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technology and engineering TEACHER

September 2021

A FOCUS ON DESIGN

ITEEA's 84th Annual Conference:

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

Planning for ITEEA's 2022 conference in Orlando is well underway and will include a diverse range of professional development and networking opportunities and the potential for both in-person and virtual attendance.

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ITEEA
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March 9-12, 2022

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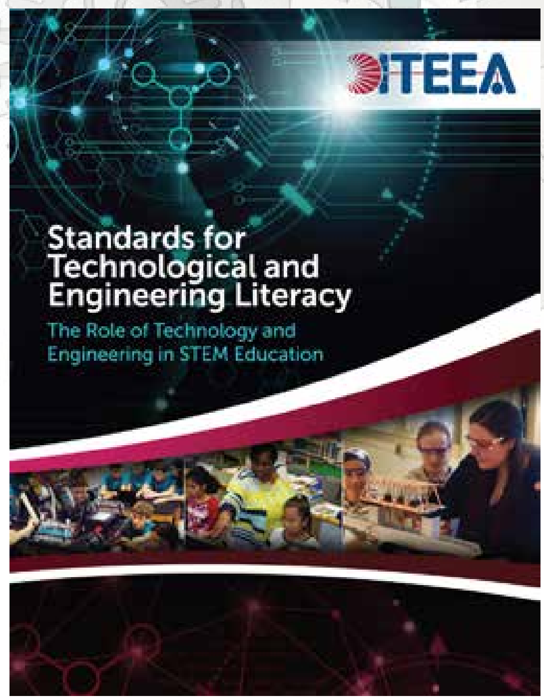
www.iteea.org/ITEEA2022.aspx

Standards for Technological and Engineering Literacy is here!

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



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

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

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

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

As a viewable PDF (FREE)

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

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contents

features

departments

on the iteea website

ITEEA's Launches Updated "Marketplace" Webpages

ITEEA recently completely revamped its Marketplace webpages. The Marketplace is designed to have one clear and effective way for companies and institutions connected to the STEM arena to advertise, exhibit, or sponsor with ITEEA. Check out this new initiative and share with your colleagues, business partners, and friends of ITEEA!

ITEEA enthusiastically begins a new chapter as the leader in Technology and Engineering Education and invites corporations and institutions to join us—and trust that you are as excited as we are for the upcoming 2021-22 school year to be another banner year!

STEM and ITEEA's growth means better opportunities for companies and institutions to attract new business. There is no shortage of fresh new concepts, ideas, and marketing options to help both reach and engage our members, as well as the much larger technology and engineering education field.

Whether organizations are interested in advertising, exhibiting, or sponsoring, they can find numerous marketing opportunities outlined on ITEEA's updated Marketplace page to help connect with this rapidly growing, essential, and significant marketplace.

Our supplier partners are pivotal to the success of not only ITEEA and our affiliates, but more importantly the future and sustainability of STEM education. Participation and involvement in our community is widely appreciated, and it's crucial to the advancement of causes and issues near and dear to our hearts – those of ITEEA's influential members.

Any inquiries regarding ITEEA's Marketplace offering should contact Bob Jonas at bjonas@iteea.org or 703-609-3974.

stem education calendar

March 9-12, 2022

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October 13, 2021
7:00pm EDT
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December 8, 2021
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January 19, 2022
7:00pm EDT
ITEEA's Roundtable Discussion Series
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ITEEA's Roundtable Discussion Series
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ITEEA 84th Annual Conference
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Orlando, FL
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April 13, 2022
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Teaching Energy and Power
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technology and engineering TEACHER

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stem education news

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The 2021-2022 ITEEA Board of Directors election ballot, including candidate biographies, will be emailed to Professional and active Life Members in late September. The highly experienced field of candidates is pictured here.

Exercise your right to vote by completing your ballot promptly! Ballots must be completed on or before October 30, 2021. Be sure that ITEEA has your correct email address—to review or update it, log on to your member profile on the ITEEA website at www.iteea.org.

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SCOPE process: fostering students' design outcome effectiveness

There is evidence that teachers can develop students' cognitive and metacognitive skills during design experiences using the SCOPE process.

by Andrew J. Hughes and Cameron D. Denson

Introduction

The purpose of this article is to help Technology and Engineering Educators scaffold engineering design and problem-solving experiences so that students taking technology and engineering courses will develop an improved ability to design. Technology and Engineering Education (T&EE) seems to increasingly focus on problem solving, design, and engineering. T&EE is not the only discipline with this focus. Science Education is similarly focused on problem solving, design, and engineering. The fact that both Science and T&EE are similarly focused on the teaching and learning of engineering begs the question of what separates technology and engineering educators from science educators in the teaching of engineering? Lewis (2004) cautioned that the introduction of engineering signaled the discipline turning away from more practical, blue-collar knowledge, towards white-collar academic traditions. Lewis (2004) highlighted John Dewey's argument that manual training was a gateway for students to integrate math and science.

The T&EE discipline is better suited to teach engineering by a strengthened connection with characteristics that make the discipline significant and unique, like shop skills, craftsmanship, technological literacy, and the tacit knowledge and skills developed through applying sound theories during practical hands-on learning. These connections help solidify T&EE importance with teaching and learn-

ing of engineering. Additionally, technology and engineering educators need to learn from and implement research-based interventions designed to improve the teaching and learning of engineering. A research-to-practice model, like implementing research-based models and interventions presented in the *Journal of Technology Education (JTE),* can provide technology and engineering educators with the tools needed to teach engineering design better. Research illustrates that improving students' ability to solve ill-structured, open-ended design problems only happens through a well-planned, structured, and scaffolded instructional process with engaging hands-on, minds-on student learning experiences.

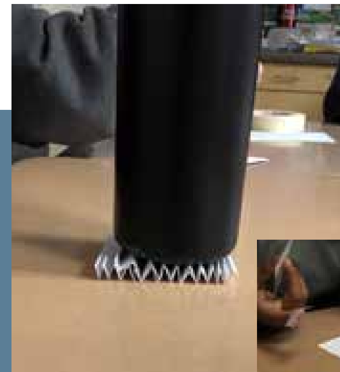
Design

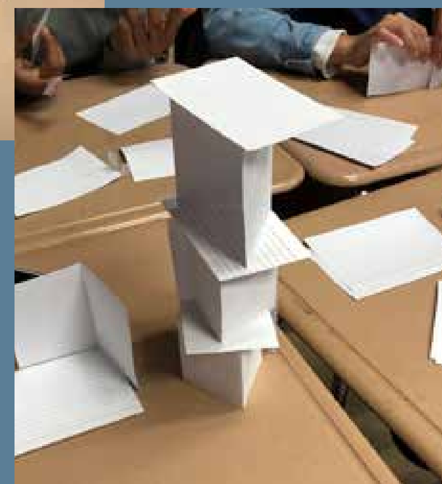
"The subject [of design] seems to occupy the top drawer of a Pandora's box of controversial curriculum matters... Even 'design' [teachers]—those often segregated from [academic content teachers] by the courses they teach—have trouble articulating this elusive creature called design" (Evans et al., 1990 as cited by Dym et al., 2005). Learning to design requires a scaffolded approach fostering development of cognitive and metacognitive abilities used to solve multi-faceted problems that have "multiple levels of interacting components within a system that may be nested within or connected to other systems" (Lammi & Becker, 2013, p. 55). The sequencing of engineering design problem solving throughout PK-12 education starts with well-structured design experiences progressing with increased ambiguity, number of plausible solutions, problem depth, and ends with open-ended, ill-structured, and ill-defined problems (Denson & Lammi, 2014). Scaffolding engineering design experiences enables both the students and teacher to become steadily more comfortable with design complexity, multiplex design processes, and challenging problems.

Design is an essential theme in technology and engineering education classrooms, yet with the release of the *Next Generation Science Standards*, design has increasingly become a theme in science education classrooms. Additionally, most classrooms with instruction centered around design are taught by teachers not credentialed in science, math, or technology education; but rather, subjects like art, business, history, music, as well as other subjects, especially at the middle school level. There is growing momentum to situate engineering design experiences in classrooms taught by teachers who do not have related industry experience or a technology and engineering education background (NGSS, 2013). Teachers who lack the appropriate pedagogical background will experience challenges in effectively introducing students to engineering design experiences. More poignantly, students will not adequately develop design skills and abilities unless teachers are adequately prepared to offer scaffolded development thorough sequenced design experiences.

Design Instruction

Based on the research literature related to design, students' design abilities do not progress much through school-based design experiences (Becker et al., 2012). This article intends to present





a scaffolded approach to the teaching and learning of design to address students' design-ability development. When design is taught, especially by those without adequate training, students' engineering design experiences are more likely to be unfocused, lacking pedagogical structure, disengaging, inauthentic, and debatably do not help students develop the underlying skills or abilities associated with improved design competence. Engineering design experiences in T&EE have the potential to be the exact opposite, especially when technology and engineering educators are provided with the tacit knowledge and skills to thoroughly apply research-based theories during practical hands-on learning. Technology and Engineering Education's approach to teaching design needs to be scaffolded but also focused on cognitive development, tool skills, measurement, geometric construction, manufacturing, instrumentation, testing and analysis, application of mathematical and scientific theories, and many other skills and abilities. Technology and engineering educators should strive to combine design experiences with adequately challenging practical hands-on experiences that connect student thinking and doing.

Design is a challenging complex task that requires both thinking and hands-on skills and abilities. The thinking involved during the design process is often related to broad terms that encompass a larger number of underlying skills and abilities. Such terms as systems thinking, problem scoping, modeling, experimenting, reflecting, and evaluating are just some of the skills that are implemented during the design process. These skills need to be embedded but also explicitly emphasized for students during design experiences. Technology and engineering educators will need to explicitly focus on the development of cognitive and metacognitive abilities to help students manage the complexity of design experiences (Table 1). The process of developing cognitive abilities requires the teacher to have students focus on problem scoping, generating alternative solutions, estimating (i.e., predicting), modeling, experimenting, and continuous evaluation (i.e., iterating). While the development of metacognitive abilities requires focus on reflection, planning, information gathering (i.e., information management), and knowledge (implying declarative, procedural, and/or conditional knowledge). Technology and engineering educators will foster students' abilities by knowing the underlying skills, understanding the interconnectedness of these skills, and the recommended approaches for developing cognitive and metacognitive skills within the learning environment. There is evidence that teachers can develop students' cognitive and metacognitive skills during design experiences using the SCOPE process.

SCOPE Process

SCOPE is an acronym for Study, Criteria, Organize, Predict, and Evaluate. The SCOPE process is designed to help students slow down and thoroughly think through the design experience by studying the design situation, identifying the problem, identifying constraints and requirements, gathering and organizing information, making predictions based on design decisions, and evaluating and selecting the best approach based on information analysis (Table 2). The SCOPE process is intended to be used with any design experience. All design experiences should start with the SCOPE process to improve outcome effectiveness. The SCOPE process is designed to promote students' success throughout any design experience. Additionally, the SCOPE process should be continuously revisited throughout iterative design experiences. The SCOPE process helps to develop students' cognitive and metacognitive abilities by connecting their thinking with their actions during design experiences. The SCOPE process can be used in conjunction with any design process the teacher decides to use and does not replace the design process.

When using the SCOPE process, a student will begin by studying the problem, which is the first part of any design experience. The "How" column in Table 2 suggests how the student will go about each stage of the SCOPE process. The How column suggests many items at each stage, but these suggestions are not all-encompassing of what happens at each stage of the SCOPE process. The "Tool" column in Table 2 provides examples of tools that students can use to record and more thoroughly analyze their thinking related to each stage of the SCOPE process. Again, the tool column suggests a few tools, but these are not the only tools that can be used to record and analyze ideas from each stage of the SCOPE process. These tools are additionally helpful in many ways including helping students keep track of progress in longer design experiences, remembering decisions that were made and reasons why, and producing accessible artifacts.

Table 1

Defining Cognitive and Metacognitive Skills

Ability Underlying Skills	Definitions
Cognition	
Problem Scoping (i.e., Problem Framing)	Aspects of design involving identifying criteria, constraints, and requirements; framing problem goals or essential issues; gathering information; and stating assumptions about information gathered.
Alternative Solution	Thinking of potential solutions, experimenting with solution ideas, and thinking of ways to address an impasse.
Estimation/Prediction	Focusing on important factors; using data to inform; making informed decisions. Thinking before acting.
Modeling	Conceptual, Graphical, Mathematical, and Working Models
Experimentation	Robust procedure to check ideas and make determinations.
Continuous Evaluation (i.e., iteration)	Repetitive process of analysis. Transitioning through and between stages of design.
Metacognition	
Declarative Knowledge	Knowledge about a person's own cognitive strategies, skills, and abilities.
Procedural Knowledge	How to use strategies and techniques to increase performance and accomplish cognitive tasks.
Conditional Knowledge Planning	When and why to use strategies for accomplishing tasks. Ability to select appropriate strategies, set goals, and allocate resources.
Monitoring (i.e., self-questioning)	Assessing cognition and strategy effectiveness.
Organizing (i.e., information management)	The use of cognitive strategies and techniques to manage information. Information management is the active process of organizing, elaborating, summarizing, and selectively focusing on important information for mental restructuring due to cognitive dissonance.
Debugging	Identify and correct errors and assumptions about tasks and implemented strategies.
Reflecting	Analysis of performance and strategy effectiveness.

Table 2

SCOPE Process

What	How (suggestions)	Tool Examples for Recording Thoughts/Ideas
S: Study; the problem carefully.	Read Carefully. Clarify; look up any words or terms you do not understand. Self-question: What am I being asked to do? What is the problem? Re-state the problem in your own words. Explain the problem to someone.	System Map/Analysis Problem Statement Affinity Diagram Checklists
C: Criteria; what are the criteria for success?	What are the constraints, criteria, or requirements of the design? Make a list of requirements. Verify the list of requirements.	Perception Analysis Check Sheet Pareto Chart
O: Organize; what information do you have?	What information do you have? What does your information tell you about the problem? What options do you have? What can you control or adjust? What can you not control or adjust?	Pert Chart Lotus Diagram If...Then Consensogram
P: Predict; what predictions can you make?	What predictions can you make about each approach? How might doing X, Y, or Z affect the outcome success? What is your plan? Is this plan feasible?	Correlation Chart Process Decision Program Chart
E: Evaluate; which approach seems like it would yield the best result(s)?	Which approach seems like it would yield the best result(s)? What assumptions have you made? Select the approach that best seems to meet the criteria AND addresses the problem you identified.	Decision Matrix T-chart

Tower Design Challenge

It is important to remember that design experiences need to be scaffolded and progressive, from simple to increasingly complex problems over time. It should also be noted that the Tower Design Challenge is situated along the spectrum from well-defined to ill-defined engineering design challenges. The SCOPE process is applicable for all design experiences along this spectrum. Over time, as the students and teacher become increasingly comfortable with more complex problems, the teacher can begin to scaffold more complex design scenarios. The ill-defined end of the spectrum will have students define and solve their own problems in open-ended experiences. As the teachers look to introduce increasingly complex design challenges in the classroom, they will need to work collaboratively with their students in order to develop more sophisticated assessment criteria (Denson & Lammi, 2014). The tools used to document students' thinking as well as other student documents like engineering design notebooks, modeling artifacts, and students' justifications for design decisions can be used when appropriate to assess students' design learning.

Designing a tower given limited materials is a common design problem in middle and high school design experiences as well as engineering teacher professional developments. The tower design problem presented here is situated near the beginning of a spectrum from well-defined to ill-defined engineering design challenges. The tower design challenge asks for individuals to design and construct the tallest note card tower that will hold the most weight being placed on top of it before failure. The design challenge further explains that (1) participant is given 20 minutes to design and build, (2) the tower must be self-supporting during measurement, (3) material used is associated with a cost, and (4) the individual with the lowest score using the equation provided wins. Small note cards, 4" by 6", cost 3 points each. Large note cards, 5" by 8", cost 5 points each. Each inch of tape costs 10 points. The score equation is as follows: score = ((amount of tape in inches x 10) + (# of small note cards x 3) + (# of large note cards x 5) – (height of tower in inches) – (amount of weight held in pounds)).

In this case, understanding the tower challenge is more difficult than it might initially seem, emphasizing the importance of utilizing the SCOPE process. When reading the problem, it seems to suggest that both a tall tower and a tower that will hold the most weight are equally important. What is not immediately noticeable is that height of the tower and the weight the tower will hold are inversely proportional, especially considering the 20-minute time limit. During the tower design challenge students are scored based on the score equation. However, without the SCOPE process, students may completely ignore the score equation, starting to build a tower without fully understanding the problem. The SCOPE process helps students spend more time thinking about and analyzing the problem.

Conclusion

As researchers, we have witnessed a disturbing trend of student engineering design experiences that in many cases lack pedagogical structure including not adequately scaffolding the experience, resulting in an unfocused, disengaging, and inauthentic experience that may negatively impact students' development of underlying skills or abilities associated with design. The authors would hope that engineering design experiences in Technology and Engineering Education are the exact opposite. There is need for more empirically-based studies that investigate the effectiveness of design interventions to help develop students' cognitive and metacognitive abilities. It is our hope that the SCOPE process will be added to the lexicon of engineering design experiences in K-12 environments. We encourage readers to create their own research designs using research-based models (including SCOPE) as the field seeks to advance knowledge in the engineering education milieu. Early results from the implementation of the SCOPE process in facilitating middle and high school students' engineering design experiences provide evidence that the process is effective in scaffolding the experiences for students. More research is needed to understand the most effective evaluation tools for educators who seek to implement the SCOPE process in their classrooms. It is our hope to work with more practitioners willing to implement the SCOPE process in their classrooms. As the field of T&EE struggles to keep a foothold on its content in the 21st Century it is important that the field shines an iridescent light on all the things that we do well, including teaching problem-solving skills. This light is strengthened when scholars and practitioners work together to form a didactic learning community.

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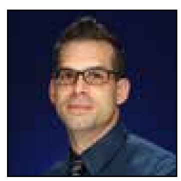

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This is a refereed article.

Explaining the SCOPE Process and Tower Design Activity

The process designers use during the initial stages of design is directly related to the success of design solutions. Expert engineers sort problems based on underlying concepts. Engineering students are distracted by surface details that lead to using inappropriate solution strategies. Incorrect problem definition inevitably leads to incorrect solution, both because students are misled by faulty conception of the problem and because they fail to realize that it is faulty, a combination of cognitive and metacognitive breakdown. This is exemplified by technology and engineering educators spending insufficient amounts of time on disposition, cognitive, and metacognition skill development while focusing primarily on knowledge and problem-solving techniques.

The SCOPE process is designed to help students slow down and thoroughly think through the design experience by studying the design situation, identifying the problem, identifying constraints and requirements, gathering and organizing information, making predictions based on design decisions, and evaluating and selecting the best approach based on information analysis. SCOPE is an acronym for Study, Criteria, Organize, Predict, and Evaluate. The SCOPE process is intended to be used with any design experience. All design experiences should start with the SCOPE process to improve outcome effectiveness. The SCOPE process is designed to promote students' success throughout any design experience. Additionally, the SCOPE process should be continuously revisited throughout iterative design experiences.

In the Tower Problem-Solving Activity students are distracted by many items including the 20-minute time limit and equation, just to name two. When students are given this problem and without using the SCOPE process, a significantly lower percentage of the students will develop the most optimized answer, mostly related to surface-level details or distractions. If you remove any of these distractions, like not having students work in a group, the success rate will increase. Why does this happen? Students are not spending a significant enough amount of time where thinking is involved, specifically studying the design situation, identifying the problem, identifying constraints and requirements, gathering and organizing information, making predictions based on design decisions, and evaluating and selecting the best approach. The Tower Problem-Solving Activity is used as an introductory activity to help students learn to work with distractions and still develop a successful answer. Rather than removing distractions that will always be present, it is better to help students utilize the SCOPE process to enhance their ability to successfully solve engineering design problems. The students are given the knowledge needed to develop the best answer to the Tower Problem-Solving Activity: the equation. However, without the SCOPE process, students ignore the equation and implement faulty problem-solving techniques. Based on the equation, the best answer is not building the tallest tower; the best answer is building a tower that will support the most weight. The height of the tower and weight the tower will hold are inversely proportional.

If you look at the equation while thinking through possible solutions, you should see that the tallest the tower could be is the height of the classroom, maybe 120 inches. Again, if you build a tower that is 120 inches tall, it will likely not hold much weight before failure. However, if you build a short, even paper-thin tower, it will hold more than 120 pounds without failing. Based on the constraints, including the time limit and equation, the most optimized answer is to lay a few note cards flat on the floor in a way that will allow the weight to be stacked on top.

Tower Problem-Solving Activity

Individually you are to design and construct the tallest note card tower that will withstand the most weight being placed on top of it before failure. You will have 20 minutes to design and build the tower. Each material used during the construction of the tower is associated with a point value.

Small Note Card	3 Points
Large Note Card	5 Points
1 inch of Tape	10 Points

Scores will be calculated by:
Score=(# inches of tape x 10)+(# of small note cards x 3)+(# of large note cards x 5)-(height of tower [in inches])-(amount of weight held [in pounds])

Note: The individual with the lowest score wins.

design tools and judgments of high school students

by Todd R. Kelley and Jung Han

"Design judgment making is the ability to gain subconscious insights that have been abstracted from experiences and reflections, informed by situations that are complex, indeterminate, indefinable, and paradoxical" (Nelson & Stolterman, 2012, p.145).

In engineering and technology education (ETE), engineering design is a key to educate students to develop critical thinking, creativity, problem-solving abilities, and communication skills through project-based learning. Within project-based engineering and technology education (ETE), the design and design judgments should be taught explicitly and practiced intentionally for the students to better understand their projects and finally become skillful designers (Nelson & Stolterman, 2012). However, design and design judgment are complex and situational, so these should be understood in consideration of the whole context where the design activity is situated (Holt, 1997; Nelson & Stolterman, 2012). Nelson and Stolterman (2012) noted that the previous practices are essential to the judgment, saying that "Judgment is…dependent on the accumulation of the experience of consequences from choices made in complex situations" (p. 139) and emphasized the complex relationship between designer and client in judgment making. In short, judgments are made during the design process, and designers should consider the whole context and all systemic relationships to make good judgments (Nelson & Stolterman, 2012).

Engineering design education should aim to develop learners' design capability that includes design judgment ability, which can be applied to real-life situations and enhance problem-solving skills.

These designs and design judgments are complex and situational, so there is a need for an understanding in consideration of the whole context.

"Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" (Dym, Agogino, Eris, Frey & Reifer, 2005, p. 104). Therefore, good designers: (1) view design as an iterative process of divergent-convergent thinking; (2) possess systems thinking; (3) manage uncertainty and make a decision, and; (4) think and communicate with a team and clients in a social process (Dym et al., 2005). Also, good judgment in engineering design includes commercial potential, and the success of a design is eventually judged in the marketplace or industry (Holt, 1997).

As design is contextual, design judgment should be made while considering the specific context of the problem. Specifically, design judgment in engineering needs to consider optimum solutions determined by industry, which is one particular context in which engineering design is embedded (Holt, 1997). Nelson and Stolterman (2012) also noted that "the meaning of the whole, in relation to judgment and design, is one of the most crucial aspects of design" (p. 157).

As discussed above, the design and design judgments are core activities in design education. However, with the complex nature of design and judgment, how to teach design and help students make good judgments is not always clear, and students struggle to make design decisions (Kelley, 2014; Kelley, Capobianco, & Kaluf, 2015; Kelley & Sung, 2017). Particularly, "as designers, we face situations where we have to make an overall judgment on the quality of a specific material used in a design. At other times, we must judge how the chosen parts of a design fit together as a whole—as composition and functional assembly" (Nelson & Stolterman, 2012, p. 146). In relation to this issue, Nelson and Stolterman (2012) proposed design judgment types that provide design practitioners with well-structured design judgment strategies that can guide the designer.

This study investigated high school students' design toolsets and their corresponding judgments. The purpose of this study was to examine an integrated STEM lesson to *assess learner's design capacity, which encompasses design judgment ability.* Since design judgment is difficult to teach and learn, identifying what learners choose when they face problems and how they improve their solutions through decision making will be critical for teachers to understand students' learning needs. With this purpose in mind, the researchers explored what judgments are made behind students' design-tool choices by examining the design activity of high school students. In this case example, researchers assess students' tool choices and design judgments observed during one class session using researchers Nelson and Stolterman's (2012) typology of design judgment to assess students' design decision making (Table 2).

The participants were high school science and ETE students in the context of a three-year-long (2016-2019 school years) integrated STEM education project titled *Teachers and Researchers Advancing Integrated Lessons in STEM* (TRAILS) (National Science Foundation [NSF] award #DRL-1513248). The results of this study were conducted in the third year of TRAILS, the 2018-2019 school year.

The current study observed one of the TRAILS classes, an integrated STEM class of one environmental science and one engineering class. Both a science and ETE teacher from each class collaborated to teach these integrated science and engineering design-based units.

This one-time observation cannot capture the overall TRAILS student design activities across classes and their design abilities and, therefore, the authors cannot generalize about the results to the greater population but can provide these results as a case example of observing students' design judgments.

Table 1 demonstrates the participating students for the current study.

Design Activity

For this study, the researchers analyzed students' choices on design tools such as design sketches, traditional prototyping tools, computer-aided design (CAD) software, and so on. The high school design teams consisted of two groups of students: an engineering and technology class (ETE) and an environmental science class. A high school science and an ETE teacher taught three TRAILS lessons collaboratively using an integrated STEM approach.
For the current study, the researchers observed and analyzed the Clean Sweep unit (www.purdue.edu/trails/clean-sweep) (TRAILS,

Table 1

Participating Students

Gender		Subject		Ethnicity	Sum
Male	Female	Science	ETE	White	
6 (27%)	16 (73%)	9 (41%)	13 (59%)	22 (100%)	22 (100%)

Note. All students submitted IRB consent forms.

n.d.). This unit challenged students to work in a cross-curricular team (science and ETE students) to design, build, and test a biomimicry-inspired engineering design solution to collect plastic pollution from an aquatic habitat (*Standards for Technological and Engineering Literacy* [*STEL*], [ITEEA 2020] – TEC 6, TEC 8; *Standards for Environmental Science and Technology* – Env. 5.5, 5.7, 8.7) (Indiana Department of Education, 2016). During the lesson, students: (a) learned how to describe and illustrate the feeding relationships of aquatic food webs; (b) communicated environmental issues of plastic pollution in marine habitats in a mass media format; (c) predicted buoyancy of an object using mathematics and predictive analysis; and (d) modeled, illustrated, and annotated the biological processes of the whirligig beetle. The Clean Sweep lesson adopted the SeaPerch structure to implement the neutral buoyancy concept in the design and add biomimicry features of a whirligig beetle that navigated on the surface of the water in a whirling motion (SeaPerch, n.d.; www.seaperch.org).

The researchers visited this class for six observations, with a total of 540 minutes (9 hours), from September 28, 2018 to March 8, 2019. The current paper focuses on the fourth observation, which was on February 13, 2019.

On the day of observation, the students were working in teams consisting of four to five students. The progress of each team was different, and the researchers focused on one team that was furthest in the progression. This team already had finished sketching, CAD design, and 3D printing in the previous classes and was assembling 3D-printed parts to the main body (SeaPerch).

Table 2

Summary of Design Judgments Typology (Nelson & Stolterman, 2012, pp. 148-157)

Design Judgment	Description
Framing Judgment	▪ "The entry point…into a design process… which includes a judgment of who the clients are." ▪ "Determine the adequate and essential condition for design to take place." ▪ Overall formation of the design process and outcome.
Default Judgment	▪ Action taken without deliberation; automatic response to a situation. ▪ Resembles instinct, but is different in that default judgment "can be refined and modified, or replaced by new ones." ▪ A sign of expertise. ▪ Default judgments are "accessible through the process of deliberate off-hand judgments."
Offhand Judgment	▪ Learning the use of tools until experienced, which leads to default judgment. e.g., "Learning how to ride a bicycle begins with full attention and deliberation until our judgments of balance become second nature and no longer require subconscious attention"
Appreciative Judgment	▪ "A matter of appreciating any particular situation…It is a process of assigning importance to some things…This form of judgment is key in the determination, or appreciation, of what is to be considered as context in a design situation."
Appearance Judgment	▪ Taste, style, nature, character, etc. ▪ Quality judgment ▪ Decisions regarding quality ▪ "It is a matter of the choice of materials…and precision and skill in crafting materials."
Instrumental Judgment	▪ Technique, technology, etc. ▪ "Considers not only technique and which instrument to use, but proportion and gauge, as well."
Navigational Judgment	▪ Making choices in an unpredictable environment. ▪ " It is the ability to formulate essential situational knowledge that is applicable to the conditions of the moment." ▪ Important to managers.
Compositional Judgment	▪ "Bringing things together in a relational whole" (Synthetic judgment). ▪ "This whole displays the qualities, attributes, nature, and character particular to an ultimate particular."
Connective Judgment	▪ "Makes binding connections and interconnections between and among things so that they form functional assemblies transmitting their influences, energy, and power to one another." ▪ "Connective judgment along with compositional judgments are therefore seminal to the creation of that which is not yet in existence."
Core Judgment	▪ "A composite of meaning and value, formed during the experience of living." ▪ Meditative judgment. ▪ Mediating different judgments into a holistic consequence.

Design Judgment and Designers' Tools

On the day of observation the design team spent most of the time on assembly. The group of five students (two female and three male) used a design brief, sketches, decision matrix, and engineer's notebook in the previous classes for problem framing (framing judgment, see Table 2). The team's custom parts were designed and 3D printed, so using traditional prototyping tools, the team focused on assembling these parts to the existing SeaPerch frame. Students used traditional assembly tools such as wrenches and drills skillfully (default judgment, see Table 4) and chose the various tools appropriately, depending on the situation. Some students, who seemed not to have experience in using a soldering iron, learned how to use it from their peers by watching and imitating their skills (offhand judgment, see Table 4). The students kept discussing the prototype they were assembling and making judgments to improve their final product. In this process, some plans were changed or modified (making a judgment as a converging process). The initial sketch for the overall design plan was done previously, but the team modified the sketch or drew new parts while they were discussing design ideas. Some materials (e.g., glue did not stick well because it was not waterproof) and tools were not effective for certain tasks, so they changed those as necessary. Trial-and-error and peer discussions played an important role in these decision-making processes.

Designers' Toolset

There are many judgments in design, and the researchers adopted Nelson and Stolterman's (2012) typology of design judgments to investigate high school students' design toolsets and their corresponding judgments. Nelson and Stolterman (2012) noted that people use judgments "to deal with the problems, questions, and challenges they face" (p. 145). For example, framing judgment is used for the "overall formation of the design" process and determining essential conditions considering the potential outcome. Appearance judgment includes "determination of style, nature, character, and experience." Additionally, instrument judgment considers technology and technicalities (Nelson & Stolterman, 2012, pp. 148-157).

Table 2 summarizes the typology of 12 different design judgments that Nelson and Stolterman (2012) created. The researchers only focused on eight judgments that were witnessed during the observation (Table 3, next page).

Table 3 demonstrates the design tools that the students used during the design process and possible corresponding judgments (Nelson & Stolterman, 2012) that they could make while using the tools.

Design Judgment and Related Tools

The results from the overall observation show that students used tools explicitly or tacitly by means of discussion, action, drawing, and so on. Table 4 (page 19) demonstrates Nelson and Stolterman's (2012) design judgment types that are related to the tools used by the students. Table 4 also indicates the design behaviors of the students in relation to their design tool usage.

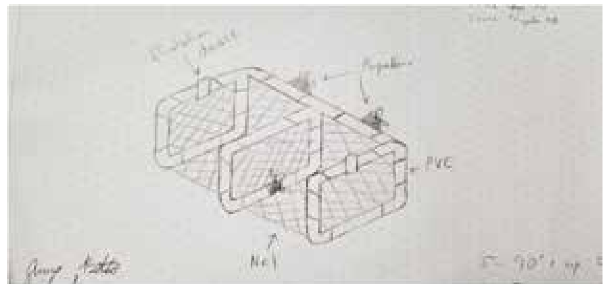
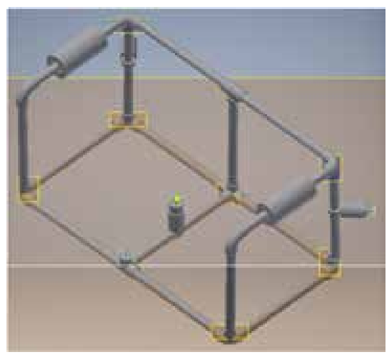
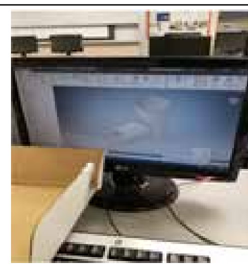
Discussion

Design tools and designer's judgment are the cores of the design, and a designer's design capacity can be increased by enhancing their design judgment as well as the ability to use tools while crafting prototypes and final design solutions. In this study, student design teams used a variety of tools to produce quality design products. Their conscious and unconscious design judgments (Nelson & Stolterman, 2012) were connected to problem framing, finding a solution, and deciding on tools, materials, and processes necessary to craft a prototype.

As Nelson and Stolterman (2012) stated, design is complex. Therefore, a designer's judgment is essential in the design process since design judgment is a convergent process that "brings diversity and divergence into focus…and gives form and comprehension to aspects of messy and complex real-world situations" (p. 144). Moreover, a designer's judgment leads the undefined situation to "a

Table 3

Design Tools and Possible Corresponding Judgments that Can Be Made Using the Tools

<table>
<tr><th>Design Tool</th><th>Possible Corresponding Judgment</th></tr>
<tr><td>Design Brief</td><td>Framing judgment – Overall design formation. Identifying clients' needs to establish constraints and criteria of the design.</td></tr>
<tr><td>Sketches</td><td>Appearance judgment – style, nature, character
A student design sketch example

</td></tr>
<tr><td>Decision Matrix</td><td>Framing judgment – Overall formation of the design process and determining the potential outcome. Determining essential conditions and deciding the best choice using a design matrix, which assesses the various design ideas. Students set weights of constraints and criteria.
Clean Sweep
<table>
<tr><th>Criteria</th><th>Weight (%)</th><th>"Diver" Solution on Idea</th><th>"Ramp" Solution on Idea</th><th>"Flap" Solution on Ideas</th></tr>
<tr><td>Available spaces</td><td>15%</td><td>5</td><td>3</td><td>4</td></tr>
<tr><td>Development Time</td><td>15%</td><td>3</td><td>5</td><td>4</td></tr>
<tr><td>Submersible?</td><td>15%</td><td>2</td><td>1</td><td>1</td></tr>
<tr><td>Emptying Efficiency</td><td>5%</td><td>4</td><td>5</td><td>2</td></tr>
<tr><td>Constraints</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Biomimicry</td><td>25%</td><td>2</td><td>2</td><td>3</td></tr>
<tr><td>3D Piece?</td><td>25%</td><td>1</td><td>2</td><td>2</td></tr>
<tr><td>Total</td><td>100%</td><td>2.45</td><td>2.85</td><td>2.7</td></tr>
</table></td></tr>
<tr><td>CAD Software</td><td>Instrument Judgment – technic, technology
</td></tr>
<tr><td>3D Printer</td><td> </td></tr>
<tr><td>Traditional Prototyping Tools for Assembly (soldering iron, wrenches, wire cutters, strippers, etc.)</td><td>Instrument Judgment – technic, technology
</td></tr>
</table>

concrete particular understanding and concomitant action, within a specific contextual setting." Thus, designers need to make sound judgments to be able to take proper actions that lead to appropriate change (Nelson & Stolterman, 2012, p. 146). Design judgment is connected to decision making, and the right decisions made by a designer lead to a good design (Holt, 1997; Nelson & Stolterman, 2012), which is also a key part of technological and engineering literacy (*STEL* Core disciplinary Standard 7: Design in Technology and Engineering Education). *Standards for Technological and Engineering Literacy* (*STEL*) noted that "there is often no single, correct solution in technology and engineering design; furthermore, designs can always be improved and refined" (ITEEA, 2020, p. 52).

ETE teachers can help students learn to make informed decisions by teaching them how other designers make decisions based on constraints and criteria. Engineering technology teachers can require students to keep engineer's notebooks (Kelley, 2011) and require design thinking reflection and defend design decisions. ETE teachers should require design teams to create a decision matrix to quantify the final design decision based on their team's identified constraints and criteria (Kelley, 2010). This requirement challenges students to consider client needs, industry standards, and specific context requirements.

In the case of the Clean Sweep unit, students were challenged to consider how a whirligig beetle navigates across the surface of the water as they worked to create a biomimicry design solution, customizing a SeaPerch unit. The team continuously made judgments by discussion, tool choice, change of materials, and so on while assembling the parts of the Clean Sweep design and testing afterwards. While assembling, they switched the tools as needed and asked each other for their opinions of the proper tools to use for the specific application. When the student design team experienced obstacles during the design construction, they tried to make the right decision to solve the problem and improve their design, which is evidence of the iterative process of design. To give an example, one design team member said, "The initial design was able to float easily on top of the water, but it would not pick up pollution easily… the netting was too high up and not enclosed. So, we added tubes of sand on the front to lower the edge of the netting and cut the blue floats in half and moved them around…" (TRAILS student reflection). This comment demonstrated that the design team tried to

Table 4

Design Judgment and Related Tools

Design Judgment *	Tools	Observational Evidence Students:
Framing judgment - Overall formation of the design process and outcome	▪ Design Brief (Criteria & Constraints) ▪ Decision Matrix	▪ Discussed clients' needs using the design brief and created a decision matrix to meet the criteria and constraints.
Default judgment - Action taken without deliberation	▪ Traditional assembly tools (wrench, drill, screwdriver, etc.)	▪ Used assembly tools that they can use from the previous experiences.
Offhand judgment - Learning the use of tools until experienced, which leads to default judgment	▪ Soldering iron	▪ Novice to using soldering iron learned from peers how to complete the circuit using this tool.
Quality judgment - Craftsmanship, material choice	▪ SeaPerch kit (PVC pipes, netting, connectors, motors, film canisters, propellers), net, etc.	▪ Discussed material choices and changed materials based on test results (e.g., glue did not stick well and was not waterproof).
Appearance judgment - Taste, style	▪ Sketches	▪ Discussed the appearance of the prototype. They used drawings to change some designs.
Compositional judgment - Bringing things together in a relational whole (Synthetic judgment)	▪ Decision Matrix (develop solution)	▪ Students created a decision matrix to choose the best solution for the current conditions.
Instrumental judgment - Technique, technology, etc.	▪ CAD software ▪ Traditional tools	▪ Students used technology tools using appropriate techniques.
Core judgment - Composite of meaning and value, formed during the experience of living	▪ Shared experience, modified value (manifested during engineering design process; brainstorming, testing, evaluating, redesigning)	▪ Students shared their experiences and design values (e.g., environmental-friendly, safety, etc.) while discussing their design.

*Note. *Adopted from Nelson & Stolterman, 2012, pp. 148-155* improve their design through design judgment, leading to making a final design decision based on results of testing and redesign.

What we should teach and what goals educators need to set are fundamental questions in education. In engineering and technology education, design instruction leads students to design expertise, enabling students to exploit ideas developed from complex authentic practices of scientists, engineers, technologists, and professionals using mathematical analysis as well as contextual knowledge (*STEL*-1Q). In sum, design judgment and design expertise are meaningful in that those are essential not only for design solutions but also in human life. Thus, researchers and educators should explore the challenges students face during the design process and what judgment they make for the final design to better help students advance their design abilities.

ETE teachers can help guide and promote decision making, from selecting the best design idea to using the proper tools and materials for the right application. ETE teachers can also help build students' capacity in making these decisions by structuring design challenges moving from crisp teacher-created design briefs toward open-ended, ill-defined engineering design challenges. Proper engineering and technological literacy development will require students to learn to make these decisions on their own. However, it requires multiple teacher-guided design experiences before students are ready to move toward open-ended real-world engineering design that they must frame on their own. Additionally, engineering technology teachers can help students understand the practices they are engaging in, which are the same practices used by STEM professionals. It is important to help students make the connections to what they are experiencing in STEM lessons with STEM workforce skills so that students are empowered to consider STEM careers as a future career pathway.

In conclusion, design is complicated and requires a lot of decisions. This case study explored, through categories of design judgments created by Nelson and Stolterman (2012), what kinds of design judgments can be made while students are using design tools. The results show that not only technology tools but also the design brief, design matrix, drawing, and discussion are all critical design tools. The authors hope that this case observation informs ETE teachers of the need for teaching how to use various design tools safely and effectively to make quality design judgments, which will help students enhance design capacity and design judgment abilities and lead to more technologically literate individuals.

NSF Disclaimer

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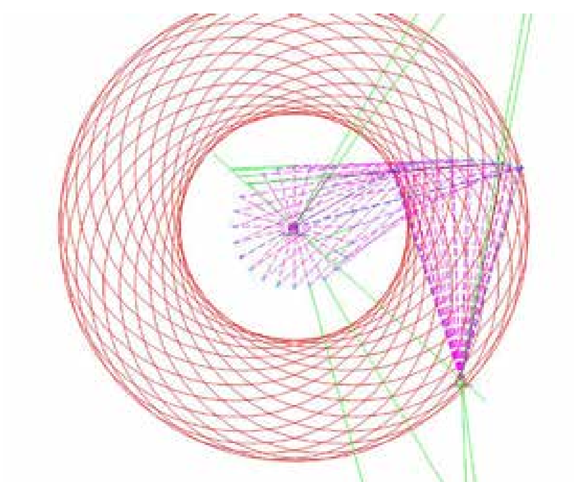
This is a refereed article.

mechanism design and analysis:

developing an understanding of mechanism motion through graphical modeling

by Andrew J. Hughes and Chris Merrill



The design of mechanisms is important for many common activities in technology and engineering education.

The intention of this article is to provide Technology and Engineering Educators (T&EEs) with foundational knowledge of mechanism design and analysis and the ability to develop middle and high school students' mechanism knowledge during practical hands-on learning activities in the STEM classroom. T&EE's implementation of mechanism design and analysis could promote students' increased depth of mechanical knowledge and ability to apply this knowledge during engineering design challenges. In this article, the authors present an introduction to four-bar mechanism design and analysis using CAD software to produce graphical representations. After designing mechanisms graphically, students should be allowed to produce their mechanisms using tools like 3D printers.

Mechanical Engineering as a discipline started during the industrial revolution in Europe around the late 1700s and early 1800s; yet the application of mechanical devices like wedges dates to the Prehistoric era. Throughout the Prehistoric and Ancient eras, simple mechanical devices like the lever, wheel and axle, pulley, inclined plane, wedge, and screw, now known as simple machines, were increasingly used. In practice, the words machine and mechanism are frequently used interchangeably, yet there are clear but subtle differences. Complex machines are combinations of two or more simple machines. **Machines** are associated with the ability to do work involving the transmission of energy and transformation of forces, *but not motion*. An internal combustion engine is an example of a machine that includes several different mechanisms. **Mechanisms** are systems made up of rigid bodies that are connected and arranged in a specific way *to produce a desired motion*. A mechanical watch is an example of a mechanism. Machines and mechanisms inhabit the same body, and, when combined during design, include consideration of motion and force to accomplish a specific objective. Another example of a machine that has multiple mechanisms is a person riding a bicycle. The person's leg and the bike's crank, seat tube, and post make a four-bar mechanism. Additionally, bicycles have gear train mechanisms.

Throughout the Ancient, Medieval, and Modern Eras developments in technology, mathematics, physics, and material science helped shape our understanding of the human-made world. For example, the basic concept of mechanical advantage was previously utilized but the concept was not formally expressed until Archimedes (287 BCE–212 BCE). Other concepts related to simple machines like mechanical trade-offs, statics, and dynamics of mechanical devices were not expressed until around the late 1500s and later. Mechanics is usually divided into two branches, fluids and solids. Solids is then divided into rigid and deformable bodies; rigid bodies into

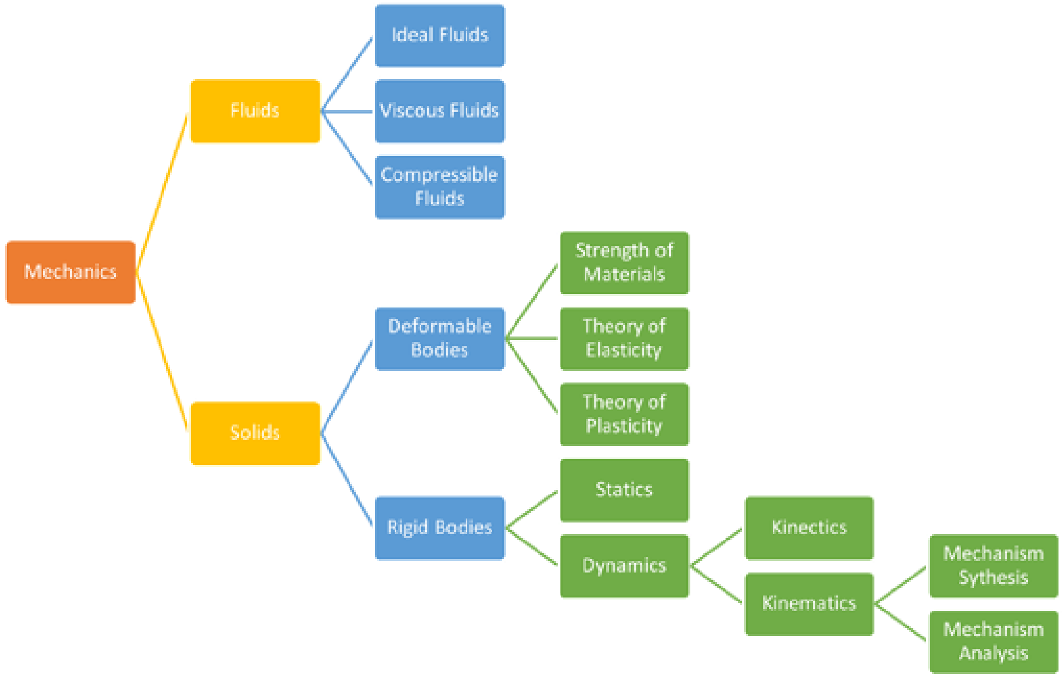


Figure 1.
Branches of Mechanics

statics and dynamics, and dynamics into kinetics and kinematics (Barton, 1982) (Figure 1).

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

Kinematics

In the study of kinematics, it is important to begin by developing an understanding of the motion characteristics for given mechanisms (i.e., mechanism analysis). To help students develop an understanding of motion characteristics, teachers can have students use CAD software to draw graphical models of various common mechanisms. Then teachers can have students design and produce their own mechanisms. Finally, teachers can add analysis of velocities and accelerations to the understanding of motion using methods like effective component, instant center, relative, difference, calculus, graphical, and/or any combination of these methods.

Figure 2 is a four-bar mechanism (i.e., four-bar linkage). In Figure 2, *Label 1* represents *Member 1*. Member 1 represents both fixed points of rotation (i.e., the mechanism's frame). *Label 2* represents *Member 2* (i.e., the crank). *Label 3* represents *Member 3* (i.e., the coupler). Finally, *Label 4* represents *Member 4* (i.e., the follower). The connections between members 1 and 2, 2 and 3, 3 and 4, and 1 and 4 are considered pivots as well as *kinematic pairs*, and more specifically *lower pairs*. Lower pairs have surfaces in contact; for example, the *pivot* surface of member 3 is in contact with the *pivot* surface of member 4. There are also *higher pairs*. Higher pairs only have one point in contact, for example a cam and follower.

To determine the motion characteristics of this four-bar mechanism, students will create a graphical model similar to Figure 2 using CAD software. The students will be able to conceptually picture the four-bar mechanism's motion by creating graphical drawings representing every 15 degrees of Member 2's rotation (Figure 3).

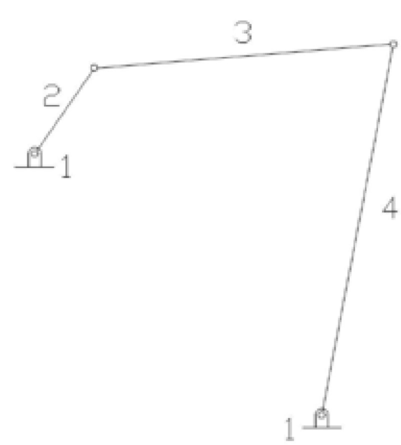


Figure 2.
Labeled Four-Bar Mechanism

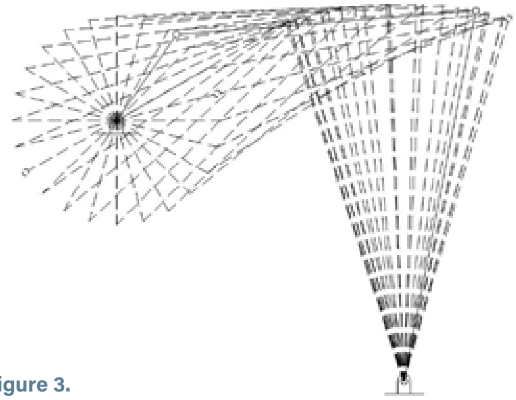


Figure 3.
Motion Characteristics

The students can use different layers, line color, and line type to have a colorful, some might say artistic, graphical representation of the four-bar mechanism's motion (see image on page 21). At this point students start to make connections between the graphical representation and the actual motion of a four-bar mechanism. This is a good time to show students a four-bar mechanism that the teacher has made based on Figure 2. The four-bar mechanism the authors used was made from wood, but the mechanism could also be 3D printed (Figure 4). Additionally, mechanisms could be made using construction paper or cardboard. Figure 5 represents the extent of this four-bar mechanism operation. In Figure 5, Member 2 is graphically rotated until Member 4 is as far left and right as possible based on the current mechanism design (i.e., the relationship between Members 1, 2, 3, and 4).

Figure 4.
3D-Printed Four-Bar Mechanism

After students spend time using CAD to graphically understand a mechanism's motion and are in the process of developing conceptual understanding, the mechanism can be modified by the students using CAD to see the impact of specific changes to the mechanism's motion. There are two common changes that help students further develop conceptual understanding of a mechanism. The most common is inversion. For example, in Figure 2, Member 1 is the frame or fixed member. The students could allow Member 1 to move and could fix any one of the other members one at a time. This is called inversion and completely changes the mechanism's motion. The other common change is the length of any one member at a time.

The four-bar mechanism in Figure 2 can also be considered a *constrained kinematic chain*. Gruebler and Kutzbach's criterion (i.e., mobility formula) are similar and are used to describe the mobility of a mechanism. Gruebler's equation is used to calculate the degrees of freedom, $F=3(n-1)-2l-h$. Where *F* is the total degrees of freedom, *n* is the number of links, *l* is the number of lower pairs, and *h* is the number of higher pairs. In Figure 2, the four-bar mechanism, there are four (4) links and four (4) lower pairs for a total of one (1) degree of freedom. This basically means that only one member needs to be controlled in order to control the motion of the entire mechanism. Knowing the degrees of freedom will help students determine if the kinematic chain is locked, constrained, or unconstrained. A locked mechanism has zero degrees of freedom. A constrained mechanism has one (1) degree of freedom, like the four-bar mechanism, meaning that one input produces defined relative motion between all links (Figure 3). An unconstrained mechanism is one with two or more degrees of freedom, meaning that one input will result in the mechanism's links taking undefined paths.

Instantaneous Centers

The instantaneous center method (i.e., instant center method) or velocities by centro method is the technique to calculate the veloc-

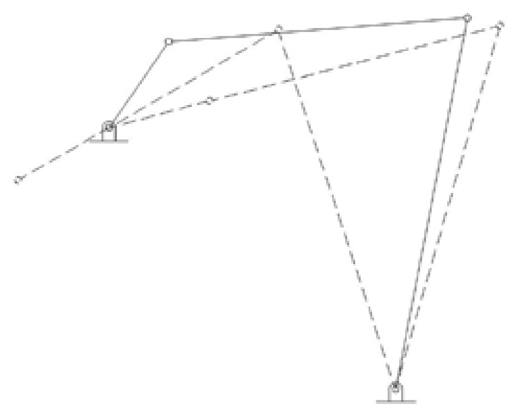


Figure 5.
Four-bar Mechanism Extents

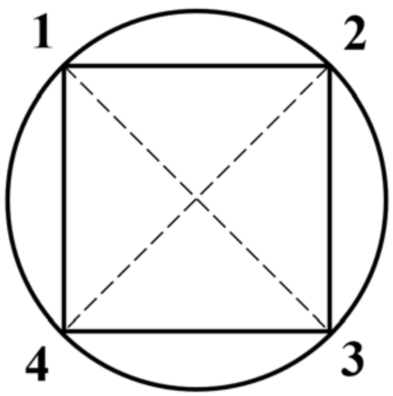


Figure 6.
Four-bar Mechanism Instant Centers

ities of a mechanism's members based on the dimensions of the mechanism. The instant center method helps to describe a mechanism's motion at any given instance as rotational motion around an instant center (i.e., point). An easy way to think about an instant center (i.e., centro) is as a point around which the members of the mechanism rotate. For simple mechanisms, the ability to analyze the mechanism is greatly simplified by the ability to visualize members' rotation around points. The key to the instant center method is finding and visualizing these instant center points that members are rotating around. The process of finding these instant centers is quite simple. The students must determine how many of these instant centers exist using this equation: number of instant centers = $\frac{(n\,(n\text{-}1)}{2}$, where n is the number of members in the mechanism. For the four-bar mechanism in this article, there are four members which, based on the equation, means there are six instant centers.

The students will use Kennedy's theorem and the derived circle method to determine the labeling and location of the 6 instant centers (Figure 6). Figure 6 shows a circle diagram, where the numbers 1, 2, 3, and 4 represent members in the four-bar mechanism.

The solid lines between 1 and 2, 2 and 3, 3 and 4, and 1 and 4 represent known instant centers, or instant centers that are easily visible (i.e., primary centros) (Figure 7).

The hidden line between 1 and 3 and 2 and 4 represent instant centers that need to be located (i.e., secondary centros) (Figure 8). In Figure 8, all instant centers are visible. Kennedy's theorem basically states that any three bodies (i.e., members) having plane motion relative to one another have three instant centers, and the instant centers all lie on a straight line. For example, in Figure 8, you can see that members 1, 2, and 3 have instant centers 12 (said as *instant center one two*), 23, and 13. In Figure 8, you can see that instant centers 12, 23, and 13 all lie on a straight line; this is basically Kennedy's theorem.

There are 3 different types of instant centers. Instant center 12 and 14 are *fixed* instant centers because they exist on fixed points

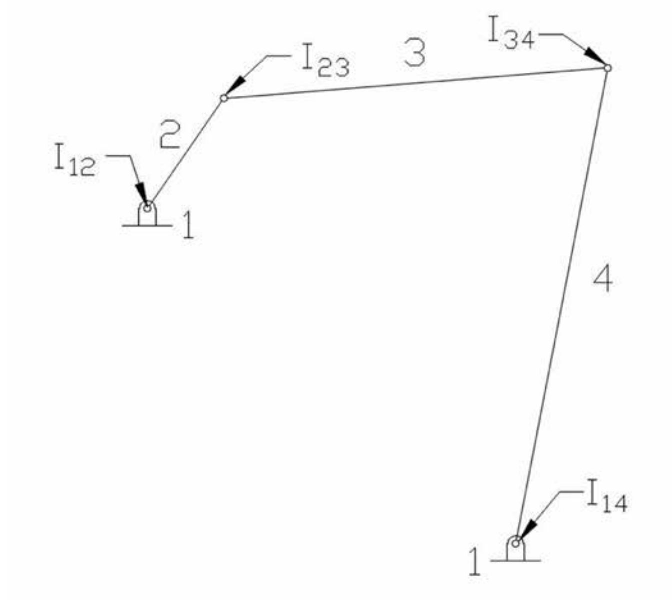


Figure 7.
Known Instant Centers

around which members 2 and 4 rotate. Instant centers 23 and 34 are considered *permanent* instant centers. Member 2 is always connected to member 3 and instant center 23 permanently exists in a circular path (i.e., centrode) defined by the rotation of member 2 and curvilinear motion of member 3. Additionally, member 3 is always connected to member 4, instant center 34 permanently exists along an arched line (i.e., centrode) which is defined by rotational

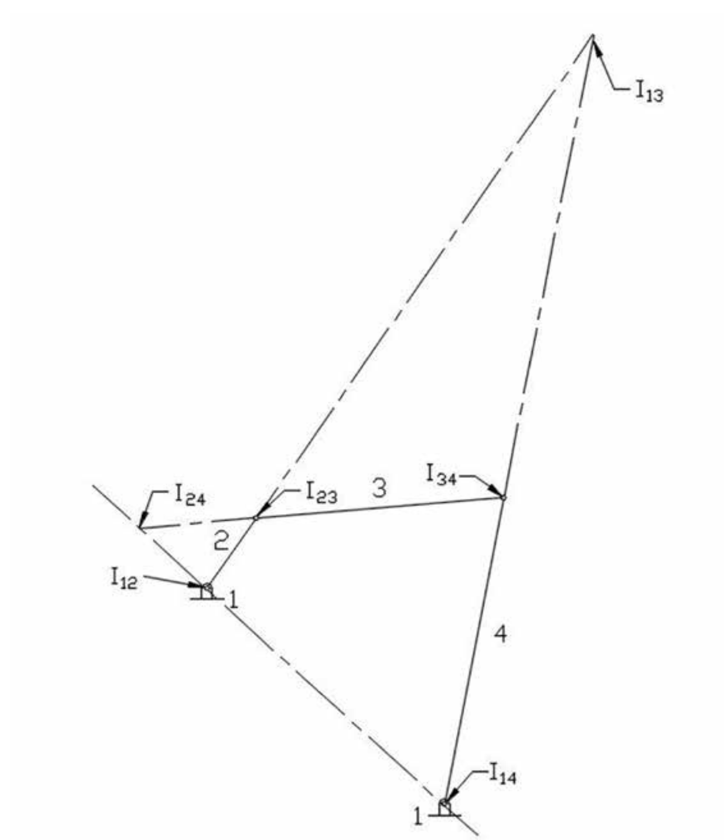


Figure 8
Instant Centers Located

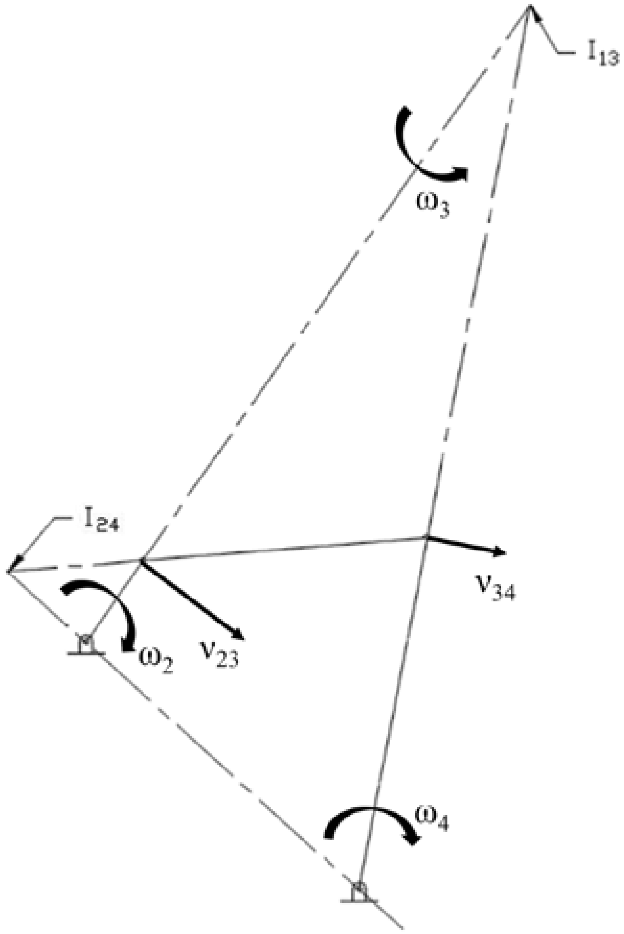


Figure 9
Link to Link Method

motion (i.e., oscillation) of member 4. Instant centers 13 and 24 are considered *imaginary* instant centers, which exist outside the mechanism at instances of the mechanism's operation and have similar characteristics as fixed or permanent instant centers. Instant centers 13 and 24 move along the corresponding center lines as the mechanism moves (Figure 8).

Determining Velocities Based on Instantaneous Centers

When first learning to analyze the velocities of a mechanism's member, students must have developed the ability to graphically and conceptually visualize the mechanism in terms of pure rotation as well as the application of the appropriate mathematical techniques. When educators are applying the instant center method in their classrooms, it is important to start with the graphical visualization and then further progress with the conceptual visualization of a mechanism's motion. The use of CAD software really helps encourage this progression. The next step is applying simple mathematical relationships to determine the velocities of the mechanism's members during specific instances of the mechanism's motion.

Link to Link Method

Using the instant center method allows the student to determine velocity by converting rotatory motion into rectilinear motion. For analysis, converting rotatory motion into rectilinear motion requires the student to determine the radius graphically and visualize that linear velocity acts tangential to the path of rotation (Figure 9).

For example, the linear velocity v_{23} is equal to the length of member 2 multiplied by angular velocity of member 2 (v_{23}=length of member 2 x ω_2) (Figure 9). If Member 2 is 1 inch long (distance determined in CAD) and rotating clockwise at a constant angular velocity of 200 revolutions per minute (RPM), v_{23} is equal to 200 inches per minute (in/min). Instant center 23 can also be treated as point on Member 3. Member 3 has the instant center 13, therefore the angular velocity of member 3 (ω_3) is equal to v_{23} divided by the distance between instant centers 23 and 13

$$\left(\omega_3 = \frac{v_{23}}{\text{distance between 23 and 13}}\right)$$

. The angular velocity ω_3 is equal to 200 in/min divided by 6.83 inches or 29.28 RPM. The linear velocity v_{34} is equal to the distance between instant centers 13 and 34 multiplied by angular velocity of member 3 (v_{34}=distance between 13 and 34 x ω_3). Therefore, v_{34} is equal to 5.47 inches multiplied by

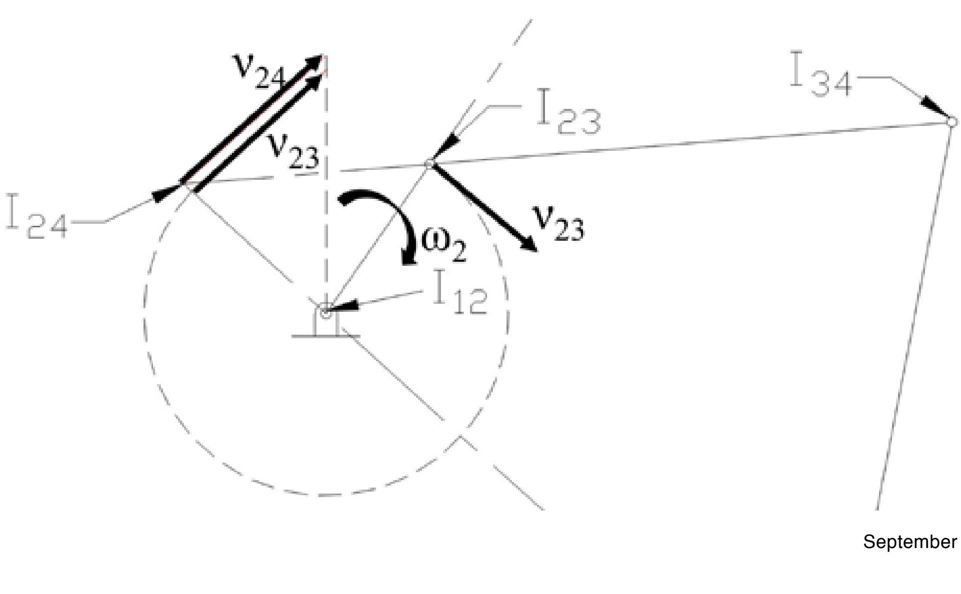


Figure 10
12, 23, and 24 Radius of Rotation Triangle

29.28 RPM or 160.16 in/min. Finally, angular velocity of member 4 (ω_4) is equal to linear velocity $v34$ divided by the length of member 4 $\left(\omega_4 = \frac{v_{34}}{\text{length of member 4}}\right)$.

Angular velocity ω_4 is equal to 160.16 in/min divided by 3.62 inches or 44.24 RPM. In certain instances of member 2's rotation, it will be impossible to determine the distance from imaginary instant centers to the fixed or permanent instant centers. This distance could be infinite or too large to practically dimension using CAD software. In these cases, the link to link method may not be appropriate and a different method is needed.

Radius of Rotation Method

Another common method associated with determining velocities using instant centers is the *radius of rotation method*. The radius of rotation method is being applied here with the assumption that the distance to instant center 13 cannot be easily determined. Using the radius of rotation method, velocities are proportional based on each velocity's radius of rotation. For example, if one velocity is known, another velocity can be determined using mathematical or graphical proportions. In the four-bar mechanism, there are 3 links that move, links 2, 3, and 4. Each link has 3 instant centers. For example, link 2 has instant centers 12, 23, and 24 (Figure 10); link 3 has instant centers 13, 23, and 34; and link 4 has instant centers 14, 24, and 34 (Figure 11).

Notice that these instant center groupings form triangles. Given the angular velocity of member 2 ($\omega 2$), the linear velocity $v23$ can be determined as in the previous section ($v\_23=\text{length of member 2 x } \omega\_2$) or $v23$ is equal to 200 inches per minute (in./min.). The aim is to calculate linear velocity $v34$ without knowing any distance to instant center 13. The linear velocity $v24$ is equal to the linear velocity $v23$ multiplied by the radius of rotation for instant center 24 divided by the radius of rotation for instant center 23 ($v\_24=v\_23 ((12\text{-}24)/(12\text{-}23))$) (Figure 9). The radii of rotation in this example, denoted as 12-24 and 12-23, are actually indicating the distances between the center of rotation (i.e., instant center 12) and the point at which the linear velocities ($v24$ and $v23$) act (i.e., instant center 24 and 23). Basically, the distance between instant center 12 and 24 as well as the distance between 12 and 23. The linear velocity $v24$ is equal to 200 in./min. multiplied by 1.0529 in. divided by 1 in. (distances determined in CAD) or 210.58 in/min. The linear velocity $v34$ is equal to the linear velocity $v24$ multiplied by the radius of rotation for instant center 34 divided by the radius of rotation for instant center 24 ($v\_34=v\_24 ((14\text{-}34)/(14\text{-}24))$). The linear velocity $v34$ is equal to 210.58 in./min. multiplied by 3.62 in. divided by 4.77 in. (distances determined in CAD) or 159.8 in/min. Notice the slight difference between $v34$ using the link to link and radius of rotation methods for determining velocity. This is likely due to rounding certain values during calculation. It is interesting to note that the graphical method provides a more precise answer.

Conclusion

Students' ability to understand kinematics, especially the motion

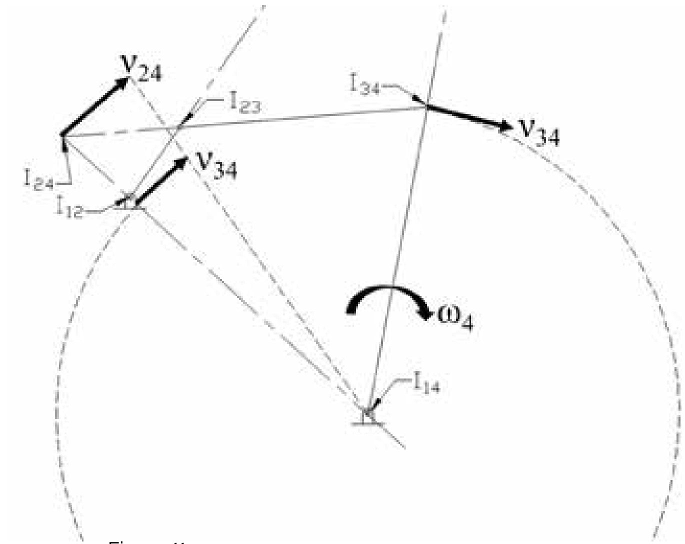


Figure 11
14, 24, and 34 Radius of Rotation Triangle

of a mechanism is enhanced by their ability to graphically and then conceptually visualize mechanism motion. In this article, the authors presented the most common mechanism to start with in the understanding of kinematics, the four-bar mechanism. The goal of this content is to have students design mechanisms graphically based on desired motion characteristics and then have the students produce their mechanisms. The design of mechanisms is important for many common activities in technology and engineering education. In future articles, other mechanisms will be covered to help develop a more thorough understanding of mechanism design and analysis.

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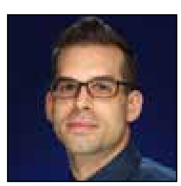

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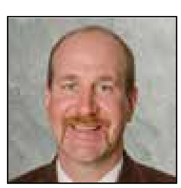

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This is a refereed article.

let's collaborate!

partnerships:

for the greater good of all

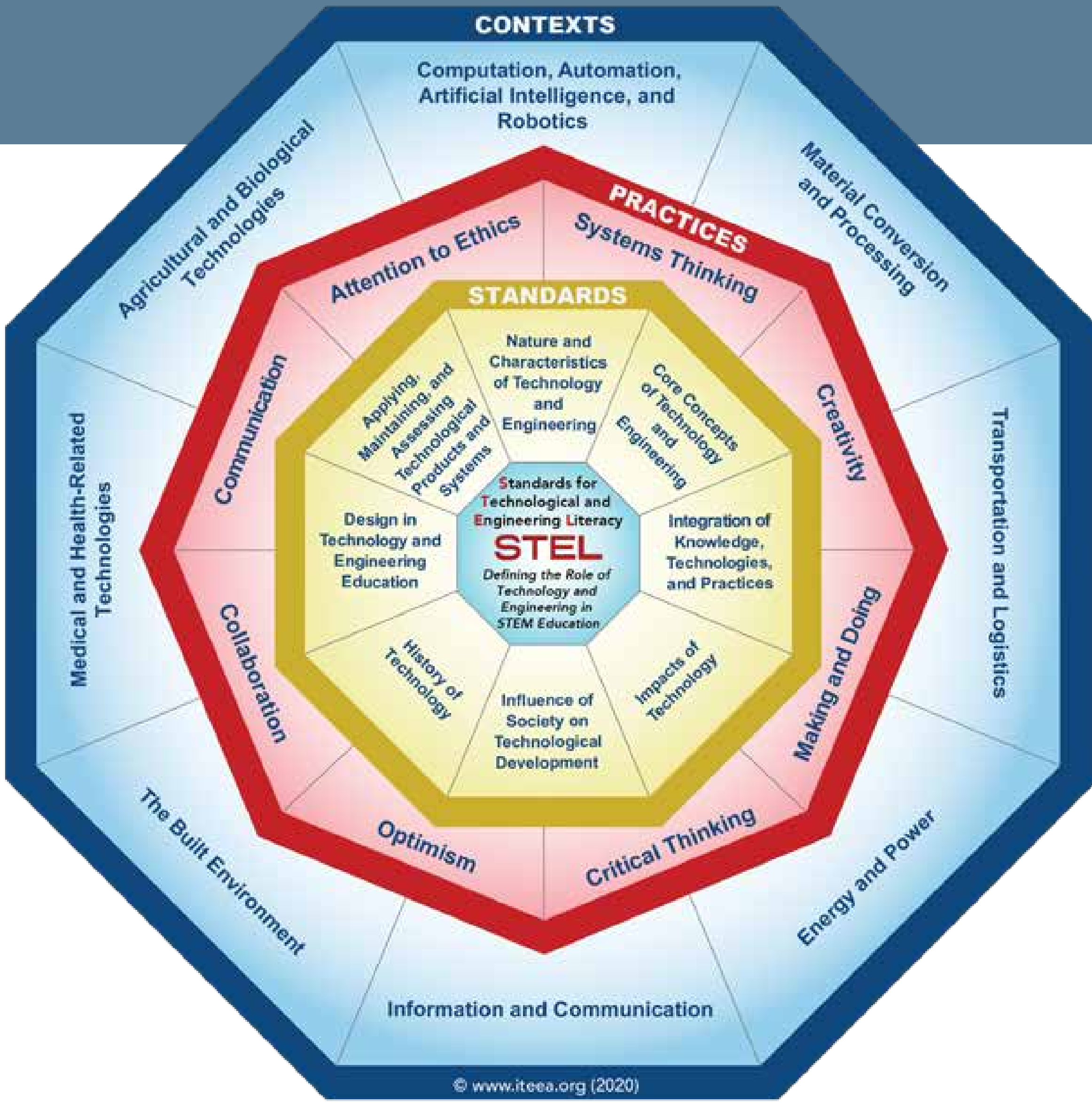
by Deborah Marshall and Lisa Ward

This year's "Let's Collaborate" will focus on two of the four key ideas for the 2022 ITEEA Conference: Creating Diverse, Equitable, and Inclusive successful Partnerships with community, post-secondary institutions, and other disciplines and Connecting Technology and Engineering Education with Other Disciplines and the Workforce.

The 2022 ITEEA conference focuses on the roadmap that *Standards for Technological and Engineering Literacy (STEL)* provides for all educators. The conference theme highlights the importance of the three organizers within *STEL*—standards, practices, and contexts with connections and learning opportunities for all STEM learners!

This is the year to re-examine the depth and breadth of your educational partnerships. What types of partnerships does your school have or are you considering? Cox-Petersen (2011) defines an educational partnership as "when two parties come together for the common good of a school or to enhance student learning" (p. 5). Partners, whether school, community, or professional should be committed to enriching educational experiences.

Partnerships are created for a variety of reasons. Ours was created through a mutual interest in integrating literacy and technology into each department throughout the school in which we were on the faculty. Since joining forces in 2007, and sometimes partnering with others in and outside of our school system, we have been and still are working to integrate literacy, technology and engineering, and all things STEAM into different levels of education.



What's Next?

Throughout our travels, we have been fortunate to meet, collaborate, and partner with some amazing educators, business/organizations, and educational institutions both within and outside of our community. One of the strengths they have in common is the ability to integrate T&E into their respective areas. We look forward to introducing these partnerships to you this year.

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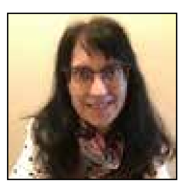

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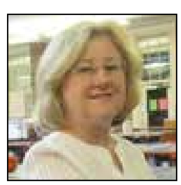


Lisa Ward *is a Library Media Specialist at Granby High School in Norfolk, VA. She can be reached at lward@nps.k12.va.us.*

Have questions or a collaboration idea you would like to see featured in our future Collaborations article? Please send them to Deborah Marshall at dmarshall@nps.k12.va.us or Lisa Ward at lward@nps.k12.va.us

Kenneth Zushma has been a teacher of technology education in the Livingston Public Schools since 2003. He is a graduate of Kean University with undergraduate studies in Industrial Arts/ Technology Education and a master's degree in Educational Leadership as well as a Columbia Teachers College NASA Endeavor Fellow.

Kenneth Zushma

Teacher of Technology Education
Heritage Middle School
Livingston, NJ

What inspired you to become a technology and engineering educator?

As a student in middle school, I was frustrated that I was not particularly "good" at much—not sports, music, or art—and only mildly successful academically. Once I took my first class in industrial arts in middle school, I looked forward to it, but didn't consider it as a career until high school. I had a teacher who took the extra time to allow me to work in the technology lab and created for me a space in high school where I felt I belonged. Once I recognized the significance of this, I decided to focus my further education on becoming a teacher in hopes that I could provide the same opportunity for other students.

What do you consider your greatest successes in the classroom?

I feel my greatest success in the classroom has been my effort to close the gender gap in our technology, design, and engineering department in Livingston. Fourteen years ago, I started a club to compete in the National Engineers Week Future City Design Challenge. When the interested students came to the first meeting, they were all female, which they noticed and embraced, and the concept of our FemGineer club was born. Over the following years, hundreds of seventh and eighth grade girls participated in the program. Several now work as professional engineers and in fields related to STEM. The group continues today to be a space where girls interested in STEM can learn and explore together.

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

Defining "failure" in the classroom is something that has evolved for me over the years. As a new teacher, (0-3 years) confident, just out of college, feeling prepared and on the cutting edge of technology education, my eyes were not as open to failures as they have since become. As I gained experience (4-10 years) and saw what veteran teachers were doing, as well as becoming more aware of my own professional shortcomings, failure began to feel like much more of an option. Now, 18 years in, I can say that I see failures much more clearly but also have the foundation to not allow it to take me off my game. Today, I find that most of my failures relate to underestimating and overestimating my students. There are times when we assume that students come with some basic skills or understandings that simply have not been a part of their education or life experience yet. Furthermore, I've learned to not be afraid to raise the bar, because many students are motivated to rise to the challenge.

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

The best part of teaching in a T&E environment is the flexibility to explore what students are interested in. While there is a fantastic, vertically articulated curriculum from Grades six through twelve, it allows for delivery of content to be conducted using the problems and projects that are relevant to the students. This fluidity in the curriculum allows for maximum student engagement.

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

When speaking to students about careers as T&E educators, I often tell them my own story: how I am fortunate to have been able to build a career around something that I enjoy doing. There are rewards that come from being an educator that simply are not available in many private sector positions. To be able to have a lasting impact on a person is a responsibility that I do not take lightly. I have had students with whom I am still in touch, who have chosen a career path for reasons that they can trace back to middle school technology education class. That is a powerful concept, and one I am not sure that students can even fully understand yet because they are only just beginning their own journey.

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

The "future" has become such an uncertainty after a long year of pivots within our educational system to respond to COVID. The changes from "normal" to "full virtual" to "hybrid" to having a mix of students at home and in the classroom simultaneously combined with the uncertainty of how to safely work in the lab together have made my classroom ambitions a bit more short-term than usual. Currently I have used grant funding to substantially enhance our 3D printing operation to allow more students to be able to utilize machines in a meaningful manner. This has become more prominent than normal during the pandemic, as students can design at their own stations and have work modeled while keeping contact to a minimum. I look forward to returning to a place of collaborative design and making…because we all know that has the greatest benefit to our students.

the legacy project

Winifred A. Mayfield, DTE

by Johnny J Moye, DTE, Glenn E. Baker, and William David Greer, Jr., DTE

Elementary and Secondary School Teacher, State Consultant, Teacher Educator, and Dean

Many industrial arts, technology education, and now technology and engineering education leaders have made their mark on our profession. Their legacy is something that members of the profession enjoy and have a responsibility to continue and build upon.

This is the seventeenth in a series of articles entitled "The Legacy Project." The Legacy Project focuses on the lives and actions of leaders who have forged our profession into what it is today. Members of the profession owe a debt of gratitude to these leaders. One simple way to demonstrate that gratitude is to recognize these leaders and some of their accomplishments. The focus in this issue will be on Dr. Winifred A. Mayfield, DTE. Regretfully Dr. Mayfield has passed away, so Dr. Gus Baker and Dr. David Greer provided information about Dr. Mayfield's contributions to the profession.

Dr. Winifred A. Mayfield, DTE

Born-Deceased: January 25, 1920 - April 26, 2000

Married/Family/Service: Dr. Mayfield was preceded in death by his wife of 56 years, Alice. The Mayfields have five children and nine grandchildren. He was a veteran of World War II.

Degrees Held: B.S., M.Ed., and Ed.D. from Texas A&M

Occupational History:
For 17 years he taught at all levels in Texas public schools, including elementary, middle, and high school industrial arts. Teaching fields included drafting, woodworking, metalworking, electricity, crafts, and general shop.

- Texas Education Agency State Industrial Arts Consultant, 3 years
- Texas A&M Industrial Education Faculty, 5 years
- University of Texas at Tyler, Department of Technology Faculty Member, 8 years, and Dean of the School of Applied Studies, 6 years.

He continued to teach until 1998, retired in 1989, and was granted Professor Emeritus status.

Dr. Mayfield was extremely involved. He was a member of the American Industrial Arts Association (AIAA), Association of Texas Technology Education (ATTE), East Texas Association of Technology Education (ETATE), International Technology Education Association (ITEA), American Vocational Association (AVA), Texas Vocational Teachers Association (TVTA), American Society of Training and Development (ASTD), Life Member of Texas Industrial Arts Association (TIAA), American Council of Industrial Arts Teacher Education (ACIATE), Texas State Teachers Association (TSTA), Texas Career and Technology Administrators (TCTA), Phi Delta Kappa (PDK) and many local service organizations.

Dr. David Greer's memory of W.A. Mayfield's contributions to the profession:

Professionally, Dr. Mayfield was involved in almost every activity related to Texas Industrial Arts Association/Association of Texas Technology Education (TIAA/ATTE) since 1954. Mayfield chaired the committee that initiated the TIAA and was elected as its first president. He served as Executive Secretary of ATTE from 1982-1993. He also initiated the Texas Industrial Arts Student Association (now TSA) and served as State Advisor for 15 years. He initiated the statewide competition for the TIASA and initiated the AIASA and served as National Advisor for six years. He wrote the first TIASA Handbook that was later adopted by the AIASA.

He served on the first Industrial Arts Curriculum Committee that developed Bulletin #565, "Industrial Arts in Texas," published by TEA in 1954. He worked on the woodworking and drafting curriculum that was a part of study "13," which produced Bulletin #615, a guide for all curriculum in the public school of Texas. He initiated the TIAA Curriculum Study in 1966 with co-chairmen M.D. Williamson and John Ballard. He chaired the TIAA Curriculum Committee, (1978-1989), that developed the course descriptions for industrial technology education.

Dr. Mayfield has served on the Legislative Committee, chaired the Industrial Arts Program Standards Committee, chaired the TIASA Advisory Committee, was an ex-officio member of the Advisory Committee for the Industrial Arts Section of the Occupational Curriculum Development Center, a member of various levels of industrial arts textbook committee, Program Chairman for the Industrial Teacher Conference at Texas A&M, Program Chairman for the AIAA Dallas in 1972, a member of the National Youth Development Committee, Chairman of the Teacher Education Council, and a member of the committee that prepared data that was responsible for higher funding for industrial arts courses at the higher education level. He has served as State Board Member of the TIAA from three regions in the state as well as president to two of those regions.

Dr. Mayfield has also published numerous articles in professional journals. He has received honors from the TIAA/ATTE such as Outstanding Teacher, Distinguished Service Award, Distinguished Leadership, Teacher Educator of the Year, and was inducted into the ATTE Hall of Honor in 1986. He received many international awards from AIAA/ITEA such as the Lockette/Monroe Humanitarian Award and was recognized as a Distinguished Technology Educator (DTE).

W.A.'s many accomplishments are a testament to what he did for all in our profession, but his greatest gift was the way that he impacted each of us individually, both personally and professionally.

Dr. Gus Baker's memory of W.A. Mayfield's contributions to the profession:

Winifred Aubrey Mayfield was born in Texas. The Directory of A&M Former Students lists W.A. as being in the class of 1949, which would suggest he enrolled in 1945, probably under the GI Bill.

Tom Hughes, Winifred Mayfield, and Laverne Eickhoff.

However, a lot of A&M's students were inducted into military service en masse in 1942 and 1943 before they graduated, and A&M let them identify with either the group they started with (e.g. a freshman in Sep. 1942 would be Class of '46) or the group they ended with. Jim Boone, for example, started in 1940 and claimed to be in the class of 1944; however, his whole class was inducted into the army in 1943, and he wound up a corporal serving in New Guinea and the Philippines. Jim finished his college degree in 1946 or '47 and not in '44. Chris Groneman was W.A.'s advisor on all his degrees, just as Chris was for both mine and Jim Boone's. Further, Aggies—particularly those who earned their baccalaureate degrees at A&M—are clannish. Those of us who were "Gronemanized" were perhaps even more so. It beat being vulcanized, which involves a lot of heat and sulfur.

In May of 1956, I was in my second senior year at A&M and had been active in both the Industrial Education Club and the honor society, Iota Lambda Sigma. I was also an athlete (fencing), and Groneman liked athletes who could read, write, and sometimes walk and chew gum at the same time. I worked on a lot of Groneman's special projects. Years later I was a graduate assistant (GA). GAs were required to work 20 hours a week for the department, and if you taught a course, he only gave you two or three hours for prep time. GAs and student workers did a lot of grunt work for Chris because Chris was so involved in athletics, writing books, developing industrial and professional contacts, and program development.

W.A. and Chris got together to start the Texas Industrial Arts Association (TIAA) and a student organization concurrently in 1956. W.A. was strong on student clubs, and Chris was strong on professional organizations. I remember running errands for Chris, setting up the meetings, exhibits, and such, and serving as a runner at the banquet to pass out door prizes, and in the process met W.A. and several other people who were involved in the organization. W.A. was elected the first president of TIAA, and John Ballard (a prof at Texas State U. – then Southwest Texas) was the first secretary.

I graduated in May, 1956 and entered the army soon after. When I got off active duty in 1958, I took a job teaching IA and math at Midland High School. I taught there with Ralph Schultz and Joe Talkington. One day late in September of 1958, Schultz and Tarkington asked me if I would be ready to go to Snyder by a certain time. I asked why, and was told to attend the monthly WTIAA (West Texas Industrial Arts Association) and that I had to go. I wasn't certain if it was camaraderie or kidnapping. Anyway, I went, and W.A.

recognized me and went out of his way to greet me. W.A. was host, program head, president of the WTIAA and advisor to the district student group.

Texas is too large to have a single group that could meet often, so the TIAA was divided into several districts. The West Texas Industrial Arts Association (WTIAA) included Midland, Snyder, Odessa, Ballinger, Abilene, Crane, Andrews, and some others. W.A.'s IA program at Snyder included two other high school teachers and a junior high teacher. W.A. headed the program and taught at the Snyder High School with Jiggs Falls and Ed Rayborn, another WWII Aggie veteran. I only remember Jiggs Falls perhaps because one of his students had won a national project contest with a plastic violin. Jiggs said they softened the plastic in a kitchen oven. Ron Foy was teaching at Ballinger, Jerry Drennan at Abilene, and Billy Mayes was at Crane. They all had strong student clubs and very competitive students even though the towns were rather small.

All of these schools were in an oil-rich environment and were well funded. Andrews School District even owned several oil wells. In the aftermath of WWII, skills were highly valued in the oil fields, and all these schools were well equipped. Most of the districts did not have specific vocational programs, and the communities considered the industrial arts programs to be good vocational preparation as well as general education. Most of these districts offered three years of IA in junior high and at least two courses in woods, metals, and drafting in the high schools. In most of these towns, only a small fraction of students went to college from high school, so the IA programs were highly valued. Further, most engineering colleges at that time recommended that entering freshmen had had drafting and either woods or metals in high school.

The Russians had launched *Sputnik* in 1957, and by 1959 the country was reforming education to stress math and science according to a book written by James Conant, a Nobel chemist and Harvard's president. Midland's administration went overboard on reforms to the detriment of IA, and Talkington and I both left in 1960. Talkington went to Greeley and earned a doctorate with Fred Kagy at Northern Colorado and went on to chair the IA program at Northern Illinois where he initiated perhaps the first computer course in an IA program. I went to A&M to be a GA working on a master's degree.

W.A. was an exceptionally ardent advocate of excellence in his program, and his shops were well equipped, laid out well, and color-coded. His main associate at Snyder was Jiggs Falls, who was very creative, good with students, and an excellent craftsman. W.A. held high standards for himself and promoted monthly WTIAA meetings at different schools to exchange ideas, compare each program with others, and strengthen professional ties. We almost always had 30 or 40 people in attendance. Considering the distances involved and the lack of travel funds, I think this was quite good. Chewy chicken and limp green beans served in school cafeterias certainly wasn't the drawing card! I don't think W.A. tried to be so much a leader as he tried to be one's co-worker and professional colleague.

Early in May, the district student organization had its contests, usually in Abilene, and we all took our best students there. We had project contests and various written knowledge contests as well. Of course, W.A. was always preeminent at this meet. The top three kids that placed in each contest were eligible for the state contest. The only college that volunteered its facilities was A&M, so the state contest was held there in late May.

When I went back to A&M in 1960, I was the only graduate assistant in the department. I taught at least one class a semester and did anything else Groneman thought I should do. I sometimes think Chris regarded me as his gradual resistant because if I had a different idea I would offer it. Of course, Chris' way was usually best, but I never learned. Chris put me in charge of checking in the kids, teachers, and one section of projects for the state contest in May of 1961. I think Billy Mayes from Crane was TIAA president that year, but W.A. was still the student association advisor, and I had to contact each of them about contest and housing arrangements. W.A. and his bunch showed up early, while Billy Mayes and his busload showed up at midnight and got both Chris and me up. Chris was more gracious than I was. W.A. was a lot easier to work with.

Chris Groneman's doctoral program in Industrial Education was approved sometime in 1961. That summer, I was finishing my Master's, and W.A., John Ballard, and Wendell Roy and a few others were starting their doctorates. W.A. and I roomed together in a dorm for one summer term. We were both taking the same courses, which meant we spent a lot of time studying and talking about our courses, which included a course in electronics taught by Jim Boone.

Jim was studying to be a ham operator, and the course sort of became the qualification course for ham radio. W.A. had trouble with electronics, and we spent a lot of time repeatedly going over it. I think W.A. memorized everything but never really understood it. At some point he explained that he had suffered a severe head injury and had trouble with abstract ideas. He told me he had been in an artillery unit exchanging fire with German artillery at the Battle of Monte Casino in Italy in WWII (1944). His crew had been ready to fire their cannon one second and then he woke up in a hospital. He thought the Germans had scored a direct hit on his gun emplacement and had exploded the gun and some ammunition as well. He spent a long time in the hospital and because of his wounds, had trouble with abstractions, a tendency to be distracted, and some slight speech difficulty. If he was given time to think things out, I think W.A. was probably a brilliant man who overcame his disabilities with persistence and hard work. I don't think he told many people about this, and I don't remember him saying anything else about the army. I never heard him complain or mention his wounds publicly or to anyone else, although I'm sure several people knew. I think he felt it was his problem and he solved it; there were more important things to do.

I finished my Master's that summer (1961) and took a job teaching at a junior high in Fort Worth, well outside the WTIAA. In 1962, Jim Boone put me in charge of running the state electricity and electronics knowledge competitions, so while we were at the contests, W.A. and I would usually manage a quick visit. I ran these contests until May of 1966, shortly before I finished my doctorate. I started my doctorate in 1964 and was a graduate assistant to Jim Boone; W.A. would occasionally be around taking a course or working on an assignment when he could get away from work. It took W.A. several years working part-time to complete his doctorate. At some point about this time, the state I.A. coordinator, Rogers Barton, retired, and W.A. took over this position. I think W.A. completed his residence requirements commuting from Austin to College Station.

I left Texas in August of 1966 to take a job in Wayne, Nebraska teaching electronics, metals, and graduate courses. Oddly enough, the president of the college, W.A. Brandenburg, had been a roommate of Chris Groneman at Bethany College in Kansas. I'm pretty sure my taking the job there was somehow prearranged.

Looking back, I think everyone respected W.A. because he was so dedicated to both the TIAA and the Texas Industrial Arts Student Association. W.A. was not an imposing figure—he was rather short and stocky with a ruddy complexion and a pre-rumpled blue suit. He knew he was not an inspiring speaker, so when he had to make a presentation, he wrote his main points out on notes, followed the notes, and then sat down. I think he thought a good speech was a short one. (He was right!) He worked harder than just about everyone else and without complaint. He never considered a task too small or too large to do right, nor was there any doubt about his dedication to the strength of the two associations. He gave ideas freely and would ask for help in achieving goals, but I never knew of him giving orders. He set standards for himself (and others) that were hard to meet, but that made you want to try.

My last memory of him was at a TIAA board of directors meeting, probably in 1990 or '91. By then TIAA had morphed into the Texas Technology Education Association (TTEA), and there were several issues about curriculum and the effects of declining programs. By then attendance at the conference was between 200 and 300, down from the 500+ in years past, and I was almost completely out of the field.

Drs. Greer and Baker personally knew and worked with Dr. W. A. Mayfield. They are in the position to recall some of Dr. Mayfield's contributions and influence to the technology and engineering profession. Without their input it is very possible that Dr. Mayfield's contributions would never be captured. It is obvious that Dr. Mayfield had a significant contribution to the profession in both Texas and nationally. His is a legacy to admire and for others to emulate.

To view Dr. Greer and Dr. Baker's (and other) legacies, the reader may find them at this link: http://www.iteea.org/About/History/LegacyProject.aspx#tabs

It is beneficial for current (and future) leaders to read about the issues that existed and how they were addressed "back in the day." In a few months the next interview will appear in this journal. If you have a suggestion of a leader to recognize, contact the author with that person's name and contact information.

Johnny J Moye, Ph.D., DTE *serves as ITEEA's Senior Fellow. He can be reached at johnnyjmoye@gmail.com.*

W. David Greer, Ed.D., DTE. *Dr. Greer is a retired industrial arts teacher, a CTE Program Director, and Adjunct Professor at University of North Texas.*

Glenn E. Baker, Ed.D. *Starting as a carpenter, oil-field worker, and law enforcement officer, Dr. Baker then become an industrial arts teacher and later went on to be a Professor of Educational Human Resource Development at Texas A&M.*

classroom challenge

bicycles as a tech ed object lesson

by Harry T. Roman

Introduction

There is lots of engineering, technology, and math involved with bicycles, and that is what this article is about. It is a subject that should warm the hearts of your middle school kids. Let's take a spin around the block and learn more about bicycles!

Start With the Basics

Begin by examining the basic components of the bicycle:

- Frame
- Wheels
- Pedals and Chain Drive
- Steering
- Braking
- Ergonomics
- Accessories

Challenge your class to investigate the evolution and intricacies of the major bike components, like:

1. Frame

What are the main concerns that go into the design of a bicycle frame? Is it structural only? Can it involve aerodynamics? If so, does that apply for all bikes? Have there been identifiable stages of evolution for bike frames? Explore how various bike designs incorporate metal and other composite substances for the frame. How does wear and tear on the bike affect frame durability? Investigate how a frame failure can occur, and what kinds of mechanical conditions cause this. Which materials are most resistant to frame failures? How do bike manufacturers account for a wide range of human weights that can sit upon their bikes?

2. Wheels

What has been the evolution of bicycle tires? How does tire design impact the frame durability? Do softer tires transmit less shock to rider and frame? How else do soft tires impact bike performance? Since the tires are where "the rubber meets the road," how does

road condition impact the life and wear of tires? What is the purpose of spoke wheels? Many early tires were pneumatic in design with an inner tube. Are inner tubes still used today? Are shock absorbers recommended for the front wheels of all bikes?

3. Pedals and Chain Drive

Obviously, pedals and chain drive do provide some gear leverage to riders, giving them a variety of speeds to choose from. Investigate the relationship between the gears, the number of teeth on the gear sprockets, speed, and tire revolution. Are these relationships the same for all bikes? What happens if you change the size of the tires and put small ones on an existing bike? Have metal chains always been the preferred drive mechanism?

4. Steering

Examine the various ways that humans steer bicycles, and the designs that have become common. Are different steering mechanisms needed for different biking applications? Does bike speed impact the kind of steering mechanism that is necessary? Does tire design, size, or width, impact steering?

5. Braking

Being able to stop at a safe distance is important. Bikes can have rear pedal brakes and/or handlebar brakes. Is there a reason for these different types? Can they be mixed on one bicycle? Which one will stop the bike fastest? How does the operation of a pedal brake differ from hand brakes; and how long does each kind last?

6. Ergonomics

Over the decades, bike designers have brought more comfort and human design (ergonomics) to bicycle design. Better, more comfortable seats are one obvious change. How the rider sits and grips the handlebars has also changed. How does this vary with bike use? Have hand brakes evolved as part of a safety or ergonomic concern?

7. Accessories

Again, over the decades, bikes have been modified to accommodate a variety of accessories or amenities. There are lights, baskets, horn, saddlebags, water bottles, steering grips...etc. that have become available to cater to the rider and their special needs. Bike helmets, of course, have also evolved rapidly in the last 10 years. Explore these and investigate how this has changed the biking experience.

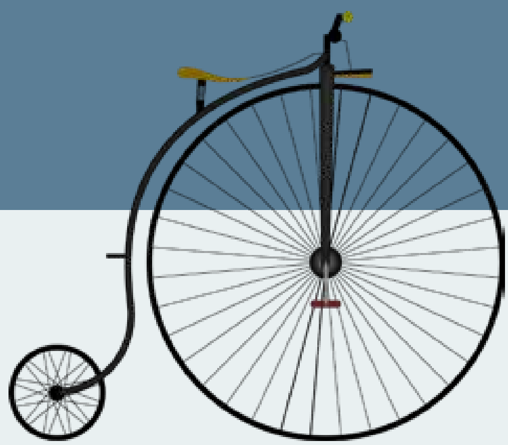
More Investigations

Examine the differences between bike classifications such as:

- Traditional street bikes
- Mountain bikes
- Racing bikes

How do they differ in design, tire type, ergonomics...etc?

Taking bikes apart in class could provide some very interesting learning lessons about bike construction. Is it possible to have several bikes available for disassembly/assembly; along with the proper tools? Can you envision this as a valuable hands-on experience for your pupils?



Some of the early horseless carriages were referred to as quadra-cycles. Why do you suppose that was? How did bicycle design impact early automobiles. Did bicycle steering carry over into early car design?

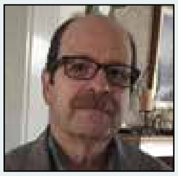
Perhaps there is a bicycle shop nearby your school where your class can visit, or have someone from the shop visit the class to explain modern bicycle design.

High-end racing bikes used by professional racing teams are a great deal different from ordinary street bikes. Some of these are actually designed with sophisticated computer design tools and tested in wind tunnels. Take some time to explore the engineering behind this kind of analysis, and the role that aerodynamics can play in professional racing bikes. Identify racing bike manufacturers and search them out on the internet to learn how manufacturers approach the design process.

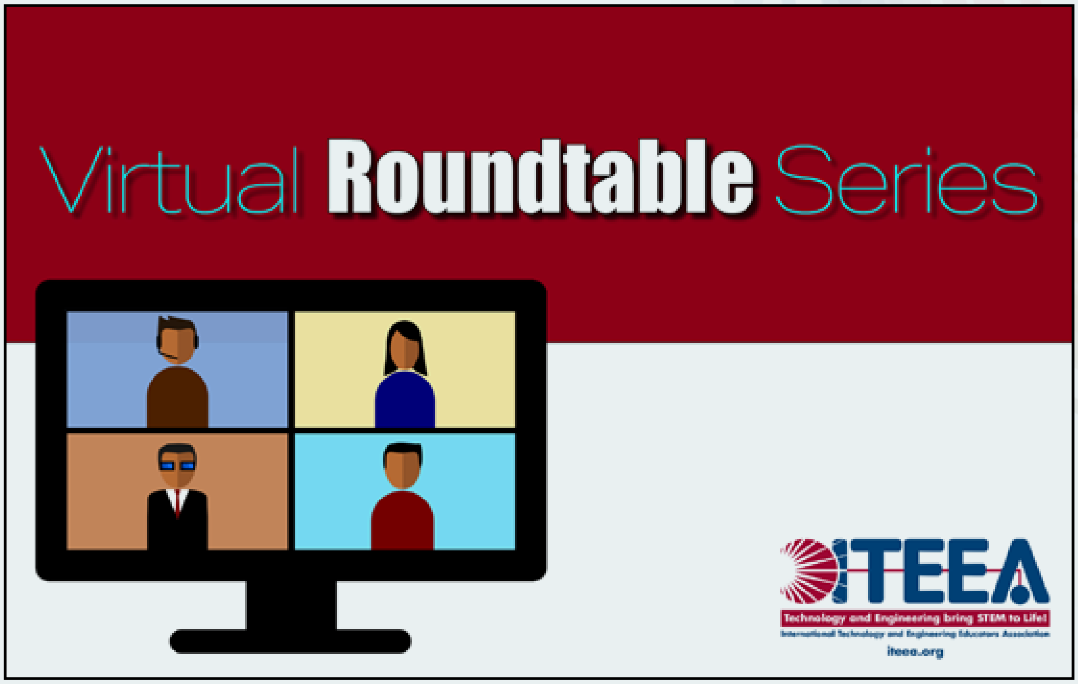
While on the internet, take some time to see how bikes and math are intertwined. Check out websites that have lesson plans for learning how bike math applies to everyday use of your bicycle. Maybe your students can come up with their own applications of bike math!

What are the laws in your community regarding bike use, such as:

- Riding on streets versus sidewalks
- Proper side of the road to ride
- Safety equipment required
- Visibility after dark
- Allowable bike condition
- Traffic rules
- Turn signals
- Permit applications, if any
- Use of bike trails



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



ITEEA's Roundtable Discussion Series Brings STEM to Life!

FREE to All!

Once or more each month, ITEEA will be offering an hour-long opportunity for the Technology and Engineering Education Community to discuss and explore specific topics online. Participation is free and anyone who registers for a particular topic can engage in the discussion. Each topic will have one or more hosts to help guide the discussion. Questions about each topic can be submitted in advance through the registration process.

- Aug 19 at 6:00pm EDT: The Power of Adaptive Technology Projects in the STEM Classroom
- Aug 24 at 6:00pm EDT: Teaching STEM Education at the Elementary Level
- Sept 15 at 7:00pm EDT: ITEEA's Council for Supervision and Leadership
- Oct 13 at 7:00pm EDT: ITEEA's Technology and Engineering Education Collegiate Council
- Nov 3 at 7:00pm EDT: Planning a STEM Night: How Tos
- Nov 18 at 6:00pm EDT: ITEEA's Elementary STEM Council - Exploring STEAM in Elementary Grades
- Dec 8 at 7:00pm EDT: Cultivating Creativity in the Classroom
- Jan 19 at 7:00pm EDT: Recruiting and Retaining Girls in the T&E Classroom
- Feb 16 at 6:00pm EDT: Teaching Sustainability Education
- April 13 at 7:00pm EDT: Recruitment, Retention, and Diversity
- May 18 at 7:00pm EDT: Teaching Energy and Power

Learn more and register at: www.iteea.org/roundtable.aspx

Additional topics coming soon.

Interested in hosting a roundtable? Contact kdelapaz@iteea.org

ITEEA's 2021 STEM School of Excellence Application Process Now Open!

The ITEEA STEM School of Excellence recognition application window is now open! ITEEA's STEM Center for Teaching and Learning™ recognizes outstanding schools for their commitment to providing a robust Integrative STEM education program. Schools recognized exemplify outstanding leadership in the field of STEM education. Recognized schools undergo a rigorous application process requiring detailed documentation to demonstrate a strong Integrative STEM program. A panel of reviewers will reach consensus that the documented evidence represents excellence in Integrative STEM education.

ITEEA created the designation as a way to officially recognize those schools whose teachers, administrators, and other stakeholders are providing a meaningful STEM education experience for students. By highlighting these schools, ITEEA hopes to help others learn effective best practices and continue sharing them more broadly into the larger STEM Education community.

School of Excellence awardees will be recognized during the second general session at the ITEEA 2022 conference in Orlando with the presentation of a banner and certificate. They will also be recognized in the May/June 2022 issue of the *Technology and Engineering Teacher* journal.

The application is now open at

https://www.iteea.org/STEMschoolofexcellence.aspx

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