphis, TN at the STEM Showcase on March 8, 2024. The teams will also be featured in the May 2023 issue of this journal.

Fifth Global Design Challenge for Elementary STEM Students

Challenge: I am going out of town and no one is available to care for my dog. I need some type of device to consistently dispense water. Can you work as a small group to create a device that can help automatically dispense water? This device should be simple to use, easy to fill, and keep the water bowl consistently full for three days.

Learn more at <https://tinyurl.com/ITEEAGDC2023>



FIRST-EVER Global Design Challenge for Secondary STEM Students

Challenge: Can you work as a member of a small design team to develop a better product or tool that can be used to accomplish a task while using only solar power to generate the required electricity? Select a tool or product that has not traditionally been powered with solar energy—one that most designers would consider impossible.

Learn more at <https://tinyurl.com/ITEEAGDCSS2023>



For questions about the Global Design Challenge contact
Jessica Nyden at jenyden@uark.edu or Michael Daugherty at mkd03@uark.edu.

Deadline: December 15, 2023



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

Launcher w/ Class View Timer™ & Track
(24 ft. L in three 8 ft. L sections), start/finish
gates (pre-wired), hand controller set, [50]
dragster kits and [2] portable air compressors.

841564U.S. Shipping is \$500 **\$2,995**

840814 Economy Original Launcher Only ..**\$245**

KELVIN® Solar Racer™ with Wood Base



Kit includes: solar motor, solar
cell with alligator leads, battery holder, wheels,
axles, tube holders for axles, washers, gear set,
wood base and instructions.

841236 Kit**\$11.45** or **\$10.25** ea./10+

841415 Bulk Pack of 20**\$8.75 Per Kit \$175**

KELVIN®

EDUCATIONAL INNOVATION



KELVIN® catalogs feature
many subjects like: Flight,
Rocketry, Boats, Cars,
Architecture, Engineering,
Design, Manufacturing,
Kre8® Modeling, S.T.E.M.
Labs, Publications, Storage
Units, Project Parts &
Materials, Robotics,
Electronics, Science,
Alternative Energy (like
Wind and Solar),
Hydroponics and more.

Download catalog PDFs
at www.kelvin.com

KELVIN® Rubber Band Glider with 13 in. wide Wing Span



Kit includes: pre-cut balsa sheet,
nose hook propeller, wire and wheels. Works
with Rubber Band PowerPole™. Requires glue.

283693 Kit**\$9.45** or **\$8.95** ea./20+

KELVIN® Jumbo Foam Cutter

\$135

Extra large foam cutter with
a cutting area that
measures 12 x 18 in.
Features guide for
straight cutting.
Arm can be easily
tilted for cutting
angles. Comes
with starter set
of [5] assorted
foam blocks,
on/off switch,
power indicator, plug and DC power supply.



842546 Assembled w/ On/Off Switch**\$135**

KELVIN® Balsa StiKutter™

- Cuts balsa up to 3/16 in. T
- Long handle
- Moveable guide
- Built-in protractor
for angles.
- Clear finger
protector with
no stop on the right side.



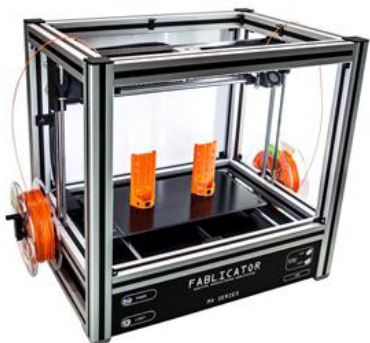
Compact 4-1/2 in. sq. base has holes for
mounting. Blade is replaceable by the teacher.

990198**\$9.95** or **\$8.95** ea./10+

Professional Grade for Industry and Education

FABRICATOR

Not your average 3D Printer!
www.fabricator.com



Additive
Manufacturing
Workstations
for Industry and
Education

Proudly Designed & Manufactured in U.S.A.

by K&L Services Group Inc.

Offices@ 215 N. 8th Street Allentown, PA 18102

PH: 610-439-3230 or sales@fabricator.com

TECHNOLOGY AND ENGINEERING EDUCATION



Bringing STEM to Life

#ReimagineTeachingSTEM

Educators: consider trying just one
teaching practice to promote integrated
STEM. Making a conscious effort to make
one small adjustment in our practice is a step
in the right direction.

As we begin this new school year, *Technology and Engineering Education's* editorial team is challenging you to pick one thing you want to try in your approach to integrated STEM education this year. Tag ITEEA (Facebook: @ITEEA STEM, Twitter @iteea) on social media and use the hashtag **#ReimagineTeachingSTEM** to share your ideas. The individual with the most liked post on Facebook or Twitter (now X) by October 31, 2023, will win a \$25 gift card from ITEEA!

TECHNOLOGY AND ENGINEERING EDUCATION



Bringing STEM to Life

Call for proposals for a Special Issue of *Technology and Engineering Education*

The editorial team of *Technology and Engineering Education: Bringing STEM to Life*, ITEEA's peer-reviewed practitioner journal, is seeking proposals for a special issue to be published in January 2025. The editorial team is interested in proposals that will focus on current issues for integrated STEM education and technology and engineering education for a large audience. The journal's readership includes elementary teachers, middle school teachers, high school teachers, college professors, administrators at local, district, state, and national levels, and industry professionals.

Detailed information and the process for proposing a special issue can be found at <https://bit.ly/TEESpecialIssue> or by scanning the QR code at right.

All proposals are due by October 1, 2023 and decisions will be made by October 31, 2023. For questions or more information, please reach out to Thomas Roberts at otrober@bgsu.edu.



Introducing ITEEA's Secondary STEM Council!



ITEEA's Secondary STEM Council (SSC) is a new collaborative network of educators dedicated to the advancement of technological and engineering literacy at the secondary level. Serving specifically middle and high school teachers and administrators, SSC will provide instructional materials, in-service professional development (PD) workshops, and technology and engineering activity curriculum packages. Further, Council members will have access to a community of peers, where they can discuss and share new ideas, challenges, and opportunities unique to secondary educators.



Already an ITEEA member? Scan the QR code to sign in and add an SSC membership.

Not yet a member? Scan this QR code to create an account and join today!



Have questions or want to learn more? Email ssc@iteea.org.

Welcome to the New ITEEA Website

[Read More](#)

We have a new look!

ITEEA has spent 2023 moving to a new membership service and website provider and we have a brand new look and updated technology in an effort to better serve all our members and users. We hope that you'll enjoy it as much as we already do.



In order to get the most out of your member experience, you will need to create a new login. Your previous username and password will not work on the new website (however, your membership, councils and journal subscriptions have been carried over). Please follow the steps below to get logged in.

With your new login, you will be able to:

- Register for ITEEA events
- Update your profile information
- View/Pay Invoices
- Access ITEEA resources
- and more!

To create your new login:

- Go to www.iteea.org/login
- Enter your email and follow the prompts.
 - If the email entered is connected to your profile (your old login email address), you'll be prompted to set your new password.
 - If the email is not recognized, please contact iteea@iteea.org so that we can get you set up with your previous account.

Legacy Data:

While your membership data, purchases and subscriptions have moved over to our new system, many of your legacy records, such as: event participation, years active in ITEEA, headshots, and biographies will not be. If you need any of this legacy data, please contact iteea@iteea.org by the end of the year to receive an export of this data. **Note: This data will no longer be accessible by the end of 2023.**

EbD BUZZ Users:

If you were using your ITEEA account in order to login to your BUZZ Dashboard, you should have received an email about your new login procedure and credentials. You will not be going to www.iteea.org to login any longer. If you have questions or did not receive new credentials please reach out to ebdbuzzsupport@iteea.org.

Online Learning Library

ITEEA's Online Learning Library resource is being transitioned during the month of August and is planned to go live at the end of the month.

We sincerely hope you find our new website layout and member experience easier and smoother to use as we continue to make ITEEA the best it can be for our members. If you have any questions or issues please do not hesitate to contact us at iteea@iteea.org for assistance.

Use STEM Skills
to Change Lives

Inspire Your
Students!

Win
Awards!
\$\$\$

Registration
**NOW
OPEN!**

iteea REACH challenge

Get inspired! See past winning projects and register today:
www.iteea.org/Reach



Activities
+ Lessons

Online
Quizzes +
Docs

Slides +
Videos

Hey Teachers! Are you looking for an Inspirational STEM Project?

Since 2019, more than 100 teams across the United States have taken the REACH Challenge, where students use their STEM skills to create adaptive and assistive technology to help change the lives of those around them. Teachers receive an **Educators Toolkit** with slides, videos, worksheets (online and pdf versions), and activities on:

- Adaptive & Assistive Technology
- User-Centered Design
- Empathy
- Listening Skills for Data Gathering
- Prototyping Tips & Tricks
- Intellectual Property 101

Projects can be submitted to ITEEA for an opportunity to earn awards for your STEM program. Change someone's life...take the REACH Challenge today!



**"Probably
the most
rewarding
experience
of my life."**

Miles
STEM Student
REACH Challenge
Winning Team
2020

**"Providing a human centered
design challenge for students
brings in another perspective
that students don't often get
and builds empathy for others.
The lessons were well planned
and easy to use. Such a great
opportunity for students!"**

Jennifer O'Gorman
STEM Educator - Olathe, KS
REACH Challenge Winning Team 2020

