STEELS Technology and Engineering Practices (TEPs)

The Technology & Engineering Practices (TEPs) encompass the abilities and dispositions that are fundamental to teaching the STEELS Technology and Engineering Standards with fidelity (PDE, 2022). The TEPs help students engage with the human designed products, systems, and processes we use to satisfy our needs and wants. Engaging in these practices is a vital component of technological and engineering literacy by helping students become proficient in the use of technology and gain design and problem-solving abilities. These eight student-centered practices help students develop the knowledge, skills, and dispositions to solve problems. Technology and engineering practices are connected and overlapping, and in fact, it would be almost impossible to teach a practice in isolation.

- **Systems Thinking** refers to the understanding that all technologies contain interconnected components and that these technologies interact with the environments in which they operate. It also includes an understanding of the universal systems model, consisting of inputs, processes, outputs, and feedback.
- **Creativity** is the use of investigation, imagination, innovative thinking, and physical skills to accomplish goals, including design goals.
- **Making and Doing** are at the heart of what makes technology and engineering so different from other fields. Technology and engineering students design, model, build, and use technological products and systems. Whether through use of computer software, tools and machines, or other methods, technology and engineering students learn kinesthetically.
- **Critical Thinking** involves questioning, logical thinking, reasoning, and elaboration in the process of making informed decisions. Critical thinking includes analytical thinking, an important component of activity in many subfields of technology and engineering.
- **Optimism** refers to a commitment to finding better solutions to design challenges through experimentation, modeling, and adaptation. It also reflects a positive view in which opportunities can be found in every challenge, as well as persistence in looking for solutions to technological problems.
- **Collaboration** refers to having the perspectives, knowledge, capabilities, and willingness to seek out and include team members when working on design challenges.
- **Communication** in technology and engineering can be considered in two ways: to define problems by gaining an understanding of the wants and needs of the users of technology, and as a means of developing and explaining choices made in the design process.
- **Attention to Ethics** is at the core of being a human in society. In technology and engineering, attention to ethics means focusing on the impact of technological products, systems, and processes on others and on the environment. Students should evaluate risks and consider trade-offs in their decision making.

STEELS K-12 Technology & Engineering Practice (TEP) Progressions

Grade Band	Systems Thinking	Creativity	Making and Doing	Critical Thinking	Optimism	Collaboration	Communication	Attention to Ethics
K-2	Learns that human-designed things are connected	Learns that humans create products and ways of doing things	Learns to use tools and materials to accomplish a task	Engages in listening, questioning, and discussing	Sees opportunities for making technologies better	Learns to share technological products and ideas	Learns that humans have many ways to communicate	Learns that use of technology affects humans and the environment
3-5	Provides examples of how human-designed products are connected	Tries new technologies and generates strategies for improving existing ideas	Safely uses grade-appropriate tools, materials, and processes to build projects	Knows how to find answers to technological questions	Engages in tinkering to improve a design	Works in small groups to complete design-based projects	Develops written and oral communication skills	Explains ethical dilemmas involving technology, such as trade-offs
6-8	Uses the systems model to show how parts of technological systems work together	Exhibits innovative and original ideas in the context of design-based activities	Exhibits safe, effective ways of producing technological products, systems, and processes	Defends technological decisions based on evidence	Critiques technological products and systems to identify areas of improvement	Demonstrates productive teamwork in design-based projects	Exhibits effective technical writing, graphic, and oral communication abilities	Shows an understanding of ways to regulate technologies and the reasons for doing so
9-12	Designs and troubleshoots technological systems in ways that consider the multiple components of the system	Elaborates and articulates novel ideas and aesthetics	Demonstrates the ability to regulate and improve making and doing skills	Uses evidence to better understand and solve problems in technology and engineering including applying computational thinking	Shows persistence in addressing technological problems and finding solutions to those problems	Considers and accommodates teammate skills and abilities when working to achieve design and problem-solving goals	Conveys ideas clearly in constructive, insightful ways, including through written and oral communication and via mathematical and physical models	Assesses technological products, systems, and processes through critical analysis of their impacts and outcomes

Technology & Engineering Practice: Systems Thinking

Overview

In technology and engineering, systems thinking is the understanding that all technologies contain interconnected components and that these technologies interact with the social and natural environments in which they operate. Technologies are more than just products; they include the processes and resources used in their development and production as well as the effects of their use on the broader systems within which the technologies are used. Standards for Technological Literacy (ITEA/ITEEA, 2000/2002/2007) defined systems thinking as "a technique for looking at a problem in its entirety, looking at the whole, as distinct from each of its parts or components. Systems oriented thinking considers all the variables and relates social and technological characteristics" (p. 242). The National Academy of Engineering (NAE, 2019b) described systems thinking in this way: "Our world is a system made up of many other systems. Things are connected in remarkably complex ways. To solve problems, or to truly improve conditions, engineers need to be able to recognize and consider how all those different systems are connected."

Systems thinking can promote the kind of interdisciplinary work that is integral to technology and engineering. If a technology and engineering student only focuses on a product or on one aspect of a technological design, they are not seeing the bigger picture through systems thinking to deeply understand what they are learning or doing in class. Holistic solutions and approaches developed through systems thinking demand consideration of scientific, mathematical, societal, ethical, and aesthetic factors.

A useful tool in promoting systems thinking is the universal systems model, first championed in technology education classrooms in the 1980s. Although deceptively simple in structure (input, process, output, feedback), this model accurately depicts the holistic examination of technology that is the hallmark of systems thinking, and it provides prompts that encourage students to engage in systems thinking. Input considers the material, financial, and energy resources needed to create a technology. Process examines how the product or system is made, and/or the requirements of its operation. Outputs examine the immediate performance of the product or system, and then more broadly at the impacts (both positive and negative) of its use. Feedback analyzes the process and outputs of a productor system and loops the insights gained from this analysis into operation of the product or system and into possible changes to improve its performance or to minimize its negative side effects on users, society, and the environment. The goal of systems thinking is the creation of technological solutions that are more effective, more efficient, and more beneficial than might otherwise be the case. Systems thinking is important at all stages of technological development and use.

Examples of Systems Thinking in Technology and Engineering

The use of design challenges is one important way that systems thinking can be encouraged in technology and engineering classrooms. A design challenge focused on product life cycles might include development of a unique toy that is tested in a daycare center. If the student just attempts to build a colorful toy, the student may not see the bigger picture. Instead, the technology and engineering teacher could provide a list of key teachable and formative assessment points to require the students to identify, think about, and reflect on user needs, criteria and constraints, production processes, safety of child products, ethics, and universal design elements. While the toy is being tested by the three-year-old end users, the students' understanding will be deeper due to the inclusion of systems thinking in the instruction developed by the teacher.

In ITEEA's REACH Challenge, middle school, high school, and collegiate teams are asked to design and develop an adaptive or assistive technology solution to help a student with a mobility need. The systems thinking necessary for this project includes understanding mobility issues;

Americans with Disabilities Act (ADA) requirements; mathematical data about the individual and their accessibility needs (e.g., height, distance); materials to be used in the solution chosen; construction processes; the type of power source; durability of the assistive technology; and the impact on the individual being helped, among other factors. Through questions that elicit both systems thinking and critical thinking, the technology and engineering teacher can reinforce the connections between all the information being gathered and decisions being made.

Technology & Engineering Practice: Creativity

Overview

Creativity in a typical context refers to imagination, "thinking outside the box," and coming up with unique ideas. In technology and engineering, creativity refers to these aspects and more. The National Academy of Engineering (2019b) described engineers who excel in their work as those who identify new patterns or imagine new ways of doing things when they look at the world. This is most apparent in the design process because engineers must use their imagination to design, model, produce, and evaluate systems and artifacts of design. Temes (2019) defined engineering creativity as "the ability to change the direction of technological progress drastically and beneficially, or the ability to induce an inflection point in the development of some engineering field" (p. 1223). Although engineering is often restricted to practical and financial applications, pure engineering research at facilities such as Edison's New Jersey Lab and Bell Laboratories harnessed creativity and innovation to develop new ways to meet human wants and needs. Warner (2000) defined creativity as "a human act or process that occurs when the key elements of novelty, appropriateness, and a receptive audience in any given field come together at a given time to solve a given problem" (p. 11). This definition suggests that in the context of technology and engineering activity it is not sufficient to simply have a unique approach; the solution must also address the need identified and be satisfactory to its end users. Open-ended problems require creative thinking that is unique, purpose-driven, and generates multiple solutions.

The National Education Association, in An Educator's Guide to the "Four Cs": Preparing 21st Century Students for a Global Society (2019), reported that all teachers should try to help students develop skills in creativity and innovation. This report defined creativity in three ways:

Think Creatively

- Use a wide range of idea creation techniques (such as brainstorming)
- Create new and worthwhile ideas (both incremental and radical concepts)
- Elaborate, refine, analyze, and evaluate original ideas to improve and maximize creative efforts

Work Creatively with Others

- Develop, implement, and communicate new ideas to others effectively
- Be open and responsive to new and diverse perspectives; incorporate group input and feedback into the work
- Demonstrate originality and inventiveness in work and understand the real-world limits to adopting new ideas
- View failure as an opportunity to learn; understand that creativity and innovation are part of a long-term, cyclical process of small successes and frequent mistakes

Implement Innovation

- Act on creative ideas to make a tangible and useful contribution to the field in which the innovation will occur (NEA, 2019, p. 25).

In the technology and engineering classroom, the use of hands-on, design-based lessons is an ideal way to foster creativity in students. Providing additional time for students to brainstorm solutions to open-ended problems and encouraging communication about individual and team ideas are two ways to build personal skills of creativity in students. This dialogue should focus on the students' thinking and talking about design to engage them more deeply in the creative design process.

Examples of Creativity in Technology and Engineering

In a high school-level course with a focus on video production, student teams were given a design challenge to produce public service announcements (PSAs). The only criteria were that the PSAs needed to be exactly 60 seconds long and needed to communicate a clear message to the viewing public about a non-profit organization. Teams of four students selected an organization from a list that included United Way, Habitat for Humanity, Shriners Hospital, and the Red Cross, among others. The marketing directors for these local organizations were contacted with an offer of a free 60-second PSA produced by the high school students. To encourage student creativity, the teacher showed them examples of professionally produced PSAs that were known for their unique messages. Students were instructed to spend a week brainstorming and researching ideas to present to the organization. The students had to prepare storyboards of their ideas and give a presentation to representatives of the organizations. The students reported that the most creative part of this PSA project was coming up with ideas and then communicating their vision to the organizations in a live presentation.

The second example of teaching creativity is from a third-grade STEM classroom. The technology and engineering education teacher presented a design problem to the class. Given a box filled with assorted materials, the students had to work in small groups of three to design an apparatus to filter runoff water from the school parking lot before it flows into the school butterfly garden. The students visited the parking lot and butterfly garden to take measurements and visualize their ideas. The teacher asked probing questions to get them to think creatively about what could be done. Back in the classroom, time was given for the teams to brainstorm possible solutions to the problem. Students were asked to reflect in their engineering journal about their ideas. Afterward, the student teams used the materials in the box to design and construct an apparatus to filter the water. Their creations were mounted near the drains in the parking lot on a day that rain was in the forecast. The next day, the apparatuses were brought back into the classroom for deconstruction and analysis of how well they collected debris. Creativity was enhanced during the discussion time at the end of this lesson when students were asked what they would do differently the next time.

Technology & Engineering Practice: Making and Doing

Overview

Making and doing can occur in many formal and informal settings, including educational environments such as technology and engineering classrooms. Making refers to the act of creating something, while doing is broadly defined as using hands-on processes associated with designing, building, operating, and evaluating technological products and systems. Doing can include a host of activities, including modeling, programming, using tools and equipment, creating presentation materials, and many others.

Making and doing have been, and continue to be, foundational components of technology and engineering. Over time, making and doing within these programs have shifted from producing pre-designed objects focused on developing industrial skills to creating innovative solutions to open-ended design challenges. The nature of open-ended design challenges allows students to create solutions using multiple approaches. Open-ended design challenges provide opportunities for students to optimize solutions based on end users' needs, design constraints, and other criteria. Additionally, open-ended approaches to design allow students to develop creative solutions and to use materials and making techniques in unique ways. This shift to an open-ended design perspective allows technology and engineering educators to foster students' higher-order thinking and design skills while integrating content from other disciplines.

Children are naturally curious, which drives their fascination with understanding how devices work or searching for new ways to accomplish tasks. When students engage in open-ended making and doing practices, they experience a process similar to what scientists, technologists, and engineers often engage in when approaching a real-world problem. The design process in which students engage is more important than the end result when it comes to developing lifelong skills. Inherent in making and doing is the appropriate use of materials and tools. Teaching students how to safely operate tools and equipment during making and doing empowers students and promotes a sense of autonomy and self-reliance. Additionally, using tools safely and learning how to manipulate materials appropriately is an authentic practice of scientists, technologists, and engineers (Love, 2017; National Academies of Sciences, Engineering, and Medicine, 2019; NGSS Lead States, 2013c). Technology and engineering educators possess unique training and expertise in regard to teaching safe use of tools and materials; therefore, they play an integral role in facilitating making and doing in classrooms and laboratories.

Safely making and doing are central to technology and engineering. This remains its signature trademark, differentiating technology and engineering from other content areas. Additionally, making and doing within the model making and prototyping stages is a hallmark of technological design, and is a key distinction between technology, engineering design, and other design processes (Hailey, Erekson, Becker, & Thomas, 2005; Kelley, 2010). However, the making and doing practices that technology and engineering educators teach students will continually evolve. One example where this evolution is apparent is in manufacturing applications. Making and doing in these areas traditionally consisted of learning how to safely use power tools and equipment. Students were later taught to create computer-generated designs and program CNC or automated equipment. As professional practices evolve with the advancement of technology and refinement of technical processes, so too must technology and engineering in order to foster students' acquisition of these emerging practices.

The study, design, and application of technology and engineering also require the use of five types of models that represent making and doing practices. These include conceptual models in the form of ideas and concepts; mathematical models that explore quantities, precision, and relationships; graphical models such as sketches, graphs, and charts; physical models and prototypes that express mass, form, and function; and virtual models that simulate designs and system performance. The extensive use of modeling is another attribute that sets technology and engineering apart from other subject areas in today's K-12 schools and is one of the reasons students find these programs so meaningful. Students could potentially use all eight of the technology and engineering practices in context of making and doing. They perform systems thinking as they design or construct items. Using their creativity and critical-thinking skills, students must analyze the requirements of a situation or problem and consider how they can ethically design a solution to address the situation. Students are able to realize at a young age that their designs often improve (optimism) when collaborating with others and incorporating their expertise and perspectives. When students are successful, they gain confidence in their abilities to function in the classroom and society. Knowing that they can be successful problem solvers, students also begin to develop a sense of responsibility for identifying solutions to meet societal needs.

Examples of Making and Doing in Technology and Engineering

GoBabyGo Style is a project found in ITEEA's Dream Ride curriculum and in Technology Student Association (TSA) activities at the middle and high school level. GoBabyGo Style involves technology and engineering students making modified ride-on cars for young children with mobility needs. Student teams have the choice of designing and building a car for use at libraries, daycare centers, or other shared spaces, or more complex vehicles that are custom-built for an individual child. A form of assistive technology, these cars are customized by students with a focus on real-time, real-world solutions. Safely turning these designs into finished products distinguishes technology and engineering students from other students who only take a theoretical approach to solving problems. GoBabyGo Style is a hands-on, minds-on project that can be linked to increased student understanding of diverse needs, ergonomics, and technological components.

A traditional activity commonly seen during the industrial arts era of the twentieth century was building a birdhouse. Students were provided a set of plans and prescriptive directions to create the same end result (i.e., project-based learning). Although this activity encompassed aspects of making and doing, it neglected a critical component—design thinking. When this project is approached from a design-based lens, it uses a different process that integrates other content areas, promotes higher-order thinking skills, and considers important contextual information to guide the design (i.e., problem-based learning). Teams of students could be tasked with researching characteristics of birds in their region, specifically learning about the habitats these birds prefer. Based on this information their challenge would be to design a birdhouse within certain size constraints that addresses environmental and biological characteristics of the bird they selected. Finalizing their solution would require students to communicate key features of their design, how it meets the needs of the selected bird species, and the environmental benefits of the design. Students must keep in mind that successful technological solutions consider the needs and wants of end users (even birds!).

Rather than having students create the habitat using hand and power tools, they could be tasked with using 3D design software to develop a virtual model and then writing the code for manufacturing it using computer numerically controlled (CNC) equipment. To further challenge students, they could be asked to design their habitat so that it has tabs or other features that allow it to be disassembled for cleaning. Students could also add microcontroller sensors that would be programmed to provide feedback or collect data about the birds using the habitat. Lastly, they could design a poster that communicates information about the bird species, its habitat needs, and the features of the birdhouse design that address those needs. Although this extended example may result in a similar end product to the pre-designed birdhouse project of 1950, it demonstrates that the process used to teach making and doing plays a critical role in the level of thinking and the degree of cross-disciplinary integration in which students engage.

Another example is the popular cardboard chair design challenge. In the past, students often built furniture from predesigned plans. In the cardboard chair design challenge, students are tasked with designing an appealing-looking chair that uses the least amount of cardboard to support an average-size child or adult. The only material they can use to hold the chair together is cardboard. Students must investigate and apply concepts relative to structural design, properties of materials, aesthetics, ergonomics, and much more. In adopting this more open-ended approach students use cost effective materials, apply higher-order design thinking skills, and integrate more cross-curricular concepts in their making and doing.

Technology & Engineering Practice: Critical Thinking

Overview

It is more important than ever to have all people develop critical-thinking skills. Whether at home or in the workplace, people must be able to compare and evaluate evidence and claims in order to make informed decisions. This entails judging the value and accuracy of information and assessing the soundness of conclusions drawn. In twenty-first century workplaces, employers want to hire employees who can think systematically about important questions and issues, collect and analyze data and information, adhere to standards in the field, be adaptable in their decision-making, and effectively communicate approaches to complex situations. Critical thinking is useful for developing better ways to structure, carry out, and evaluate actions both at home and at work.

In education, critical thinking is primarily developed in students by employing critical thinking questioning throughout the instructional process. Teachers should ask thought-provoking questions that lead to longer and more detailed discussions in a climate of openness and inquiry. “Quality talk” is a strategy where authentic questions are asked, and students must respond with well-reasoned words and fully articulated explanations. This type of dialogue can also be encouraged within student peer groups as they investigate situations and solutions.

The practice of critical thinking is promoted within the classroom settings of nearly every discipline. In language arts, this might mean delving into the possible meanings of a work of literature. Computational thinking, most often associated with the field of computer science, refers to the use of critical thinking and informed reasoning to solve problems and design systems, including computer software. No matter the disciplinary setting, critical thinking involves use of higher-order skills such as analysis, evaluation, and synthesis.

In technology and engineering classrooms, the teacher can enhance students’ critical-thinking abilities through thoughtful project selection. The most effective types of projects center on design-based learning with authentic, ill-defined/open problems to solve. Students must systematically work to find alternative solutions, critically examine the problem and solutions, analyze results from preliminary solutions, and be ready to answer questions when presenting and defending their solutions. Student debates on technological issues can spark thoughtful discussion on the impacts of technology. Use of case studies can result in deeper work and understanding by students. Through careful question posing, students can transition from what they know using convergent questions to what they need to know through use of divergent questions.

Examples of Critical Thinking in Technology and Engineering

In an eighth-grade technology and engineering class, the teacher opens a discussion about the impacts of technology with a focus on driverless vehicles. Critical-thinking questions are asked of students during the introduction, individual and group guided practice, and during closure. Some of these questions are:

- What everyday activities will be impacted by the use of driverless cars?
- Why do you think that driverless cars will be normal at some point in time?
- If this becomes the norm and manufacturers stop making driver-operated cars, what will the impact be?
- What still needs to be invented in order for this to become a reality?
- What will be the impact on manufacturing? Will the shape of cars change as a result?
- In what ways will roads and pedestrians be safer?

Students are asked to develop their own critical-thinking questions. This discussion leads into an activity where students program autonomous vehicles to maneuver through an obstacle course. After testing, they can assess the challenges encountered in successfully programming the vehicles and discuss how these observations might apply to creation of driverless cars.

A second example at the high school level asks students to role play a famous inventor of technology. Students must research the context in which the inventor lived and worked, the special obstacles they faced, and the impact of their invention on society. Students can prepare a presentation for the class with a list of critical-thinking questions they ask of the class during and after their in-character presentation.

In a third example, the teacher in a high school cybersecurity class has posed a scenario in which a bank's computer system has been hacked. Students need to work together using computational thinking to determine how the hacking was accomplished, how to thwart the electronic invasion, and how to get the bank's system back online. The teacher begins this project by asking questions during the introduction and teacher demonstration. Students are taught how to ask critical-thinking questions of each other in small teams in order to help develop solutions. The teacher circulates the room, listening in on the small group discussions. A rubric is used by the teacher to partially assess students on their participation as identified by asking critical-thinking questions. When the students begin to write countermeasures through programming, their critical-thinking questions and discussion should lead to positive solutions. After the project is complete, the teacher asks the groups critical-thinking questions about their solutions, including what they would change.

Technology & Engineering Practice: Optimism

Overview

The National Academy of Engineering (NAE, 2010) identified optimism as one of six engineering habits of mind and defined it as a "world view in which possibilities and opportunities can be found in every challenge and an understanding that every technology can be improved" (p. 45). According to the NAE (2019b), "engineers, as a general rule, believe that things can always be improved. Just because it hasn't been done yet, doesn't mean it can't be done. Good ideas can come from anywhere and engineering is based on the premise that everyone is capable of designing something new or different" (para. 5). In a similar vein, the UK's Royal Academy of Engineering (2014) identified improving as an engineering habit of mind that involves “relentlessly trying to make things better by experimenting, designing, sketching, guessing, [and]…prototyping” (p. 50). Improving might be said to be at the heart of technological and engineering activity, because this practice embodies the ingenuity and know-how that precede successful development of technological products and systems. It also acknowledges the trade-offs that are inherent in the creation of any technology, and the need to seek optimal solutions.

A more nuanced view of optimism in technology and engineering classrooms is that it is a direct reflection of a student’s motivation to succeed. Technology and engineering design challenges require dedication and focus to identify satisfactory solutions. This is accomplished when students display the persistence or “grit” to keep working on a problem or challenge.

The desirability of having a positive attitude about the ability of technology and engineering to make the world a better place must be tempered by critical thinking and attention to ethics. Belief that the world can be improved through technology and engineering should not suppress critical analysis or lead to limited or naïve points of view about the role of technology and engineering, illustrating the importance of systems thinking, with its holistic approach to technological activity.

Optimism (or improving) as a technology and engineering practice can be developed in students through awareness of prior inventions and innovations, including the details of their development and the outcomes of their use. During open-ended design challenges, students can be encouraged to dig more deeply to identify improvements to design solutions, rather than focusing on initial ideas. By providing support, instruction, and mentoring at key points within a lesson, teachers can help students build a sense of confidence by facilitating successful completion of tasks. Students can be encouraged to reflect on their work in ways that help them articulate what strategies were successful and what barriers they encountered in solving a problem. This type of metacognitive activity helps them build a critical awareness of their own abilities as a thinker and learner.

Examples of Optimism in Technology and Engineering

In a middle school technology education class, the teacher presents a project that offers multiple opportunities to exhibit optimism and persistence. Three student teams are given an open-ended problem to develop an urban farming system that does not use electricity and that prevents water loss. Each team brainstorms ideas and potential solutions for a rooftop farm. As students near completion of their design phase, the teacher announces that teams will not be developing their own ideas but will have to develop the ideas from a different group. The teacher models how to approach this fresh problem as an opportunity. After the development phase, the student teams are directed to use the development plans from a different group to construct the farming systems as a scale model. In order to drive home the message about the importance of optimism and persistence, the teacher has an open discussion during closure to solicit student reflections on the process. This middle school project was developed at Massachusetts Institute of Technology.
In a second example, a high school-level activity focuses on use of scientific visualization to illustrate or analyze a STEM concept. Beginning with selection of a STEM process, students must justify both their selection and their target audience. In one example, a student selects the process of converting mechanical energy to electrical energy within a turbine, with the goal of demonstrating to middle school students how turbines can convert moving water or wind into electricity. The student must research this conversion process and also learn about computer hardware and software tools that can be used to create the visualization. Achieving a successful product requires consideration of color, movement, perspective,

and other attributes. Through testing on peers and, eventually, with students from the target audience, the student will continue to refine their project until an effective visualization is achieved.

Technology & Engineering Practice: Collaboration
Overview Collaboration is about working with one or more people to accomplish a goal. As we go through life we face different challenges, some routine and some more difficult. At times, we may realize that we are not adequately equipped to solve those problems on our own. We realize that we need the assistance of others. In other situations, we may realize that multiple perspectives are needed in order to achieve a satisfactory outcome and thus we seek out collaborators who bring differing areas of knowledge and expertise to the table. Collaboration is a learned skill. Educators understand that “collaboration is essential in our classrooms because it is inherent in the nature of how work is accomplished in our civic and workforce lives” (NEA, 2019, p. 19). Prior to entering school, students may never have experienced collaboration in a group setting. The challenge is to ensure that students understand that even though they may not agree with others’ opinions, those opinions are valuable and should be considered. Collaboration and teamwork leverage the perspectives, background knowledge, skills, and dispositions of team members to accomplish tasks. As a result, more ideas are brought to the table and a greater amount of critical analysis can be done, contributing to the likelihood of success in design and other kinds of activity. Technology and engineering classrooms and laboratories offer unique opportunities for students to work together in an effort to solve design challenges. Completing hands-on activities to solve real-world problems is the cornerstone of technology and engineering. Working in collaborative teams is also common in technology and engineering but can be expanded upon. Students, particularly those with limited project collaboration experience, will benefit from guidance on how to structure a group activity so that all perspectives are considered, there is equitable distribution of the workload, and team members develop a sense of accountability to the group. Collaborative efforts can also be enhanced by expanding membership in the groups to include students from other classes to include interdisciplinary perspectives. Teleconferencing tools have also made it possible to rethink classroom boundaries, opening the potential to bring in collaborators from other regions and countries.
Examples of Collaboration in Technology and Engineering An example of a collaborative activity demonstrates how having students communicate with each other helps them learn group dynamics and how to work as a team. While focusing on a communication activity, students at the K-2 grade level could learn strategies for communicating in a team setting. Realizing that working in a team may be very new to these young students, the challenge is to help students understand the role they play as a team member. An activity might be as simple as asking students to communicate with each other to solve a simple technological problem. Each team would then discuss the problem and report to the class how they worked together to solve the problem.

Another example occurs in a high school engineering class located near a major theme park. The theme park announced plans to tear down an original structure and install a new roller coaster in its place. The technology and engineering teacher took this opportunity to create a new design project by assigning small groups to design and build key sections of a model roller coaster based on a theme that would fit into the local amusement park. The real engineer working on the project visited the class to give a presentation on what is involved in roller coaster design. The students came up with a wild west theme for the roller coaster with sections of the final coaster going through gold mining areas, small western towns, and the highest point of the track topping out on Hopi tribe mesas. The teams collaborated to construct a model roller coaster using flexible scale-model railroading track and custom-designed coaster cars. When completed, the theme park engineer was invited back to discuss and critique their project.

Technology & Engineering Practice: Communication

Overview

Communicating is an activity we experience and practice daily. People must adequately articulate their thoughts and ideas in order to properly function in society. Possessing complex communication and social skills is necessary both for taking in and processing information as well as for conveying information to others. The National Academy of Engineering wrote that, in the context of engineering design, “communication is essential to effective collaboration, to understanding the particular wants and needs of a ‘customer,’ and to explaining and justifying the final design solution” (NAE, 2009, para. 8). Communication is a process that people use to inform, educate, persuade, control, manage, and entertain. Obviously, good communication skills are necessary for people to be successful in school and future occupations. Today, students must process and analyze more communications than ever before in the history of humankind. They must determine which resources are accurate, which are important, and which require some type of response. In addition to receiving and understanding information from others, students must develop the skills necessary for formulating and clearly communicating their own thoughts and ideas.

We learn to communicate from birth. Communication skills develop through experience and repetition of those experiences. Before students enter formal schooling, they learn to communicate by interacting with their family and friends. In an educational setting, teachers provide new experiences in the classroom. Very possibly, entering kindergarten may be the first experience a child has to communicate in a diverse or unfamiliar environment. In school, the goal is for students to receive a teacher’s message, process it, and then apply relevant information to themselves, their lives, and the lives of others. Students must be attentive and learn to receive and decipher the meaning of what is being communicated to them.

Technology and engineering students experience problem-solving activities in classrooms and laboratories. Often, these activities require collaborating with others. In addition to developing their individual problem-solving skills, students are expected to learn how to communicate their ideas and the solutions they used to solve a problem. During group activities each student is expected to listen to other students, express their own ideas and points of view through language, drawings, or models, and then discuss the shared information to solve a problem or issue. Often, students must also prepare formal presentations to explain their work, whether in the form of technical reports, spoken presentations, via drawings or models, or through other means.

Examples of Communication in Technology and Engineering

In an elementary school design challenge based on the Disney Toy Story movies, students are told that they need to design a device to help the toys travel back home from their adventures. Given an assortment of resources, student teams design and build devices that can carry the toys safely back to their toy shelves. Students reflect after the activity about which communication style and decision-making method they used within their group: consensus, majority, or loudest voice. Introduction to communication styles in small-group work at the elementary level can develop better communication skills as students move up to middle school and beyond.

A second activity, designed for high school students to develop their communication skills, is the Technology Student Association (TSA) Prepared Presentation competitive event (TSA, n.d.). Students learn that presenting information to an audience is frequently used to communicate facts and ideas. Students prepare and deliver an oral presentation that includes audio and/or visual enhancement based on the current year's Technology Student Association conference theme. Each student pays particular attention to the interest and appeal of the introduction. Their presentation must be clearly and sequentially organized. Students' stage presence (personal appearance, poise, posture, attitude, personality, and confidence) is evaluated. Students must demonstrate proper grammar, pronunciation, articulation, and clarity of voice. Students provide a conclusion tying together the information presented. When all students have completed their presentations, classroom discussion begins. Discussions may focus on the challenges of gathering, sorting, and organizing information; what graphical principles were most effective in conveying information; strategies that helped them overcome shyness about speaking in front of an audience; and why it is important for students to become good public speakers.

Technology & Engineering Practice: Attention to Ethics

Overview

The teaching of ethics starts with young children at home, on the playground, in daycare, and other places. Simple lessons on sharing toys, speaking respectfully to others, and knowing the difference between right and wrong are presented to children. Additionally, children learn that there are consequences for breaking rules. These lessons and admonishments continue into the elementary years and beyond. Although there may be more resistance to these messages from students at the middle and high school level, the idea that society must rely on all citizens to be ethical in their decisions and treatment of others is the basis of a stable society. In some cultures, the sense of ethics may be stronger than in others. For example, in Japan, a found wallet is typically turned in to the police for return to its owner. In other cultures, this might not happen.

Teachers try to help their students learn to work effectively in small groups and to respect people with exceptional needs or who are different from themselves. Reading selected books (e.g., Dr. Seuss stories) to the class can reinforce the ideas of respect for other people and the environment. Preparing written reports in social studies about negative historical events and their consequences helps students see beyond their own home and world. Ethics in education and real life includes the standards and values of integrity, discipline, and honesty. Teachers should model ethics by treating students equitably, respecting differences in students, and not singling out students in front of the class. Students, in turn, should respect their instructor and agree to abide by class rules. This is accomplished more easily when students work with the teacher to develop class rules.

Any technology or system designed by technologists and engineers should be evaluated for its potential impact on people, society, and the environment. Sometimes, unintended consequences and impacts don't become apparent until after production and distribution have been initiated. Furthermore, these impacts might affect some groups or places differently than others, making identification of consequences more challenging, but also more critical. The National Academy of Engineering (2019b) refers to this attention to ethics in technology and engineering design as "conscientiousness," which focuses on the responsibility of engineers to consider the moral issues involved in their work. With multinational corporations becoming more global in structure, it is also important for people to learn to respect and work with people from other cultures.

In the technology and engineering classroom, students should be taught that over-optimism about solutions can lead engineers into murky ethical dilemmas. Through discussion of selected examples, they can better understand the differential impacts that a technology can have on individuals and on the environment, setting the stage for critical thinking to inform decision making. Students can be taught how to use techniques such as risk analysis, technology assessment, cost-benefit analysis, and decision diagrams. To be truly effective, any technology needs to do not just the immediate task for which it was designed but should be optimized to perform the necessary functions the least harmful impacts on users and the environment possible.

Examples of Attention to Ethics in Technology and Engineering

In an elementary after-school Girls in STEM Club, fifth-grade girls go on field trips, host guest female engineer speakers, and work on engineering projects. The goal of this club is to increase the number of girls considering STEM careers in their future. One project that they work on is a Special Needs Mobility Project where the girls design and construct a cardboard device for moving mobility challenged students through a typical elementary school classroom and then giving a presentation about their solution. This project allows the girls to weigh numerous ethical considerations including gender equality, respect for exceptional students, and testing the impacts of their designs.

An example occurs in a high school technology and engineering course. The instructor logged into www.ePALS.com to locate a technology teacher in a foreign country to jointly plan a transnational project for their students. A Japanese teacher expressed interest in this idea and a project was developed that linked student teams to work on a scale-model International Space Station (ISS). The work was done in WebQuest and the teams consisted of two American and two Japanese students working on different components (living quarters, power, experiment bay, and control) of the ISS. To build engagement, the students were told to design the ISS for teenagers living in space. Occasional teleconferences were held for the two classes to show and discuss bottlenecks and meeting project deadlines. When the balsawood scale model was completed in the U.S., it was shipped to Japan for painting. Eight U.S. technology education students travelled to Japan to put the ISS together as part of a large media event at Mie Gakuen High School in Tsu City. This project met many goals of attention to ethics, primarily learning to respect and work with other cultures.

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