Standards for Technological and Engineering Literacy

The Role of Technology and Engineering in STEM Education

A joint project of International Technology and Engineering Educators Association (ITEEA) and its Council on Technology and Engineering Teacher Education (CTETE) 2020.

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ITEEA

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DEDICATION

William E. Dugger, Jr.
1937-2018

The inspiration for *Standards for Technological and Engineering Literacy (STEL)* was Dr. William E. Dugger, Jr., who led the *Technology for All Americans Project* in the 1990s, first publishing *Standards for Technological Literacy (STL)* in 2000, and tirelessly traveling the globe to explain and promote *STL*. Due to his persistence, the technological literacy standards were adopted by states, districts, provinces, classroom teachers, textbook companies, test developers, other professional associations, and many other ITEEA stakeholders. He was a friend and colleague to us all. *Standards for Technological and Engineering Literacy* is dedicated to his memory.

PREFACE

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The importance of educational programs that focus on the study of technology has not waned since the publication of *Standards for Technological Literacy* in 2000. Then, as now, the primary outcome sought is enhanced technological literacy among all students. The goal is to develop individuals who have a broad, conceptual understanding of technology and its place in society, enabling them to be active participants in the technological world and careful creators and users of technology. All technological systems are embedded within social and environmental contexts and all have, or will have, both intended and unintended consequences. Many of our current global problems were created by our technological choices. This increases the need for technologically literate citizens who participate in decision making.

Extensive changes have taken place in education in the past twenty years. There is an increased emphasis on design, and specifically on technology and engineering design, in the PreK-12 curriculum. This reflects a commitment to design-based learning and an acknowledgement that learning can be enhanced through inquiry, critical thinking, hands-on making and doing, and a focus on learning skills that students can apply throughout their lives, regardless of context. Additionally, there is societal recognition of the role played by science, technology, engineering, and mathematics (STEM) education in preparing students for college and career readiness, including high-skill careers. In spite of this recognition, the role that technology and engineering play, and should play, in the education of PreK-12 students is often narrowly defined and misunderstood. *Standards for Technological and Engineering Literacy* aims to address these needs.

Standards for Technological and Engineering Literacy articulates the role that technology and engineering play within STEM, but the interdisciplinary connections between technology and engineering to other subject areas do not stop with science and mathematics. It is recognized that literacy comprises capabilities within a broader array of subject areas, including language arts, social studies, and the arts. Therefore, the standards attempt to highlight the larger interdisciplinary nature of study in technology and engineering, in which social, ethical, economic, environmental, and aesthetic factors must be considered alongside technical factors. The processes of designing, making, and doing have long been hallmarks of the technology and engineering education laboratory-classroom and provide ample opportunities for students to consider and apply content knowledge, skills, and dispositions from many disciplines.

Standards for Technological and Engineering Literacy provides an updated vision of what students should know and be able to do in order to be technologically and engineering literate. The document does not define a singular curriculum model nor does it claim to serve as STEM standards. It describes what the content and practices of technology and engineering education should be in Grades PreK-12. It will be up to states and provinces, school districts, teachers, and others to develop curricula based upon these standards in ways that make sense for particular educational settings.

Standards for Technological and Engineering Literacy has departed from the original 2000 *Standards for Technological Literacy* document in several notable ways. The number of core content standards has been reduced from twenty to eight and associated benchmarks from 288 to 142. This reflects input from the technology and engineering profession and from other members of the STEM community, and a desire to focus on what might be termed "power" standards—that is, standards and benchmarks that define the enduring ideas and abilities that will withstand technological changes over time. The former "designed world" standards have been reconceived here as technological and engineering *contexts* in which the core standards are applied. This reflects a desire to move beyond an approach that attempts to cover an overly broad scope of technological and engineering activity to one that more realistically allows for local emphases and variations while still helping students assimilate and apply the core content and practices. For each context area, examples of curricular approaches are suggested. In addition, the document outlines technological and engineering *practices* that identify key attributes and personal qualities that all technology and engineering students should exhibit. Thus, *Standards for Technological and Engineering Literacy* is a foundation upon which educators can build curricular approaches and assessments, design learning environments, connect with the larger educational community, and prepare students for their future.

This work was made possible through grants from the National Science Foundation and the Technical Foundation of America. We are indebted to the members of the revision project's leadership team, who have been part of this effort from its inception, the review/writing team members who shared their time and expertise in helping the document take shape, and the many individuals who have reviewed and provided feedback on drafts of the document. We hope that this document will serve as a catalyst to continue to promote the goal of technological and engineering literacy for all.

01

The Need for *Standards for Technological and Engineering Literacy*

Technology and engineering are pervasive in all aspects of our lives. Every human activity is dependent upon the products, systems, and processes created to help grow food, provide shelter, communicate, work, and recreate. As the world grows more complex, it is increasingly important for everyone to understand more about technology and engineering. People need to understand technology's impacts on their lives, society, and the environment, as well as how to use and develop technological products, systems, and processes to extend human capabilities. These understandings are all important elements of technological and engineering literacy.

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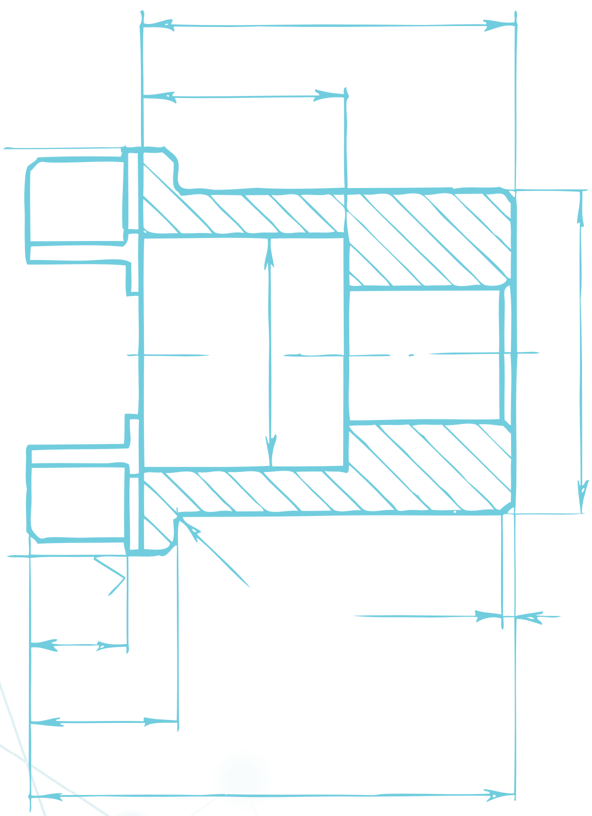
The Need for *Standards for Technological and Engineering Literacy*



Defining Literacy

Literacy once referred simply to the ability to read and write, but today is much more broadly defined. A report by the National Academies of Sciences, Engineering, and Medicine (2016) contrasted *foundational literacies*, referring to textual literacy and numeracy, and *disciplinary literacy*, or knowledge within a specific domain. Both are useful concepts, and content standards for any disciplinary field must arguably address both types of literacy. Literacy is a fluid construct, meaning that knowledge, skills, and abilities in a given field will change over time. There are a number of links between scientific, technological, engineering, and mathematical literacy, yet each has some defining features. One important defining feature of technological and engineering literacy is the emphasis on process and action, including designing and making. The purpose of *Standards for Technological and Engineering Literacy* is to articulate the components of technological and engineering literacy. Although "STEM literacy" is less well defined, many have argued that enhanced literacy across these four disciplines will yield the kind of functional literacy needed to solve our most pressing societal needs.

Technological and Engineering Literacy for All

All children, adolescents, and adults need to know more about technology and engineering. A primary reason is to increase society's overall understanding about an area that impacts all facets of our lives, yet about which few have a deep knowledge. For example, many people view technology merely as communication devices such as smartphones and computers, which represents a narrow understanding of the definition of technology. Similarly, many people think of engineering as merely an occupation, without understanding how engineering connects to their everyday lives. The goal is not to make everyone technologists or engineers but to broaden technological and engineering literacy so that people can make informed decisions about technology and better contribute to its design, development, and use.

The increased call for people to enter science, technology, engineering, and mathematics (STEM) occupations is an important reason for more people to study technology and engineering. STEM jobs create new goods and services through research and development and contribute to our overall quality of life. Technology and engineering, however, have not traditionally been considered core subjects in PreK-12 education and thus have not received the same educational focus as science and mathematics. All occupations require the use of technological products, systems, and processes, and therefore people with higher levels of technological and engineering literacy are better prepared for the workforce. Occupations required in a modern society demand people who are critical, transdisciplinary thinkers with the ability to adapt to new technologies. This need can be addressed by expanding technology and engineering education.

Technology and engineering have a tremendous impact on us as consumers. Everything we purchase, from homes and automobiles to food, clothing, and medicine, is a result of technological and engineering activity. Increasing the overall level of technological and engineering literacy will help consumers better understand design parameters, manufacturing processes, and critical concepts such as sustainability and product life cycle, among others. Consumers with a better understanding of technology and engineering will make better-informed decisions regarding the products they buy and the services they use.

Technology and engineering impact even our leisure activities. For example, the sports, games, and recreational activities we engage in are often equipment-intensive. This equipment was developed and continues to evolve through iterative design and the inclusion of new materials and processes. Injuries from these activities are treated through the use of diagnostic and rehabilitative medical technologies. These are examples of the pervasive use of technology and engineering in our society about which people may give little thought. Understanding the relationships between our leisure activities and technology and engineering can make our activities safer and more enjoyable.

A final example regarding the importance of technological and engineering literacy for all is provided by considering socio-cultural implications. Technological products, systems, and processes are designed and created for an intended purpose but can often be used in unintended ways or have unpredictable or undesirable consequences. For example, although an herbicide might be highly effective with regard to reducing farm labor demands, it may later be determined to have detrimental impacts on animals and humans. These types of socio-technological issues arise all too often because not all outcomes regarding the design and implementation of technology can be predicted, or because of a narrow focus on a limited set of design parameters. Learning about technology and engineering can equip people to consider and address the broader implications of decisions about technology and engineering.

The reasons why all people should study technology and engineering go far beyond the preceding examples of our occupations, consumerism, leisure activities, and culture. The core disciplinary standards, technology and engineering contexts, and practices described in this document provide a comprehensive structure that details the elements of technological and engineering literacy for all. The result is a document that provides a map for teachers, administrators, and other education professionals to create rigorous and relevant PreK-12 technology and engineering programs.

Teaching and Learning about Technology and Engineering

The value and importance of technological and engineering literacy is accepted by a wide group of experts. Despite this consensus, formal technology and engineering courses are not available in all schools. Some countries, states/provinces, and localities have put compulsory technology and engineering education programs in place, but many students receive little or no exposure to the study of technology and engineering, particularly those in Grades PreK-5. They are graduating with minimal understanding of one of the most powerful forces shaping society today.

Technology and engineering are complex and constantly evolving, so teachers should spend less time on discrete facts and more time on the broad dimensions of knowing, thinking, and doing in the context of technology and engineering. The *knowing* dimension involves taking in information, organizing it, and understanding factual and conceptual relationships. The *thinking* dimension entails making sense of information through questioning, analysis, and decision making. The *doing* dimension involves using technology and engineering in applied ways such as designing, making/building, producing, and evaluating. All three of these dimensions—knowing, thinking, and doing—are symbiotic and equally important in the development of technological and engineering literacy.

The goal of technology and engineering education is to develop students with a breadth of knowledge and capabilities who see the interactions between technology, engineering, and society and can use, create, and assess current and emerging technologies. This goal is achieved by focusing teaching and learning across all three domains of learning: cognitive, affective, and psychomotor. The benchmarks in *Standards for Technological and Engineering Literacy* are written using action verbs that progress across the grade bands within these domains. The intent is to help curriculum developers and teachers scaffold instruction in increasingly sophisticated ways as students advance in their study of technology and engineering.

Although the T & E in STEM are often treated synonymously, it is necessary to more closely define the intent of including engineering within the context of *STEL*. *STEL* does not attempt to encompass the full spectrum of engineering content. Technological and engineering literacy, with its emphasis on technological products, design, and technology/society interactions, affords a broader base than would a more exclusive focus on engineering and its content subfields (e.g., mechanical, civil, electrical, and so on). Another way this relationship has been expressed is by referring to the disciplinary study of engineering as a noun (Engineering), and the use of engineering design and application of engineering habits of mind as a verb (engineering). This latter characterization is used in these standards. In this formulation technology provides the base for the *STEL* document, while engineering (as a verb) connects the key ideas and selected engineering practices and habits of mind that provide critical linkages within STEM and to the broader educational environment.

Technological and Engineering Studies as a Disciplinary Integrator

All educational subjects have characteristics that define the discipline: content, an epistemological basis, and a history of practice, inclusive of curricula, teaching, and research. These characteristics drive the educational process, but disciplines are not formed in a vacuum and do not evolve in isolation. Education is, by nature, interdisciplinary. At first glance, technology and engineering education may seem solidly grounded in the sciences and mathematics, but there are also strong connections to the arts and humanities. For example, developers of transportation systems such as trucks and electric cars must consider not just the technical aspects of personal mobility but also aesthetic principles that will appeal to users; human factors principles that will enable the vehicle to be safe and to better fit the needs of users; social factors that will influence acceptance and adoption of the device; and communication of ideas, plans, and marketing through proficient technical writing skills. These interdisciplinary connections are crucial for technological and engineering literacy and are a fundamental element found throughout *Standards for Technological and Engineering Literacy*.

The acronym STEM is perhaps the most visible reference to technology and engineering's interdisciplinary relationships. Too often, however, what passes for "STEM education" involves an unbalanced focus on science and mathematics, with marginal attention to technology and engineering. This is likely due in part to the fact that science and mathematics are considered core subjects in most schools while technology and engineering, when offered, are typically electives. Furthermore, an exclusive focus on STEM downplays the role that other disciplines must play in successful technological and engineering activity. *Standards for Technological and Engineering Literacy* is designed to help educators better understand what technology and engineering education is and how to teach it, while also highlighting the multi-disciplinarity that is at the heart of technological and engineering literacy.

One of the challenges in communicating a clear understanding of technological and engineering literacy is that it encompasses such a broad area of human activity, one that is constantly evolving. *Standards for Technological and Engineering Literacy* attempts to distill this broad field into a set of essential knowledge, skills, and dispositions (the eight core standards and associated benchmarks) that are widely applicable across a range of contexts and that incorporate acknowledged technology and engineering practices. These are described more fully in the chapters that follow. By focusing on essential knowledge, *Standards for Technological and Engineering Literacy* defines a level of literacy that is expected of all learners across the PreK-12 spectrum, much as we expect all students to achieve a certain level of language literacy, scientific literacy, and mathematical numeracy. Technological and engineering literacy is as fundamental to successful participation in the modern world as these other forms of literacy.

Technology education, which involves the study of human-designed products, systems, and processes to satisfy needs and wants, is arguably the broadest disciplinary structure encompassing dozens of specialties. These range from technical education (focused on preparation for a career in specific technical fields), to information technology/computer science, to the many engineering sub-specialties, among others. Technology and engineering education, as defined in *Standards for Technological and Engineering Literacy*, provides an effective launching point for continuing study to prepare individuals for a career in these more specialized fields. Technology and engineering education in the PreK-12 environment also provides essential foundational understandings and abilities for all individuals, regardless of their college or career aspirations.

An important feature of technology and engineering education is its unique set of delivery methods that involves hands-on, design-based strategies to teach and engage students. These authentic experiences often come from co-curricular activities such as service learning projects or participation in student organizations such as the Technology Student Association (TSA). Co-curricular activities frequently include engaging students in design challenges, technical competitions (e.g., VEX Robotics and TEAMS), and informal learning experiences such as museum visits. The technology and engineering contexts and practices contained in the following chapters provide comprehensive details about the unique pedagogies used in technology and engineering learning environments.

Standards for Technological and Engineering Literacy does more than provide a checklist for the technological facts, concepts, and capabilities that students should master in a technology and engineering laboratory-classroom. Technology and engineering teachers, as well as art, language, history, science, mathematics, and other educators, have a role in helping all students become technologically and engineering literate. Technology and engineering are pervasive in all we do throughout our lives, and this should be reflected in broad teaching and learning experiences. The world is constantly changing, and we must provide students with the knowledge, technology and engineering knowledge and dispositions to be lifelong learners capable of adapting to these changes.

02

Overview of *Standards for Technological and Engineering Literacy*

Standards for Technological and Engineering Literacy presents, in a systematic manner, what students should know and be able to do in order to achieve a high level of technological and engineering literacy. In other words, the standards prescribe what the outcomes of the study of technology and engineering in Grades PreK-12 should be and in this way provide guidance for educators who wish to update their curricular approaches at the local, state, and national levels.

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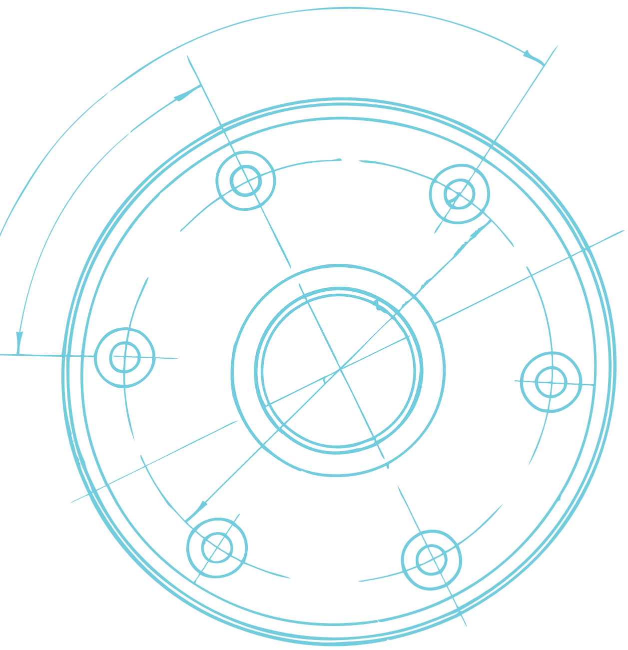
Overview of *Standards for Technological and Engineering Literacy*



TECHNOLOGY is the modification of the natural environment, through human-designed products, systems, and processes, to satisfy needs and wants.

ENGINEERING is the use of scientific principles and mathematical reasoning to optimize technologies in order to meet needs that have been defined by criteria under given constraints.

TECHNOLOGICAL AND ENGINEERING LITERACY is the ability to understand, use, create, and assess the human-designed environment that is the product of technology and engineering activity.

The foundation for *Standards for Technological and Engineering Literacy* was established with the release in 1996 of *Technology for All Americans*: *A Rationale and Structure for the Study of Technology*, ITEEA's (then ITEA) *Standards for Technological Literacy* in 2000, and, in 2019, *Standards for Technological Literacy Revision Project: Background, Rationale, and Structure*. The 2019 *Background, Rationale, and Structure* document provided an exploratory look at the structure and content for the study of technology and engineering, and *Standards for Technological and Engineering Literacy* is a refinement and elaboration of this work.

The original *Standards for Technological Literacy: Content for the Study of Technology (STL)* document was released by the International Technology Education Association in 2000. Many changes have occurred since then, including new standards in other disciplines (e.g., the *International Society for Technology in Education Standards* and *Next Generation Science Standards*); an increased focus on STEM, engineering, and 21st Century Skills (Partnership for 21st Century Learning, 2019); and development of new or emerging technologies. These changes prompted work to revise *STL* into *Standards for Technological and Engineering Literacy*. Like the original *STL*, *Standards for Technological and Engineering Literacy* (henceforth referred to as *STEL*) is not a prescriptive curriculum but rather a description of the content that should be covered in PreK-12 curricular models developed at regional and local levels. The single biggest difference between *STL* and *STEL* is the reduction in the number of standards from twenty to eight. The seven Designed World standards were re-conceptualized as contexts in which the core disciplinary standards and benchmarks are taught, rather than as standalone standards.

General Structure of *Standards for Technological and Engineering Literacy*

Globally, technology and engineering programs have varying structures and content. Thus, a student taking a technology and engineering course in one region may not receive the same core information or study the same basic concepts and principles as a student in another region, even when the course titles are identical or similar. *STEL* provides a consistent set of core content standards for the study of technology and engineering that will enhance the learning of PreK-12 students, regardless of where they live or their future goals. For example, these core disciplinary standards can be applied equally well in a robotics course in the United States, a textile design course in New Zealand, or an electronics course in Egypt.

In Chapter 3, *STEL* prescribes the core content knowledge and skills that should be learned and accomplished by each student in the study of technology and engineering at four levels, beginning with Grades PreK-2 and continuing through Grades 3-5, Grades 6-8, and Grades 9-12. The standards and benchmarks are tailored to be age-appropriate and are planned so that the material at each level builds on, amplifies, and extends the standards and benchmarks of earlier grades.

Features of *Standards for Technological and Engineering Literacy*

STEL was created with the following basic features:

- It offers a common set of expectations for what students in technology and engineering or STEM laboratory-classrooms should learn through the dimensions of knowing, thinking, and doing.
- It is developmentally appropriate for students.
- It provides a basis for creation of meaningful, relevant, and articulated curricula at the national, state/provincial, and local levels.
- It promotes interdisciplinary connections with other school subjects in Grades PreK-12.

STEL is not a curriculum. A curriculum provides specific details on how the content is to be delivered, including organization, balance, and the various ways of presenting the content in the laboratory-classroom, whereas standards describe what the content should be. Curriculum developers, teachers, and others should use *STEL* as a guide for developing appropriate curricular approaches for a given setting. In laying out the essentials for the study of technology and engineering, *STEL* represents a recommendation from educators, technologists, engineers, scientists, mathematicians, and parents about what skills and knowledge are needed in order to become technologically and engineering literate.

STEL does not prescribe an assessment process for determining how well students are achieving the standards, although it does provide criteria for such assessments, whether formative or summative. Assessment practices deal with how well students learn the content and abilities put forth in *STEL*. Closely tied with assessment is how well a teacher has directly taught and guided students in the learning process, as well as how much support the school and school district have provided in this effort. The ultimate goal in any educational assessment process should be to determine how well each student is attaining technological and engineering literacy in Grades PreK-12. Assessment takes place in many forms, from daily records of students' work via design notebooks, interviews, quizzes and tests, projects, prototypes, and portfolios of longitudinal activities in the laboratory-classroom, to standardized tests. Plans for comprehensive assessment throughout a student's education must be designed, implemented, and regularly monitored. As with all successful instruction, the developed curriculum and assessments should align with the objectives of the adopted standards.

As a final note about the features of *STEL*, readers will find a minimal number of citations within the document. This stylistic decision was made in an effort to enhance the document's readability. However, a comprehensive bibliography of the references used in the creation of *STEL* can be found in Appendix C. The 2019 ***Background, Rationale, and Structure*** document (Buelin et al., 2019) also provides a preliminary review of literature that was conducted to inform the work done on *STEL* in early summer 2019, prior to the *STEL* revision conference.

Basic Structure of *Standards for Technological and Engineering Literacy*

Three organizers used within *STEL*, when embedded into courses and activities, work together as an effective framework for teaching technological and engineering literacy. These include the core disciplinary standards, technology and engineering practices, and technology and engineering contexts (Figure 2.1). This graphical depiction can be imagined as a set of three octagons that can be rotated to indicate application of the core standards across a range of disciplinary contexts and using a variety of technology and engineering practices.

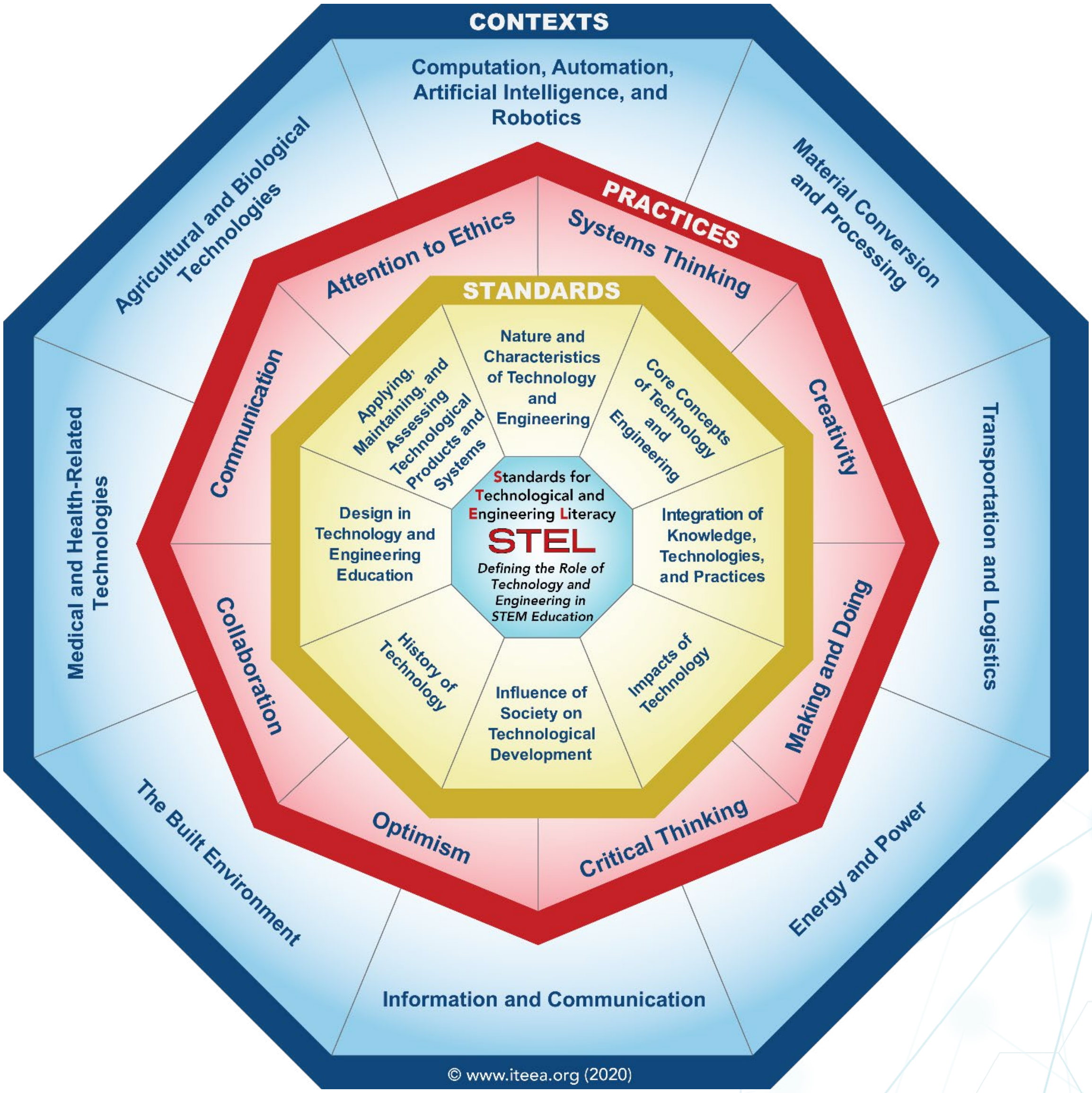


Figure 2.1. Three technological and engineering organizers for teaching.

02

The *core disciplinary standards* represent information, ideas, and processes that are common to all context areas. The eight *context* areas replace the "Designed World" standards found in the original *STL*. Then, as now, they are meant to encompass the broad areas of technological activity in which humans are engaged. The relationship between the core standards and context areas should be apparent in this document. For example, the ideas, concepts, and principles found within the core disciplinary standard "History of Technology" can be used to understand the influence of a given communication technology on human well-being. Technology and engineering *practices* describe universal practices and dispositions that can be applied in both the core standards and contexts. For example, students working in a team (collaboration) could analyze (critical thinking) the impacts of the printing press upon human progress. Simply stated, the core disciplinary standards are common and universal to the eight technology contexts. Students apply the eight technology and engineering practices in developing a firm understanding of these standards and contexts.

Core Disciplinary Standards

The eight core disciplinary standards presented in *STEL* are described in Chapter 3. The standards include:

1. Nature and Characteristics of Technology and Engineering
2. Core Concepts of Technology and Engineering
3. Integration of Knowledge, Technologies, and Practices
4. Impacts of Technology
5. Influence of Society on Technological Development
6. History of Technology
7. Design in Technology and Engineering Education
8. Applying, Maintaining, and Assessing Technological Products and Systems

When applied in educational settings, these standards guide students to understand technology and engineering; become familiar with technology and engineering concepts; and recognize the relationships between technology, engineering, and other fields of study. *STEL* examines the use of technology and engineering in a broader context by examining technological effects on human society and the built and natural environments, by exploring how societal factors shape technology and engineering practices, and by tracing the history of technology. Additionally, students develop an understanding of design processes with an emphasis on the attributes of design, the engineering design process, and other problem-solving approaches, and they acquire abilities in designing, making, developing, operating, maintaining, managing, and assessing technological products and systems.

STEL specifies what every student should know and be able to do in order to be technologically and engineering literate, while offering criteria to judge progress toward a vision of technological and engineering literacy for all students. As a whole, the eight core disciplinary standards and their associated benchmarks fall into three types: what students should know and understand about technology and engineering, what they should be able to do, and their attitudes towards technology and engineering. The first type, ***cognitive*** benchmarks, set out basic knowledge about technology—how it works, and its place in the world—that students should possess in order to be technologically literate. The second type, what might be called *process* benchmarks, describe the ***psychomotor***, organizational, and procedural abilities that students should have. The third type of benchmark falls into the ***affective*** domain, describing how students receive, respond to, value, organize, and characterize technology and engineering. The three types of benchmarks are complementary. For example, a student can be taught about design processes, but the ability to use a design process and to apply it to develop a solution is only fully developed through hands-on experiences. Likewise, it is difficult to perform a design process effectively without having some theoretical knowledge of the technical parameters of the design challenge. Success in design can be attributed to motivation and persistence, which are tied to the affective domain.

Format of the Core Standards

Each core disciplinary standard follows this format:

- The number and title of the standard is given.
- A narrative follows, which explains the intent of the standard. Key ideas for each standard are presented in bold text.
- Grade-level material is presented next for Grades PreK-2, 3-5, 6-8, and 9-12. Under each grade band, a narrative explains the standard and provides suggestions on how the standard can be implemented in the laboratory-classroom at that grade band.
- Each grade-band overview is followed by a series of benchmarks that detail the particular knowledge, skills, and dispositions that students must attain in order to meet the standard. Each benchmark begins with a verb linked to the cognitive, psychomotor, or affective domain. Each benchmark is further explained by supporting sentences that offer examples and additional details.

Benchmarks

Benchmarks in *STEL* identify the fundamental content elements for the broadly-stated standards. Benchmarks are objectives that outline the knowledge, skills, and dispositions that will enable students to meet each of the given standards at the PreK-2, 3-5, 6-8, and 9-12 grade levels. The benchmarks begin with a verb, are identified by an alphabetical listing (i.e., A, B, C), and are highlighted in bold type. They are followed by supporting sentences that provide further detail, clarity, and examples. The benchmarks describe what is required in order for students to meet each standard.

Research in education has shown that when previously learned knowledge is tapped and built upon, students are likely to acquire a more coherent and thorough understanding of concepts and processes than if they are taught as isolated abstractions (National Research Council, 2012). With this in mind, the *STEL* benchmarks are articulated from Grades PreK-2 through 9-12, progressing from very basic ideas at the early childhood level to more complex and comprehensive ideas at the high school level. This does not mean that the verbs in the PreK-2 benchmarks were only written at the lower levels in the cognitive domain, however. In addition, certain concepts found in the benchmarks extend across grade levels to ensure more complete learning of an important topic related to a standard.

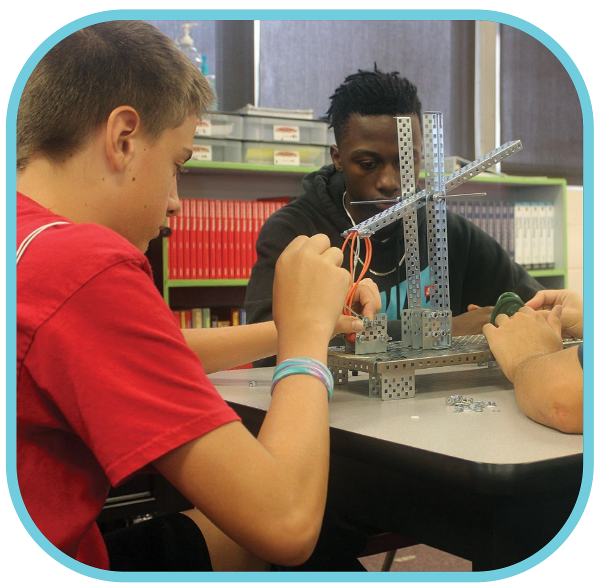
The standards and benchmarks were established to guide students' progress toward technological and engineering literacy. Resources referenced in the development of *STEL* included standards from other subject areas, such as *Next Generation Science Standards* (NGSS Lead States, 2013b); *Standards for Mathematical Practice* (Common Core State Standards Initiative, 2019); *Criteria for Accrediting Engineering Programs* (Accreditation Board for Engineering and Technology [ABET], 2016); and others.

Technology and Engineering Practices

The technology and engineering practices detailed in Chapter 4 were adapted from the 21st Century Skills (Partnership for 21st Century Learning, 2019) and from research on engineering habits of mind (e.g., National Academy of Engineering, 2019b). The result is a student-centered set of practices that reflect the knowledge, skills, and dispositions students need in order to successfully apply the core disciplinary standards in the different context areas.

The eight Technology and Engineering Practices, as covered in Chapter 4, are:

1. Systems Thinking
2. Creativity
3. Making and Doing
4. Critical Thinking
5. Optimism
6. Collaboration
7. Communication
8. Attention to Ethics



Systems thinking refers to a holistic understanding that all technologies are composed of interconnected parts and that they are embedded within larger systems (e.g., ecosystems) that impose constraints upon them. It also includes an understanding of the universal systems model, which examines technologies in terms of their inputs, processes, outputs, and feedback mechanisms. *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 and build technological products and systems. This may be accomplished using computer software, hands-on tools, or other methods, and in most cases comprises some form of kinesthetic learning. *Critical thinking* involves logical thinking, reasoning, and questioning in the process of making informed decisions.

Optimism, in the context of technology and engineering education, means having a belief that technologies can be improved and 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. *Collaboration* refers to having the perspectives, willingness, and capabilities to work as part of a team in which all members' inputs are valued. *Communication* in technology and engineering education can be considered in two ways: as a tool used to understand the wants and needs of the intended users or the community, and as a means to explain and defend choices made in the design process. Communication is used in problem formulation, research, report writing, analyzing, evaluating, and creating solutions. *Attention to ethics* is at the core of living in society. In technology and engineering education, attention to ethics means focusing on the impact of technological products, systems, and processes on others and the environment. Students should evaluate risks and consider trade-offs in their decision making.

Technology and Engineering Contexts

Chapter 5 identifies the eight contexts that are common to technology and engineering education. These might also be thought of as content areas, applications, or disciplinary topics. The technology and engineering contexts presented in *STEL* describe the settings where the core disciplinary standards and benchmarks are taught or applied. For example, a robotics class taught at the secondary level in the United States might have a unit or activity matched to Standard 1, Benchmark 1Q: *Conduct research to inform intentional inventions and innovations that address specific wants and need*s. This same benchmark could be taught in other technology and engineering courses, or even in other academic classrooms. In this example, the standard and benchmark would be grouped within Context 1: Computation, Automation, Artificial Intelligence, and Robotics.

The narrative provided for each of the eight technology and engineering contexts provides a description of the context, conceptual understandings within that context, and an overview of possible settings in that context. Also included are brief examples of how students at each grade band could apply specific core disciplinary benchmarks from Chapter 3 into lessons within the context. These brief examples are meant to illustrate how *STEL* might be implemented across a range of common technology and engineering courses. Further work on implementation models must be done by curriculum developers (including ITEEA's STEM Center for Teaching and Learning™) and teachers to translate *STEL* into curriculum models and instructional materials for different educational settings.

The eight technology and engineering contexts are:

1. Computation, Automation, Artificial Intelligence, and Robotics
2. Material Conversion and Processing
3. Transportation and Logistics
4. Energy and Power
5. Information and Communication
6. The Built Environment
7. Medical and Health-Related Technologies
8. Agricultural and Biological Technologies

Primary Users of *Standards for Technological and Engineering Literacy*

A variety of groups and individuals can be expected to use *STEL*. Curriculum developers, textbook publishers, and developers of laboratory equipment may be among the first users of the document. Teacher educators should use the document in designing pre-service programs for future technology and engineering teachers. Teacher certification providers may find the standards helpful in developing certification exams for technology and engineering teachers. Ultimately, the success of *STEL* rests with teachers.

Other users of *STEL* will include superintendents, principals and other administrators, curriculum coordinators, directors of instruction, and supervisors, all of whom are part of planning, overseeing, and delivering standards-based education. Professional and nongovernmental organizations such as the National Academies, National Assessment Governing Board (NAEP TEL), and Organisation for Economic Cooperation and Development (OECD PISA) may consult this document when updating their assessments of technology and engineering literacy. Furthermore, parents can familiarize themselves with the document in order to become involved with their children's education and to reinforce the concepts and processes being taught. Parents of home-schooled children can incorporate *STEL* into their instruction.

Recommendations for Using *Standards for Technological and Engineering Literacy*

Individuals involved in curriculum development, teaching, or assessment should consider the following recommendations:

- *STEL*, taken in its entirety, is intended to provide a comprehensive picture of technological and engineering literacy. For optimal literacy, upon graduation from high school students should have met all standards.
- The benchmarks specify how students progress toward technological and engineering literacy and what students need to know and be able to do in order to meet the standards.
- The standards should be integrated with one another rather than being presented as separate parts.
- *STEL* should be included in the curriculum at each grade, particularly in the technology and engineering laboratory-classroom but also in other subject areas, as appropriate (e.g., elementary science classes). Teachers should be familiar with standards for grades preceding and following the grade level at which they teach.
- *STEL* should be applied in conjunction with other national, state, provincial, and locally developed standards in technological and engineering studies and related fields of study.

- School systems should begin to move toward a PreK-12 technology and engineering program for all students.

A variety of resources, including instructional materials, textbooks, supplies, and kits to aid the laboratory-classroom teacher, are necessary to support *STEL*. These resources should be age-appropriate, gender-neutral, and progressively more rigorous and richer in content, with a clearly designated level of application specifying one or more of the four grade bands (PreK-2, 3-5, 6-8, and 9-12) to maximize impact. These resources should allow for alterations that consider the changing nature of technology and engineering; include various teaching methodologies, and differentiate the teaching to accommodate students of varying abilities; feature experiences and activities that enhance and promote authentic learning, including problem-based and design-based learning; and incorporate varied methods of assessment in order to provide a broad picture of students' progress.

Standards for Technological and Engineering Literacy and STEM Collaborations

The acronym STEM does not refer to a unitary content area. However, *STEL* operates from the premise that the integrated approach suggested by "STEM" is an important one, and may be necessary for achieving the kind of functional literacy needed to solve our pressing societal needs. *STEL* further recognizes that technology and engineering are critical to, and must be better articulated within, STEM. ITEEA has authored, with Advance CTE, the Association of State Supervisors of Mathematics, and the Council of State Science Supervisors, the document *STEM⁴: The Power of Collaboration for Change*. It articulates three principles to drive STEM education:

1. STEM education should advance the learning of each individual STEM discipline. This principle allows for the integrity of learning the individual disciplinary concepts even within integrative STEM experiences. Content from each discipline is delivered without changing its basic structure, purpose, or rigor.

2. STEM education should provide logical and authentic connections between and across the individual STEM disciplines. The academic disciplines of science, technology, engineering, and mathematics contain natural, coherent connections for students at all ages. In particular, technology serves as a means for highlighting these coherent connections and engaging with the creative thinking and problem solving required by authentic, real-world scenarios. All four disciplines work together as students engage in design challenges, laboratory experiences, and tasks that integrate the disciplinary concepts.

3. STEM education should serve as a bridge to STEM careers. Student interest and confidence in STEM are strongly correlated with postsecondary success in STEM fields. Career advising should be a key component of STEM education. For example, meaningful interactions with industry experts and authentic experiences within STEM workplaces can help students make connections to academic content and explore their STEM-related interests.

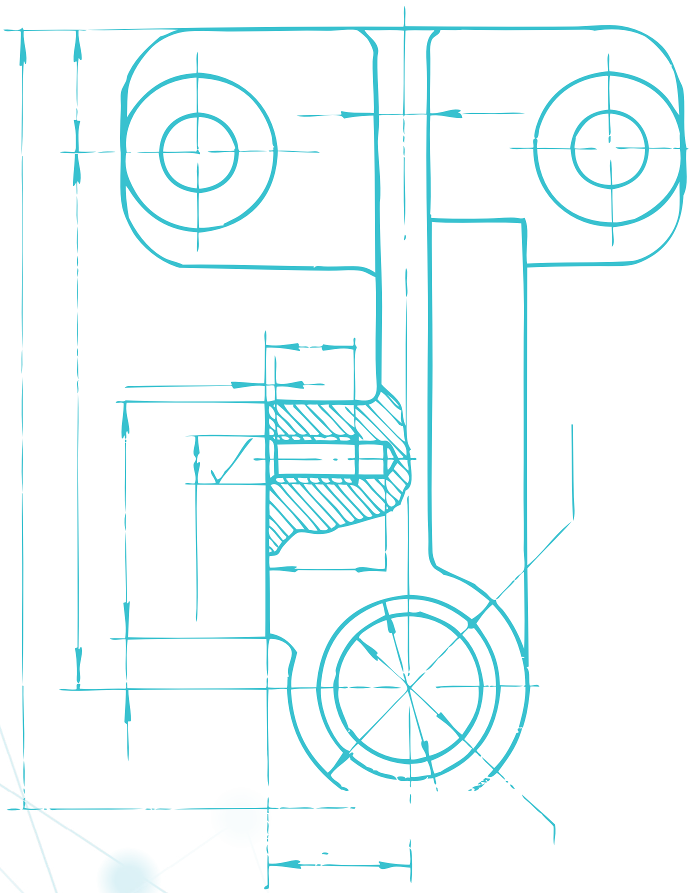
03

Core Disciplinary Standards

The eight core disciplinary standards and 142 benchmarks that follow are the critical descriptors of what all students should know and be able to do in technology and engineering education.

03

Core Disciplinary Standards



The eight core disciplinary standards presented in this chapter include:

1. Nature and Characteristics of Technology and Engineering
2. Core Concepts of Technology and Engineering
3. Integration of Knowledge, Technologies, and Practices
4. Impacts of Technology
5. Influence of Society on Technological Development
6. History of Technology
7. Design in Technology and Engineering Education
8. Applying, Maintaining, and Assessing Technological Products and Systems

The format of each standard follows this structure:

- The standard is expressed in sentence form.
- A narrative follows that explains the intent and key ideas of the standard. Key ideas are the bold text in the narrative.
- Material is presented by grade bands: PreK-2, 3-5, 6-8, and 9-12. Under each grade band is a short explanation of the standard at that grade band, with suggestions on how the standard can be implemented in the laboratory-classroom.
- Each grade-band overview is followed by a series of benchmarks that detail the knowledge and abilities that students must attain in order to meet the standard. Each benchmark begins with an active verb linked to the cognitive, affective, or psychomotor domain.

Benchmarks in *STEL* provide the essential content elements for the standards. Benchmarks are objectives that define the knowledge, skills, and dispositions needed to meet each of the given standards at the PreK-2, 3-5, 6-8, and 9-12 grade bands. The benchmarks are identified by an alphanumeric listing (e.g., STEL-1A, STEL-6B, STEL-7C) and are highlighted in bold type. They are followed by supporting sentences (not in bold) that provide further detail about how the benchmarks can be implemented in order for students to meet the standards.

Standard 1: Nature and Characteristics of Technology and Engineering

The words *technology* and *engineering* have many meanings and connotations, some of which were defined and explained in Chapter 1. In order to build a foundation for the study of technology and engineering, students must first gain an understanding of the nature and characteristics of these disciplinary fields. These foundational understandings can then be expanded upon to develop the knowledge, skills, and dispositions that are associated with technological and engineering literacy.

Three key ideas clarify the nature and characteristics of technology and engineering. The benchmarks that follow all link back to these key ideas, with increasing levels of specificity and complexity across the grade bands. The first key idea is that the study of technology and engineering requires knowledge of the natural world and the human-made world. Students learn that there are similarities and differences between the natural world and human-made world and that changes in one can have intended and unintended impacts on one or both. A firm understanding of this first key idea will lead to advanced concepts such as designing to imitate nature (biomimicry) and design for sustainability.

A second key idea is that the study of technology and engineering as a human activity is interdisciplinary. Many connections have been drawn between science, technology, engineering, and mathematics. However, each discipline brings unique characteristics to STEM education:

- *Technology* is the modification of the natural environment through human-designed products, systems, and processes, to satisfy needs and wants.
- *Engineering* is the use of scientific principles and mathematical reasoning to optimize technologies in order to meet needs that have been defined by criteria under given constraints.
- *Science* involves investigation and understanding of the natural world.
- *Mathematics* enables communication and critical analysis and is how we make sense of the human and natural world using numbers and computational reasoning.

The study of technology and engineering draws upon knowledge, tools, and processes from across the human experience. This can refer to the processes by which knowledge is obtained and through which technological products and systems are created. It can also be used very broadly in reference to an entire system of products, knowledge, people, organizations, regulations, and social structures (e.g., the technology of the electric grid, or the entirety of the internet).

Although they have some unique characteristics, the design processes used in technology and engineering are similar to the discovery and design processes embedded within other disciplines.

03

In science education, the term *scientific method* has traditionally been used to describe a linear process with a prescribed series of steps that scientists follow when investigating cause and effect relationships of phenomena in the natural world. A more accurate description of scientific inquiry for the classroom is that it provides a platform for student-centered approaches for investigating phenomena in the natural world. Students pose questions and develop scientific inquiries to test their created hypotheses. This approach moves away from the scientific method, which often uses linear approaches to lab investigations (sometimes called "cookbook" science). Recent research and practices in science education have suggested that, similar to design processes used in technology and engineering, scientific inquiry is not a linear process. Portions of scientific inquiry have been re-conceptualized as a progressive process more accurately reflecting practices of scientists in the field and including elements from the design process as described in technology and engineering education.

In mathematics education, practices such as engaging in quantitative and abstract reasoning, modeling systems, looking for patterns and structure, and constructing viable arguments allow students to communicate and analyze mathematical phenomena. In addition, mathematical processes contribute to communicating and analyzing phenomena. These processes include problem solving, reasoning and proof, communication, connections, and representations. In technology and engineering education, the design process has long depicted an iterative process where students design, test, and redesign in recursive fashion, often yielding a variety of potential solutions.

Models for technology and engineering design are often adapted to suit the grade band and abilities of students. These models provide a blueprint to help students integrate content from various disciplines while solving problems related to the natural and human-made worlds. Technology and engineering education is more than design, however; it includes use of tools, developing and maintaining technological systems, innovation, and analysis of technological developments, to name a few.

A third key idea is that the study of technology and engineering involves the ability to understand, use, assess, and create technological products, systems, and ways of thinking. As a result of their knowledge and innovations, people have modified the world to provide both necessities and conveniences. A technologically and engineering literate person understands the significance of technology and engineering in everyday life. Throughout history, modification of the natural world has taken on different forms. Understanding these forms can lead to greater knowledge about human innovation.

Grades PreK-2

In Grades PreK-2, young children begin to understand that people use technology and engineering design to adapt the natural world to help them meet human needs and wants. They also begin to see how science relates to the natural world and technology relates to the human-made world, identifying the differences between them. In addition to learning how to safely use age-appropriate tools (scissors, pencils, rulers), materials (plastic, wood, glue), and processes (improve, create, imagine), children should begin to explore how technology, science, mathematics, and engineering have shaped their world.

Technological, scientific, mathematical, and engineering practices should be encouraged at an early age; children are natural problem solvers.

Young children are aware of the world in which they live, but they do not generally know the origins of the technologies they encounter. For instance, students may not understand how the food they eat is grown, transported, and processed. By learning how technological systems such as buildings, highways, phones, and computers have altered the natural world, students can begin to comprehend the vast influence of technology on their lives.

To demonstrate their understanding of the nature and characteristics of technology and engineering, students in Grades PreK-2 should be able to:

STEL-1A. **Compare the natural world and human-made world.** The natural world includes trees, plants, animals, rivers, oceans, mountains, and other items that make up the earth's landscape, biomes, and climate. The human-made world includes pencils, rulers, computers, buildings, airplanes, roads, refrigerators, communication devices, and other items developed for the betterment of humans.

STEL-1B. **Explain the tools and techniques that people use to help them do things.** By using technology and engineering, people adapt the natural world to meet their needs and wants and to solve problems. All people use tools and processes created through technology and engineering in every aspect of their daily tasks.

STEL-1C. **Demonstrate that creating can be done by anyone.** Using technology and engineering tools and techniques, anyone can design or improve things to enhance their lives. Creation of new knowledge, approaches, and inventions can occur through either individual or collaborative efforts. Even young children can view themselves as creators.

STEL-1D. **Discuss the roles of scientists, engineers, technologists, and others who work with technology.** Technological advancement does not occur without the teamwork of many people who have knowledge and skills in distinct areas. Being able to recognize the unique contributions of these individuals is a necessary part of the technological and engineering design process. Young children can develop an appreciation of how people with different specialties can collaborate to design, create, build, and test a product or system. Analogies often work well with students in this grade band. For example, they can understand how a vehicle is purchased from a dealer, maintained by a mechanic at a service center, and driven by a family member. All of these people have something to do with the vehicle, but each in their own way.

Grades 3-5

In these grades, the study of technology and engineering should build on previous learning by increasing the students' understanding of the useful applications of technology. As students continue to develop a clearer understanding of the natural world and the human-made world, they will acquire a sense of the relationship between technology, engineering, mathematics, and science.

When students design, make, or use various technologies, they should begin to see that different processes and techniques are utilized. Teachers should provide opportunities for students to engage in a variety of experiences in order to better understand the best strategies for carrying out tasks, depending on the situation and the need.

Students in this grade band should continue to develop solutions to challenges. Those challenges should be drawn from their understanding of the world—both in their local communities and in the broader, global community. Students should develop a connection to solving problems they see, and know that through the technology and engineering design process they can design, build, and improve solutions to address the challenges they see around them.

In addition, students in Grades 3-5 should investigate how people's perceptions of the world have evolved as technologies have advanced. For example, students can explore how media has enabled us to view stories and news from any part of the globe, how transportation systems have made it possible to travel across a country in a few hours, and how information systems have empowered people to receive information almost instantaneously.

Technological development is shaped by economic and cultural influences. As new technologies appear and some demands are satisfied, the wants of humans change, new ideas and innovations emerge, and the cycle repeats itself. This ongoing effort to improve products and systems means that technologies continually change.

To demonstrate their understanding of the nature and characteristics of technology and engineering, students in Grades 3-5 should be able to:

STEL-1E. **Compare how things found in nature differ from things that are human-made, noting differences and similarities in how they are produced and used.** For example, the essentials for natural plant growth are sunshine (photosynthesis), air, water, and nutrients; whereas human-made items require an idea, resources (e.g., time, money, materials, and machines), and techniques. Things found in nature, such as trees, birds, and wildflowers, require no human intervention. On the other hand, creating human-made products, such as shoes, requires human effort and innovation.

STEL-1F. **Describe the unique relationship between science and technology, and how the natural world can contribute to the human-made world to foster innovation.** People have, from the beginning, looked around to identify and use the materials and resources available to improve their lives. Raw materials and resources are shaped into tools, systems, and forms of energy to provide people with products that satisfy a need or want. Energy is harnessed to provide power and heat, and animals and crops are raised for food and clothing. These and other processes continue today as people use raw materials to create items they want and need.

STEL-1G. **Differentiate between the roles of scientists, engineers, technologists, and others in creating and maintaining technological systems.** The roles of scientists, engineers, and technologists are interrelated, yet each contributes a unique area of expertise to every endeavor. Students should be able to identify how individuals with different areas of content knowledge inform the creation of technology, and why this collaboration is important.

STEL-1H. **Design solutions by safely using tools, materials, and skills.** People use appropriate tools and skills to help them do their work (e.g., a carpenter uses a hammer to build a house; a doctor uses diagnostic imaging machines to treat patients). People also use resources, such as metal, wood, cloth, and stone, to make things they use every day.

STEL-1I. **Explain how solutions to problems are shaped by economic, political, and cultural forces.** For example, the interests, desires, and financial resources of a group of people will influence the type of transportation system developed for that community. A transportation system for a large city may rely on mass transit, while one in a smaller town might rely on personal vehicles.

Grades 6-8

Students in the middle grades will explore in greater detail the scope of technology and engineering. From personal and classroom experience, students will be familiar with specific ways in which technology changes, including an emphasis on how creativity is central to the development of products and systems.

Creating an invention or innovation is closely related to addressing a need or want, but in some cases the creation of something new precedes identification of a need. For example, Percy Spencer, an engineer at Raytheon Corporation, conducted tests on a radar project using vacuum tubes in the mid-1940s. When running the experiment, a candy bar in his pocket melted. This unexpected result led to the development of microwave ovens.

For innovation to occur, a critical analysis of a problem must take place within the context of creating new knowledge. This is often achieved through research and development (R&D), which is the practical application of scientific, mathematical, and technical knowledge to create new and improved products, processes, and services that fill market needs. For example, knowledge developed about microprocessors by engineers and scientists led to the development of modern computer systems. Companies spend considerable resources on developing new understandings of how things work in hopes of creating new products and systems or of improving existing ones. Students can evaluate the commercial applications of technologies and how economic, political, and environmental concerns have influenced their development and adoption.

To demonstrate their understanding of the nature and characteristics of technology and engineering, students in Grades 6-8 should be able to:

STEL-1J. **Develop innovative products and systems that solve problems and extend capabilities based on individual or collective needs and wants.** For example, the news is full of stories about young innovators such as Marie Elena Grimmett, who at age 14 developed a system for using recyclable plastic beads to filter out a harmful antibiotic used to treat livestock and commonly found in water supplies in rural areas. This development process entails the important step of problem finding, which often results from needs or wants that students have identified in their own lives or the lives of family members.

STEL-1K. Compare and contrast the contributions of science, engineering, mathematics, and technology in the development of technological systems. Students at this level can discern the contributions the fields of science, engineering, mathematics, and technology (as well as other disciplines) contribute to the advancement of technological tools and systems. One way this can be accomplished is by conducting case studies of specific technologies and learning more about their history.

STEL-1L. Explain how technology and engineering are closely linked to creativity, which can result in both intended and unintended innovations. Creativity requires an individual to use knowledge and experience from different subjects to create something new or to use something in a new way. Many inventions are inspired by perceived needs and wants—the toothbrush, for example. Other inventions emerge in unexpected ways. For example, Stephanie Kwolek was working to find a replacement for steel cords in tires when she inadvertently invented Kevlar. Creatively exploring new ideas is often key to improvement of technological products and systems.

STEL-1M. Apply creative problem-solving strategies to the improvement of existing devices or processes or the development of new approaches. Design and problem solving are seen as iterative processes that involve idea generating, making or building possible solutions, testing, and redesign. Creative problem solving allows for new insights that lead to improvements such as greater efficiency, better performance, lower environmental impacts, and so on. For example, students learning about aerodynamics might devise modifications to a model rocket design to make it more streamlined and accurate.

Grades 9-12

In Grades 9-12, students will gain a broader perspective of the importance of human innovation and ingenuity in refining existing technologies and developing new ones. They will also continue to develop higher-order thinking skills, such as analyzing, designing, and critiquing. By the time they graduate, students should have developed a strong understanding of the relationship between technology, engineering, mathematics, and science, among other disciplines. This realization includes knowing specifically what technology and engineering are and recognizing that they have intellectual domains and content bases of their own.

Technology and engineering are intricately woven into the fabric of human curiosity and are influenced by human capabilities, cultural values, public policies, and environmental constraints. Students need to recognize these influences and understand how their integration can inform technological development. For example, the development of earmuffs was a direct result of harsh, cold winters. Chester Greenwood, a young boy whose ears seemed to be especially sensitive to the cold, decided to develop something new. He designed a special device made of loops of wire and covered with black velvet and beaver fur. Neighbors and friends were so pleased with Chester's invention that they, too, wanted earmuffs, and thus a demand was created, which led to an 1872 patent for this accessory. The particular environment, in addition to human creativity, capability, and the resulting demand, determined the success of earmuffs.

New technologies change the world around us in both expected and unexpected ways. Technological advances build on prior developments and lead to additional opportunities, challenges, and advances in an accelerating spiral of complexity. These advances make modern society vastly different from what was known even as recently as two or three generations ago.

Students should realize that inventions occur both by intentional design (e.g., putting a human on the moon) and by serendipity (e.g., 3M Post-it® notes and NASA spinoff technologies). They should realize innovations can also be planned and intentional, such as refinement of Edison's light bulb, while others grow unexpectedly out of lines of work that take off in new directions that were not initially anticipated. Technological and engineering design, or the purposeful application of scientific and technical knowledge, speeds up development, while various changes in the physical, political, or cultural environment can speed up or slow down technological development. For example, the Cold War accelerated the development of both military and space technologies. In contrast, the early enthusiasm for hydrogen fuel cell-powered vehicles has not yet resulted in their widespread adoption in the consumer market, due to technological, political, and economic barriers.

To demonstrate their understanding of the nature and characteristics of technology and engineering, students in Grades 9-12 should be able to:

STEL-1N. Explain how the world around them guides technological development and engineering design. Technological developments are best achieved through experiences and interactions within a given context. For example, design of buildings should take into account local conditions including soil type, wind, and snow loads, and should also match local building codes and building styles.

STEL-1O. Assess how similarities and differences among scientific, mathematical, engineering, and technological knowledge and skills contributed to the design of a product or system. Developing and improving products or systems require scientific, engineering, and technical expertise. Articulating how knowledge and skills from each contributed or will contribute to a product or system is a necessary component of innovation and design.

STEL-1P. Analyze the rate of technological development and predict future diffusion and adoption of new technologies. The rate of development of inventions and innovations is affected by many factors, such as time and monetary investment. Many new technologies build upon previous technologies, often resulting in quick development and dispersion. For example, the rapid development of consumer-scale drone technologies has built upon earlier military applications of these devices. Predicting the future of this technology will entail looking at its market potential across a variety of applications and considering the legal and cultural barriers that might slow adoption.

STEL-1Q. **Conduct research to inform intentional inventions and innovations that address specific needs and wants.** Years of research led to the design and development of laser systems used in atmospheric studies and other applications (LiDAR or LADAR). This same type of laser system was then modified and reapplied to treat the buildup of plaque in the arteries through laser angioplasty (i.e., surgical repair of a blood vessel such as an artery).

STEL-1R. **Develop a plan that incorporates knowledge from science, mathematics, and other disciplines to design or improve a technological product or system.** Designing, maintaining, and improving products or systems often require unique knowledge and skills. For example, a botanist could diagnose problems associated with crop growth, allowing an agricultural engineer to design a system for automating the care required for better crops, which in turn requires a technologist to provide maintenance and feedback on the system for maximum efficiency. These experts rely on collaboration to design, maintain, and improve products or systems.

Standard 2: Core Concepts of Technology and Engineering

Like other branches of knowledge, technology and engineering have a number of core concepts that characterize and distinguish them from other fields of study. These concepts serve as cornerstones for the study of technology. They help unify the study of technology and engineering by helping students understand the designed world.

The core concepts of technology and engineering define fundamental aspects of technology and should be integrated into technology and engineering education classes at every opportunity and in various contexts. Seven core concepts are presented below as key ideas that define Standard 2, but can also be found interspersed throughout the other standards. They include:

- **A system is a group of interrelated components designed collectively to achieve a desired goal.** Systems thinking involves understanding how a whole is expressed in terms of its parts, and conversely, how the parts relate to each other and to the whole. Systems should be studied in different contexts, including the design, troubleshooting, and operation of systems, both simple and complex.
- All technological activities require resources, which are the essential inputs needed to get a job done. **Basic technology and engineering resources (or inputs) include tools and machines, materials, capital, money, knowledge, energy, time, and, most importantly, people.** Tools and machines are those devices designed to extend and enhance human capability. Materials have many different qualities and can be classified as natural (e.g., wood, stone, metal, and clay), synthetic (e.g., glass, concrete, and plastics), and composite (materials engineered to improve properties; e.g., plywood and metal alloys). Capital is represented by physical assets such as buildings, equipment, and other assets necessary for the creation of products and systems. Money allows for purchase of materials, tools, and other needs. Knowledge is the information needed to solve technological and engineering problems. Energy is the ability to do work; all technological systems require

energy to be converted and applied. Time, which is allotted to all technological activities, is limited, and therefore its effective use is critical in technological endeavors. All of these resources are important, but without some form of human input nothing can be designed, processed, or implemented.

- Requirements are the expected outcomes of a completed product or system and present the designer with limitations, criteria, constraints, and opportunities during the development process. Collectively, these can be considered the design parameters that guide technological and engineering activity. Some of these may include safety needs, legal restrictions, available resources, cultural norms, time, and technical expertise.
- Trade-offs encompass a choice or exchange of one quality (or requirement) over another. For example, the decision to favor the best material regardless of weight in order to achieve maximum strength may require a designer to make a trade-off of costs or weight. In order to meet established requirements, trade-offs are made in order to achieve the characteristics of an optimal design. By definition, trade-offs involve compromises; it is impossible to optimize every requirement.
- Optimization is a process or methodology of designing or making a product, process, or system to the point at which it is the most fully functional and effective. The entire process of creating should include optimization—from the initial idea to the final product or system. Most often, optimization requires making trade-offs.
- A process is a systematic sequence of actions used to produce an output. Beginning students may use trial-and-error or tinkering, but as students advance they need to learn more formal technology and engineering processes. Designing is the process of applying knowledge and creative skills in the development of a product. The process of making models, as well as modeling in virtual environments, is used to demonstrate concepts and to try out visions and ideas. Maintenance is the process of working with the parts of a system or the system as a whole to ensure proper functioning and to prevent unnecessary errors. Management, which is the process of planning, organizing, and controlling technology, is used to control resources and to ensure that technological processes operate effectively and efficiently. Assessment of products and systems is the process of asking questions and examining events to uncover deeper patterns or problems. The end goal of assessment is to improve the process or system.
- Controls are the mechanisms or activities that apply information to cause systems to behave in desired ways. The household thermostat is an example of a control used to regulate room temperatures. Controls may not always succeed or work perfectly. Understanding the role of feedback, or the use of information about the system to regulate its inputs and functions, is important in being able to determine how controls work in various kinds of systems.

Grades PreK-2

Students in early childhood education will acquire a basic understanding of many core concepts of technology that will help them as they learn more about the subject. Repeated exposure to those concepts will enable them to make connections and begin to recognize patterns in technological development. They should begin to notice, for example, how the use of a system, such as a heating and cooling system, depends on resources and requirements.

Through hands-on activities students will learn that technology and engineering activity requires tools, materials, actions, safety, and planning. In addition, they will discover that many of these core concepts relate to their daily lives. For example, a young child making a device out of Lego® components quickly learns that achieving the desired results requires a plan; that the more complex the device being made, the more time it will require to build; and that they are limited in their ability to build objects by the number of Lego® parts they have in their possession. Simple electronic devices that contain control elements readily illustrate the concept of feedback. The laboratory-classroom should have available a variety of opportunities for students to discuss, explore, and apply these core concepts.

To demonstrate their understanding of the core concepts of technology and engineering, students in Grades Pre-K-2 should be able to:

STEL-2A. Illustrate how systems have parts or components that work together to accomplish a goal. For example, a bicycle can be thought of as a system. It has many parts—wheels, handlebars, pedals, brakes, gears, and chains—and each is important for the bicycle to function properly.

STEL-2B. Safely use tools to complete tasks. Many tools have specific functions and selecting the right tool makes the task easier. People use tools to make objects, to achieve a desired outcome, and to communicate. Children use scissors to cut paper, glue sticks to fasten components together, markers to sketch ideas, and computers to search for information.

STEL-2C. Explain that materials are selected for use because they possess desirable properties and characteristics. Paper, wood, cloth, cardboard, and found objects are the most common materials young children use in making the items they design. By working with materials, they learn through observation and testing which materials perform better for given tasks.

STEL-2D. Develop a plan in order to complete a task. For example, young children learn that if they want to accomplish something, such as design and make a birthday card for a parent, they must have the materials available, and they must have the card ready by a given date.

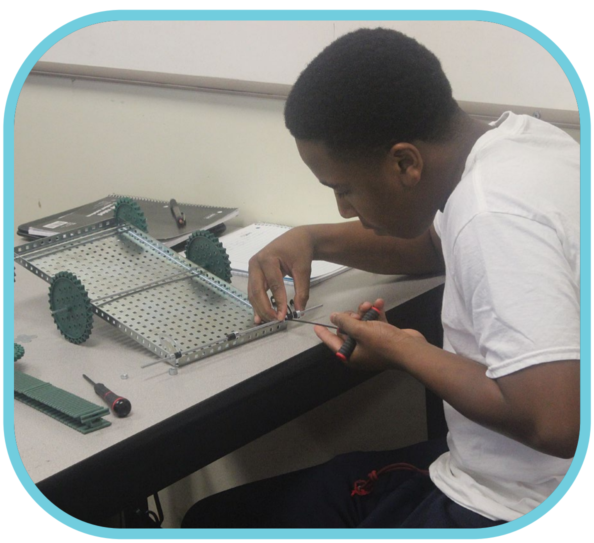
STEL-2E. Collaborate effectively as a member of a team. To operate at the most effective level, team members must learn to communicate and work together as a unit. Strategies to work together in a team must be modeled by the teacher and laid out as an expectation within the laboratory-classroom setting.

Grades 3-5

In Grades 3-5, a strong emphasis is placed on the concepts of systems, resources, requirements, and processes. At this level, becoming more familiar with the core concepts of technology will enable students to develop a more holistic picture of the study of technology and engineering. For example, students should be able to identify available resources in their own communities. These resources might include tools and machines in their homes, materials used in building the roads and sidewalks they use when going to and from school, or the information needed to use a new product.

Students should have opportunities to classify technological systems in order to explore them more easily. Problem solving is another major skill that students in this grade band practice in mathematics, science, technology, and engineering. Through examination of diverse resources and processes, students can develop additional skills by expanding their knowledge through the use of advanced tools. Whether they are using glue guns, hand tools, or computers with design-oriented software, students should recognize the importance of tools in accomplishing tasks.

Introducing the concept of requirements provides a foundation that will enable students to understand more complex ideas in later grades. Students should begin to understand the parameters that determine a design or how a product will be developed and used—the safety needs, the physical laws that will limit the development of an idea, the resources available, the cultural norms, and so on. Future discussions of requirements will be related to the use of resources and other core concepts of technology and engineering.



To demonstrate their understanding of the core concepts of technology and engineering, students in Grades 3-5 should be able to:

STEL-2F. **Describe how a subsystem is a system that operates as part of another, larger system.** An example of a subsystem is the assemblage of water pipes in a house, which is part of a larger fresh-water distribution system in a town, city, or community.

STEL-2G. **Illustrate how, when parts of a system are missing, it may not work as planned.** A computer does not work when the power fails or when the battery has been removed.

STEL-2H. **Identify the resources needed to get a technical job done, such as people, materials, capital, tools, machines, knowledge, energy, and time.** Elementary students involved in problem-solving activities such as Odyssey of the Mind need to develop a list of resources that they will need for a play they must perform in front of judges. Strategic planning of resources might include the backdrop, costumes, props, what roles the team members will play, and a consideration of deadlines.

STEL-2I. **Describe the properties of different materials.** Students should understand the difference between natural and human-made materials and their basic properties. For example, wood, stone, metal, glass, and concrete are hard and dense; leather, paper, and some metals are flexible; glass and some plastics are transparent. Some materials conduct heat and electricity while others insulate to stop or delay transmission of heat or electricity. The properties of a specific material determine whether it is suitable for a given application.

STEL-2J. **Demonstrate how tools and machines extend human capabilities, such as holding, lifting, carrying, fastening, separating, and computing.** The use of tools and machines, such as glue guns, mini-saws, rulers, scissors, gears, clamps, and computers, makes it possible for people to accomplish more tasks.

STEL-2K. **Describe requirements of designing or making a product or system.** Requirements are the criteria or expected outcomes we use when designing. For example, it is often impossible to

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make a product in a certain way because of the cost of materials or because of time constraints, such as needing the product to be made more quickly than is possible with the method in question. These limits are considered in making decisions about designing and making a product.

STEL-2L. Create a new product that improves someone's life. Inventions are created to fulfill a human need or want. Inventions are the way that humans attempt to improve upon the natural world. Identifying various products that have helped people with disabilities, such as ITEEA's "Dream Ride GoBabyGo Style" initiative, is a good starting point for helping students find needs and consider innovative ways of meeting those needs.

Grades 6-8

After developing a general understanding of the core concepts of technology and engineering in the prior grades, students can now investigate these topics and their interrelationships in greater depth. Many aspects of the development and use of technology deal with these systems, resources, requirements, optimization, trade-offs, processes, and controls. Understanding these main ideas will provide a strong foundation for concept development, application, and transfer of technological knowledge in later years.

Students should continue to explore and learn more details about systems, such as the fact that they can take many forms and that systems may have numerous subsystems. Students might investigate, for example, how work cells function as a subsystem of a larger manufacturing system. Simple and complex systems are a vital part of students' lives. Just as the students have internal organs that will not function outside of their bodies, the parts and subsystems of a technological system will not work properly unless the system is complete. If, for example, a system controlling traffic lights were to suddenly malfunction and cause traffic lights to get out of sequence, the results could include a major traffic jam, an accident, and many irate citizens.

A core idea for students at this grade level is systems thinking, a practice that focuses on the analysis and design of the whole system as distinct from its many parts. Students should learn to look at a problem in its entirety by considering as many possible requirements and trade-offs as they can. Prior to this level, students have tended to concentrate on the parts that make up the whole. This shift in focus can be challenging, requiring students to expand their thinking by considering "what if?" options whose outcomes are unknown. Teachers should approach this technique as an introduction to future work in higher grade levels.

Experiences working with different types of technologies and processes help students learn how devices work, as well as how to fix them when they break or do not perform as designed. This information is used in determining the cause of a malfunction, maintaining products and systems, and managing various aspects of technological development. Understanding various processes requires knowing the context in which a particular process should be used and when it is needed. Therefore, students should have varied opportunities to use many resources, tools, machines, materials, and processes in order to experience the effects of trade-offs and feedback systems. Students need to learn how to determine if a product, service, or system conforms to specifications and tolerances required by a design.

To demonstrate their understanding of the core concepts of technology and engineering, students in Grades 6-8 should be able to:

STEL-2M. Differentiate between inputs, processes, outputs, and feedback in technological systems. Inputs consist of the resources that flow into a technological system. The processes are the systematic sequences of actions that combine resources to produce an output—encoding, reproducing, designing, assembling, or propagating, for example. The output is the result, which can have both positive or negative impacts. Feedback is information used to monitor or control a system. A system often includes a component that permits revising or refining the system when the feedback suggests such action. For example, the fuel level indicator of a vehicle is a feedback system that lets the user know when the system needs additional fuel.

STEL-2N. Illustrate how systems thinking involves considering relationships between every part, as well as how the system interacts with the environment in which it is used. Systems are used in a number of ways. Systems also appear in many aspects of daily life, such as communication systems and transportation systems. Analyzing a system is done in terms of its individual parts or in terms of the whole system and how it interacts with or relates to other systems. For example, discussing a computer system may involve the particular parts of a single computer, or it may include an entire computer network. Discussing a transportation system may involve listing the various parts of a particular form of transport (e.g., airports, airplanes, air traffic control, airport security, etc.), or it may be discussed by comparing the overall attributes of one type of transportation system to another (e.g., the type of vehicles used, energy inputs, control mechanisms, and so on).

STEL-2O. Create an open-loop system that has no feedback path and requires human intervention. An example of an open-loop system is a light switch in a room. The electrical system has no feedback loop but requires someone to flip the switch (input) to send electrons to the bulb (process) and make light illuminate the room (output).

STEL-2P. Create a closed-loop system that has a feedback path and requires no human intervention. Systems can be designed to utilize automated controls that both receive information from the system and take action based on the content of that feedback. An example is the water heater in a home, which has a thermostat to provide feedback and automatically adjusts the system when it needs to be turned on and off.

STEL-2Q. Predict outcomes of a future product or system at the beginning of the design process. Careful designers should consider possible outcomes of a technological product before the product is completed. This is a habit of mind that students should continually expand through design, problem solving, ideation, and systems thinking.

STEL-2R. Compare how different technologies involve different sets of processes. For example, data processing includes designing, summarizing, storing, retrieving, reproducing, evaluating, and communicating information. The processes of construction include designing, developing, evaluating, making and producing, marketing, and managing.

STEL-2S. Defend decisions related to a design problem. By requiring students to defend their actions and communicate their findings after attempting to solve a problem, students develop empathy, flexible thinking, accountability, and metacognition skills (i.e., awareness and understanding of their own thought processes). Helping students develop technology and engineering habits of mind involves the teacher explicitly modeling, teaching, and providing students opportunities to demonstrate expected behaviors.

Grades 9-12

By the time students enter high school, they should be familiar with the core concepts of technology and engineering. At this level, students can begin to analyze how those concepts interact in issues that affect them, their community, and the world. Cross-themed topics, such as how resources can be sustained and how resources are related to requirements or optimization considerations, should be discussed and explored in detail. Students should focus on the concepts of systems analysis, stability of systems, and control systems. They should recognize that the order in which processes are used is variable and that new technologies are often created out of existing ones. Adoption of new technologies is dependent on many factors, including how well they are accepted by users and their costs. Through use and feedback, some technologies are determined to have trade-offs that are unacceptable, and their use is discontinued.

Students need to shift from focusing on how the development of technology affects them locally to a broader, global outlook. The use of systems thinking requires students to examine all aspects of a problem, such as its criteria, constraints, and positive and negative consequences. Using systems thinking helps students to determine if the development of a particular system is worth the effort and cost, and what trade-offs might need to be considered to determine the best approach. Resources can also be examined from a global perspective by exploring the sustainability of the Earth's resources. The management of work and resources is a major factor in the success of the commercial applications of products and systems. Poor management can lead to excessive costs, poor quality, and inefficiency. Good management helps ensure that processes and resources operate effectively and efficiently. The use of schedules, in addition to the allocation of material and space, affects the use of many technologies.

Students should learn that the processes of technology and engineering do not always happen in a linear order. For example, prototypes, which are often made as part of the design process, are used to help assess the quality of a design before the product or system is actually made and used. Likewise, students need to understand that innovations must be brought to market in a deliberate way. Once innovations have been designed, they must be tested and prepared for future use. Because of requirements—capital, timing, demand, and production problems, for example—not all technologies make it to market. The life cycle of a product (or system) spans from its initial concept to its eventual withdrawal from the marketplace. Some product life cycles are quite long, while others may be very short.

The importance of optimization and trade-offs in technological development requires more time and effort for students to understand. Students should have opportunities to use simulation or mathematical modeling, both of which are critical to the success of developing an optimal design. If a mathematical or virtual model is not possible, then students will have to rely on their personal experience and use of physical models. Students will need to recognize the limitations of physical models and the limits their use imposes on being able to make various adjustments.

Likewise, students need repeated exposure to the process of determining trade-offs, because this idea is encountered in many areas of human endeavor, including science, economics, and business, as well as technology.

Finally, the study of controls involves simple as well as complex systems. The human body includes controls that determine breathing, circulation, and digestion. These systems in nature are much more complicated and sophisticated than the most advanced human-made control systems. Reliability, feedback, and the basic function of a control device determine how efficient and beneficial it proves to be. Therefore, students need exposure to an array of experiences and activities that focus on designing and working with control systems.

To demonstrate their understanding of the core concepts of technology and engineering, students in Grades 9-12 should be able to:

STEL-2T. Demonstrate the use of conceptual, graphical, virtual, mathematical, and physical modeling to identify conflicting considerations before the entire system is developed and to aid in design decision making. Systems thinking applies critical thinking and creativity with informed compromises to complex, real-life problems.

STEL-2U. Diagnose a flawed system embedded within a larger technological, social, or environmental system. Systems are made up of components (i.e., subsystems). A food processor is only one component in a larger food preparation system that, in turn, is a component in a larger home system. Troubleshooting a flawed system or product allows students to identify possible areas for improvement. For example, a recycling program at their school might have very low participation rates by students and staff members. Investigating the components of the program (system) will help students identify ways to improve it.

STEL-2V. Analyze the stability of a technological system and how it is influenced by all the components in the system, especially those in the feedback loop. Automated control systems in a vehicle, for example, automatically detect and control the speed of the vehicle.

STEL-2W. Select resources that involve tradeoffs between competing values, such as availability, cost, desirability, and waste, while solving problems. Technological development involves decisions about which resources can and should be used. For example, some homes are very energy efficient, while others consume large amounts of energy due to the selection of materials and appliances and the construction methods used.

STEL-2X. Cite examples of the criteria and constraints of a product or system and how they affect final design. Sometimes requirements can be constraints, criteria, or both. Consideration and management of these requirements are essential in design. For example, online retailers have had to consider the promise of fast home delivery (criteria) with the constraint of distribution center locations in last-mile delivery systems.

STEL-2Y. Implement quality control as a planned process to ensure that a product, service, or system meets established criteria. Quality control is concerned with how well a product, service, or system conforms to specifications and tolerances required by the design. For example, a set of rigorous international standards has been established to help companies systematically increase the quality of their products and operations. As consumers, we rely on quality control in manufacture of the products we purchase and use as a way of protecting the investment we make.

STEL-2Z. Use management processes in planning, organizing, and controlling work. Management is sometimes defined as getting work done through other people. Teamwork, responsibility, and interpersonal dynamics play a significant role in the development and production of technological products. Management processes are used to oversee and guide these functions.

Standard 3: Integration of Knowledge, Technologies, and Practices

There are many opportunities to connect ideas and procedures from different content areas. New products and systems build on previous inventions and innovations, while demonstrating how knowledge acquired in one setting can be applied to another. For example, understanding how to mass produce a biological product developed in a research laboratory is essential to the building of a biotechnology company. The biotechnology industry has learned that there is a vast difference between engineering a product in a laboratory and mass producing it for customers. Research about the various efforts addressing production problems associated with bioprocesses is proving to be vital.

Three key ideas clarify the integration of knowledge, technologies, and processes. The benchmarks that follow all link back to these key ideas, with increasing levels of specificity and complexity across the grade bands. The first key idea is that technology and engineering are interdisciplinary, relating to more than one content area. The interconnection between technology and engineering and other content areas is often not recognized, or it is sometimes taken for granted. Technology is so ubiquitous in our lives that it almost becomes invisible. Through the years, technological advances have assisted people and organizations through innovations that have changed how we live, work, and play, and have led to entirely new fields of study. Effective technology and engineering education promotes transdisciplinary thinking by integrating cross-curricular content and practices necessary for successful technological development.

The second key idea is that technology and engineering impact, and are impacted by, technology transfer with other fields. Science, engineering, and technology have separate identities but are closely connected. Science provides knowledge about the natural world that contributes to many technological products today. In return, technology and engineering provide science with the tools needed to explore the world. These fields have many similarities, such as the development of codified sets of rules and reliance upon testing of theories in science and of designs in technology and engineering. The fundamental difference between them is that science seeks to understand a universe that already exists, while technology and engineering anticipate needs and opportunities and apply knowledge and creativity to develop solutions.

Mathematics and technology have a similar relationship. Mathematics offers a language that expresses relationships in science and technology and provides useful analytical tools for scientists and engineers. Mathematical practices and processes help students analyze data in order to make informed choices. Technological innovations such as the computer can stimulate progress in mathematics, while mathematical inventions such as numerical analysis theories can lead to improved technologies.

The third key idea is that technology and engineering knowledge and practices advance and are advanced by other fields. All fields of study have relationships with technology through ways of thinking, not just through products and systems. The designers of bridges, dams, and buildings are often influenced by forms found in art and nature (e.g., aesthetics). In turn, technology affects activity in the humanities, often quite profoundly, with inventions that offer new capabilities and approaches. For example, the synthesizer and the computer have aided in the composition and performance of music, while computer databases have revolutionized research in the social sciences. Technological advances such as genetic engineering and the internet have also caused changes in the way we think about intellectual property rights such as patents and copyrights.

Grades PreK-2

Learning becomes more meaningful when young children can connect knowledge gained in the classroom to their everyday experiences. The study of technology and engineering provides many opportunities to make such connections. As students establish these connections early in their education, they will begin to understand how technologies influence their daily life.

Because the study of technology and engineering has numerous relationships with other areas of the PreK-2 curriculum, it is particularly important to introduce technology and engineering at this early level of development. Teachers can focus on the common ground between technology and engineering and other content areas (e.g., science, mathematics, social studies, language arts, health, physical education, music, and visual arts).

One effective method is to use themes from diverse and relevant stories in young children's literature, which offer opportunities to learn about themed connections between various curricula. When stories are read in class, students could use visuals, drawings, or diagrams to examine and describe designs that may be present. Students could copy a design using a variety of materials or software applications and analyze which were easiest to use, best suited for the design, or provided the best results. Classroom discussions about the story could provide opportunities for students to build connections between science, technology, engineering, mathematics, and other content areas. By analyzing structures, children engage with concepts such as properties of materials, construction techniques, and measurement.

Through these types of activities in Grades PreK-2, children will have opportunities to explore, discover, problem solve, and make connections between technology and engineering and other areas of study—important components in the process of learning and understanding about the value of technology and engineering to society and culture. Through the combined investigation of these content areas, students will develop a well-rounded knowledge base.

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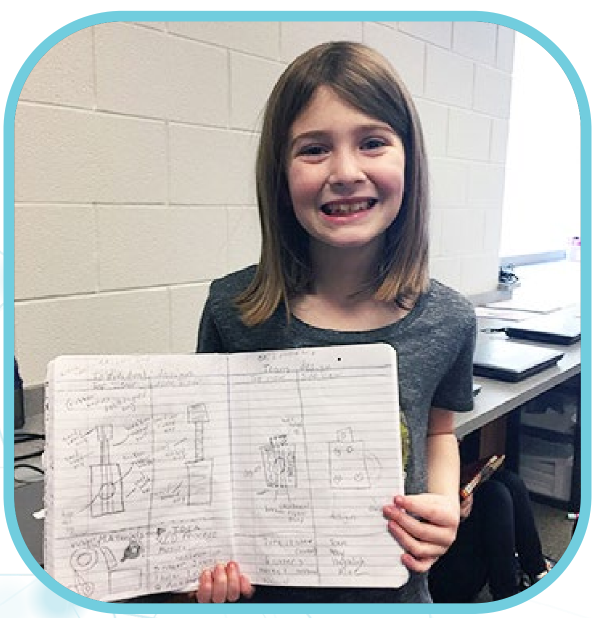
To demonstrate their ability to integrate knowledge, technologies, and practices, students in Grades PreK-2 should be able to:

STEL-3A. Apply concepts and skills from technology and engineering activities that reinforce concepts and skills across multiple content areas. Young children can use building blocks to develop computational and critical-thinking skills by introducing design, measurement, and structural concepts. The intentional translation of skills learned in physical education, such as teamwork, can be applied to problem solving. Drawing in art class can lead to new ways of thinking about design and visual appeal.

STEL-3B. Draw connections between technology and human experiences. Young children learn to count through nursery rhymes and playing with manipulatives. Children's books often include graphics and some even generate sound. Teachers can have students identify technological connections from their homes, traveling in vehicles, and other experiences, and through this help young students understand the role of technology in their lives.



Grades 3-5

Students in Grades 3-5 will develop an understanding of the relationships between technology and engineering and other content areas. Students build confidence when they explore how things work and how technology affects the development of new products and services. Multiple areas are often combined in the development of new products and machines. Mechanical parts, such as springs, wheels, belts, gears, and levers, can be combined to produce more complex machines and systems, such as a roller coaster.

Although technology is a human enterprise with a content and history of its own, it is interdependent on other fields of study. By creating safe laboratory-classroom environments where this interdependency is highlighted, teachers can increase the opportunities for ideas to flow naturally from lessons in one subject to lessons in another. For example, rockets and space fascinate many children and offer a natural opportunity for teachers to bring together several fields of study. Students could begin by studying the moon's surface and movement in their science lessons. Next, they could take a historical look at the development of various rockets and space exploration. The students could then design a rocket and build a model to test their design. They could apply their estimation skills learned in a prior mathematics lesson to determine how far their rockets could fly. Finally, they could write a creative paper describing what it would be like to be an astronaut traveling in space. By seeing these connections made in the classroom, students will gain a clearer understanding of the concepts and principles being learned.

To demonstrate their ability to integrate knowledge, technologies, and practices, students in Grades 3-5 should be able to:

STEL-3C. **Demonstrate how simple technologies are often combined to form more complex systems.** Students could construct a small robot to demonstrate simple circuits using wires, a motor, and a power source (battery). Another example would be how an escalator uses the wheel and axle, inclined plane, pulley, gears, belts, and an electric motor to move people from one level to another.

STEL-3D. **Explain how various relationships can exist between technology and engineering and other content areas.** Students can learn how to convert energy from the wind to power a motor or from acidic fruits such as oranges and grapefruits to energize an LED light. This type of project uses information from mathematics, science, and other fields to develop a deeper understanding among students about technology and engineering products and systems.

Grades 6-8

Through the study of technology and engineering, students in Grades 6-8 begin to discover the answer to the perennial question, "When am I ever going to use this knowledge?" The study of technology and engineering in the middle-level grades helps students recognize relationships among different topics in technology and engineering, make connections across content areas, and integrate ideas and concepts in a structured setting.

Students need various opportunities to explore how technological ideas, processes, products, and systems are interconnected. For example, in the healthcare system technological devices that monitor the heart, blood pressure, and breathing are dependent on other technological devices, software, and hardware in order to perform properly. If one aspect of a system is not functioning properly, the entire system might malfunction or break down.

Students should be encouraged to look for relationships between the study of technology and engineering and other content areas. For example, in a themed unit on Roman history, students in social studies could study Roman instruments of conquest including the catapult and trebuchet. In their technology and engineering class, they could design and build these instruments using the Roman power source of skein tension. The performance of their catapults and trebuchets could be analyzed mathematically to determine optimal solutions based on data collected. Students should understand that knowledge gained in one content area can be applied to another and can also lead to the exploration of various careers. Such experiences will enable students in Grades 6-8 to develop systems thinking by understanding how parts work together to form the whole.

To demonstrate their ability to integrate knowledge, technologies, and practices, students in Grades 6-8 should be able to:

STEL-3E. **Analyze how different technological systems often interact with economic, environmental, and social systems.** For example, a navigation system in a delivery vehicle uses sensors that provide input to the distribution center and sends customers notifications when their products are delivered. If a package is delivered to a wrong address, GPS data can accurately determine the location to which the package was actually delivered.

STEL-3F. Apply a product, system, or process developed for one setting to another setting. Technology transfer is a creative way for people to address needs and wants. For instance, an automated pump based on biology laboratory designs was created for the Mars *Viking* space probe. The pump was modified for use as an insulin delivery mechanism, providing patients with a way to automatically regulate blood sugar.

STEL-3G. Explain how knowledge gained from other content areas affects the development of technological products and systems. For example, skills learned in fine arts are used in designing and rendering examples of technological products and systems. Studying the history of technology and engineering provides people with a way to learn from past successes and challenges.

Grades 9-12

At the 9-12 grade levels, students will build upon their existing knowledge of technology and engineering to incorporate a deeper understanding of their integration with and connections between other content areas. Students will see that technological developments and societal interests are interdependent and that economic, scientific, political, and other considerations are as important as technical ones when designing technologies.

Using one product or material for a different purpose than its original intent is called technology transfer. For example, material used in making helicopter blades has been used to make medical devices that can be implanted in arteries to save people's lives. Technology transfers like this may help spur more innovations and can have large economic implications.

Science, mathematics, language arts, health-related fields, fine and performing arts, and social studies offer direct connections to technology and engineering. Teachers in these content areas can include the use of tools, artifacts, resources, simulations, and computer models to better illustrate the knowledge or concepts they are teaching. Likewise, students in a laboratory setting can use content from other fields when studying technology and engineering.

To demonstrate their ability to integrate knowledge, technologies, and practices, students in Grades 9-12 should be able to:

STEL-3H. Analyze how technology transfer occurs when a user applies an existing innovation developed for one function to a different purpose. For example, aerospace composite materials were used to design an advanced, lightweight, and easy-to-maneuver wheelchair.

STEL-3I. Evaluate how technology enhances opportunities for new products and services through globalization. Developing countries have in many cases bypassed telephone landlines in adopting cellular technology, which has been used not just for communication but also to complete a variety of other tasks, such as banking. This concept is referred to as late-comer advantage.

STEL-3J. Connect technological progress to the advancement of other areas of knowledge, and vice versa. For instance, cloud data storage aided the connectivity of physical devices, known as the internet of things (IoT). This advancement has enabled real-time mathematical, economic, medical, and other applications of data collection, analysis, and production. The increased speed of statistical analysis through computer processors is powering technological innovations.

Standard 4: Impacts of Technology

Humans inhabit a technological world. Over the course of time, technological artifacts and engineering systems created by humans have become more complex, powerful, and ubiquitous. Technology influences every aspect of our lives, such as where we live, what we eat, how we travel, and the ways we communicate. Many of engineering and technology's impacts on society and the environment are widely regarded as desirable. However, other impacts are regarded as less desirable. Technological and engineering development can magnify the inequalities among people and societies by creating a situation in which a minority of people and groups control and use a majority of the world's resources. As the pace of technological change continues to quicken, questions arise as to whether society's political and social norms can effectively keep up.

Four equally important key ideas provide a foundation for student understanding and capabilities related to the impacts of technology and engineering. The benchmarks that follow all link back to these key ideas, with increasing levels of specificity and complexity across the grade bands. One key idea is that **technology and engineering have both positive and negative impacts on society and the environment.** These negative and positive impacts usually happen simultaneously. In other words, no technology is completely beneficial or completely harmful. Furthermore, a technology that is beneficial for one group or situation might have very different (and less positive effects) on others. For example, many communities along the Mississippi River have erected permanent floodwalls to protect their towns from devastating floods. However, these floodwalls can intensify flooding in areas downriver that lack such barriers.

A second key idea is that **decisions made about technology and engineering involve consideration of costs, benefits, and trade-offs.** Individual citizens need to be able to make responsible, informed decisions about the development and use of such technologies. Every technology has both costs and benefits (economic, societal, environmental). Weighing these costs and benefits leads to a determination of what trade-offs will be considered and prioritized in the final design of the technology. For example, computerization has enhanced the productivity of workers across many fields. However, these systems are costly, need to be frequently updated or replaced, and introduce the need for specialized training. On a social level, networked computing has redefined the culture of work, blurring the line between work and leisure time.

A third key idea is that **responsible creation and use of technology requires the sustainable use of renewable and non-renewable resources and handling of waste.** Sustainable development encompasses use of natural and human resources in ways that enhance communities and quality of life, result in more equitable distribution of resources, and ensure that these resources are available for future generations. To achieve sustainability, these goals must be included in technological and engineering decision making. For example, the increasing demand for transportation leads to debates about resource allocation and equitable access. This can encompass the types of fuel that will dominate, modes of transportation that are prioritized, and what the supporting infrastructure will look like.

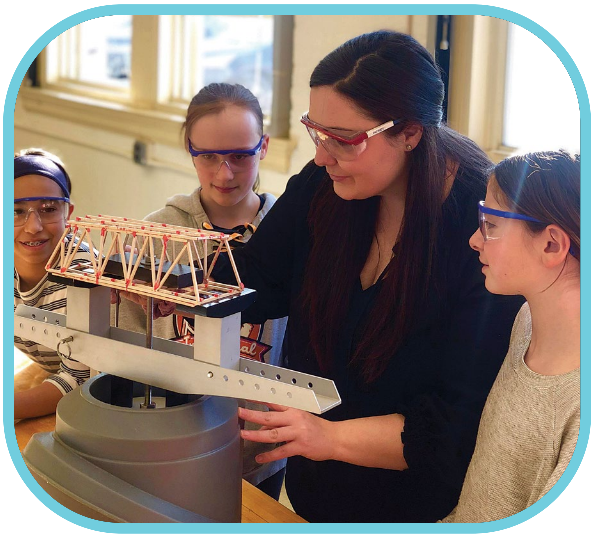
A fourth key idea underpinning this standard is that **use of technology can lead to fundamental changes in individuals, in human cultures, and in the environment.** These changes can lead to alterations in human biology and behaviors. They can also disrupt existing cultures in ways that were unforeseen and unintended. In addition, the use of technology has led to significant environmental changes, but these can be difficult to predict due to the complexity of our ecological systems. For example, mechanization and chemical fertilizer use in agriculture resulted in substantial decreases in the number of farm workers needed. This led to increased urbanization, changes in work patterns, and loss of population in rural areas. From an environmental perspective, although the use of fertilizers has increased food production, it has led to ecological changes such as contamination of soil and water.

Grades PreK-2

Young children are exposed to a variety of technologies before entering school. Household appliances, toys, mobile phones, computers, and different forms of transportation are commonplace for young children. As they continue to explore the broader world around them, young children become aware of more than their immediate surroundings and individual lives. Thus, this exposure offers a natural opportunity for young children to start learning about technology by being asked to reflect on how they use everyday technologies in their daily lives and how their interactions with these technologies affect the broader world around them.

Building young children's awareness that technologies are all around them and are connected to each person's life provides a foundation for future exploration of the effects of technology and engineering. Guided discussions, observations, and activities allow young children to become aware of other forms of technologies in their lives, how they are used, and what makes them effective. Young children should come to understand that technology can be helpful and harmful to society and to the environment. Encouraging young children to look at both the positive and negative results of technology use helps them develop the critical-thinking skills that will be important for future decision making about technology. For example, young children can explore various materials and products to determine if they can be reused or recycled. If they conclude that an item can be reused, the students could develop ideas and plan ways to reuse the item. If they conclude that an item cannot be reused or recycled, they could discuss an alternative plan to reduce the waste created by using the item. Activities like this help young children understand the importance of using materials in a sustainable manner. Younger children generally demonstrate concern about the environment and will often enthusiastically participate in a recycling program.

In addition to exploring the positive and negative impacts of technology, young children should also explore how using technology impacts and changes daily life. Young children can investigate the technologies they use in everyday life to complete tasks. For example, young children can investigate different writing utensils (e.g., large pencil, typical pencil, marker, finger on a touch screen) by exploring the materials used in each and any waste produced by maintaining the materials (e.g., sharpening pencils). Activities like this allow young children to realize how essential technology is to most daily tasks, how a variety of technologies can be used to meet the same need, and how deciding which technology to use can affect other people and the environment.



To demonstrate their understanding of the impacts of technology, students in Grades PreK-2 should be able to:

STEL-4A. **Explain ways that technology helps with everyday tasks.** Children should be able to identify activities they engage in regularly and describe how different technologies help them do these tasks more easily. Contrasting the lifestyles of earlier societies with their own will provide ample examples.

STEL-4B. **Illustrate helpful and harmful effects of technology.** Children can examine a familiar technology and explain how it can be both helpful and harmful. For example, a crayon can be used to draw creatively but can also be used to write on bedroom walls.

STEL-4C. **Compare simple technologies to evaluate their impacts.** Given a basic task, children can decide what tool to use to complete the task. In helping to clean the classroom after an activity, a student would need to select different tools to clean the floor, desktops, or walls.

STEL-4D. **Select ways to reduce, reuse, and recycle resources in daily life.** Children should give examples of the ways they handle waste at school or at home.

STEL-4E. **Design new technologies that could improve their daily lives.** Children can brainstorm needs or wants and devise possible solutions to meet a need. Teachers and parents can pose "what if?" questions to young children. "What if you and your friends could build something in the school's playground to make recess more fun? What would you build?"

Grades 3-5

Elementary grade students are eager to know about the world around them—how things work or why they work the way they do. They ask questions such as: Why does a plane fly, and how is it built? How did early people measure the length of something? How do escalators and elevators work? Learning how technology and engineering influence or change their lifestyles takes time and experience. Providing opportunities for students to explore, ask questions, and use resources allows them to find answers to their technology questions, which, in turn, will lead to more questions. As they explore and make connections, students build a foundation that will be useful in problem solving and in understanding the impacts of technology.

Elementary students can consider topics such as transportation, land use, pollution control, communication, and other technological topics. Students should be asked to analyze how and why decisions are made, and how the use of technology results in both expected and unexpected outcomes. For example, they can investigate how poorly designed or constructed landfills can lead to contamination of surrounding soil, water, and air. Students will learn from these examples that making sound decisions demands examining both the costs and benefits of technological development. It is not too soon for students to understand how their lives have been impacted by technology and how they can have an impact on technology as well.

It is important for students in Grades 3-5 to pose questions about how technology impacts humans and the environment in both positive and negative ways. They should be given opportunities to investigate the ways their lives are impacted by technology. For example, contrasting different ways of getting to school (e.g., school bus, walking, biking, car) will allow them to explore the impacts of technological choices.

To demonstrate their understanding of the impacts of technology, students in Grades 3-5 should be able to:

STEL-4F. Describe the helpful and harmful effects of technology. Students can begin to explore more fully the idea of intended, unintended, positive, and negative outcomes inherent in technologies. Students at this age learn how their own lives have been impacted through technology and how technological processes generate undesirable waste and emissions.

STEL-4G. Judge technologies to determine the best one to use to complete a given task or meet a need. Through exposure to the function and use of various age-appropriate tools/ technologies, students can determine which tools are best for a given task and can explain their selection.

STEL-4H. Classify resources used to create technologies as either renewable or non-renewable. An introduction to material resources and how they are recovered will help students understand the concept of renewability and its importance and can be tied to concepts they learn in science.

STEL-4I. Explain why responsible use of technology requires sustainable management of resources. Building on their initial understandings about material resources, students can tie concepts of renewability, scarcity, and resource demand to sustainable use, defined as availability of a resource for use by future generations.

STEL-4J. Predict how certain aspects of their daily lives would be different without given technologies. Historical examples of daily life before modern technologies such as airplanes, computers, modern agriculture, sanitation, and so on will give students opportunities to consider how their lives have been impacted by technology.

Grades 6-8

Middle grade students can explore broader issues in technology, including cultural, social, economic, political, and environmental effects. They are more interested in how the use of technology influences their own lives and the lives of others. Students at this level should begin to think more critically about the differential impacts of technology, and learn how to objectively look at the pros and cons of a given technology in order to be informed decision makers. They can investigate how technology has affected society and the environment in both positive and negative ways.

Students could explore how a waste product is recycled, reused, or re-manufactured into a new product. By tracing the life cycle of a product, students will be able to identify the impacts of technological decision making. For instance, single-use plastic products were developed as convenient, inexpensive ways of meeting needs (e.g., water bottles, utensils, packaging). However, unintended consequences of this development include micro-plastics in the food chain and increasing problems with solid waste management.

Furthermore, middle grade students should be given opportunities to apply critical thinking to developing alternative strategies that alleviate negative outcomes of technological decisions. For example, lack of access to fresh, healthy food in some areas is a major concern, resulting in so-called food deserts. By first investigating the factors that are associated with food deserts, students can then generate alternative solutions (e.g., enhanced transportation options for delivering and accessing food; backyard or community gardens).

To demonstrate their understanding of the impacts of technology, students in Grades 6-8 should be able to:

STEL-4K. Examine the ways that technology can have both positive and negative effects at the same time. The form and function of technologies are shaped by the criteria considered when the technology is developed. Even beneficial and well-intentioned solutions can have negative impacts. For example, flush toilets led to improved health and hygiene; at the same time, they created a need for water treatment strategies that consume large amounts of energy and fresh water. This type of example provides students an opportunity to consider the importance of design criteria.

STEL-4L. Analyze how the creation and use of technologies consumes renewable and non-renewable resources and creates waste. Building on students' knowledge about material resources and their growing understanding of sustainable resource use will provide opportunities for learning about methods of accessing resources (e.g., harvesting, mining, drilling) and the by-products of these activities.

STEL-4M. Devise strategies for reducing, reusing, and recycling waste caused from the creation and use of technology. Given specific examples in their home or community, middle grades students should be able to consider various options for minimizing or managing resource use (waste) and select or design practical strategies for waste reduction.

STEL-4N. Analyze examples of technologies that have changed the way people think, interact, and communicate. At this age, students should be able to identify and discuss specific examples of technologies that have led to fundamental changes in humans. Obvious examples include things like social media and smartphones; students should be encouraged to dig deeper and identify less obvious technologies.

STEL-4O. Hypothesize what alternative outcomes (individual, cultural, and/or environmental) might have resulted had a different technological solution been selected. Development of technologies typically proceeds from a set of criteria identified through analysis of a need or want. Using specific technological examples, students can investigate the positive and negative outcomes of their use and consider how these outcomes could have been altered, given emphasis on different design criteria.

Grades 9-12

High school students are developing more subject matter knowledge and can be challenged to think more deeply about how technologies affect society and the environment. Their understanding of the world can extend beyond their immediate circumstances. They can synthesize information from multiple disciplines to make connections between their

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own experiences and society at large. Working from this foundation, students will learn that the changes caused by technology are often driven by the desire to improve life, but this ideal is not always met. Some products and systems have emerged as a result of new technological knowledge or techniques without consideration of a current need.

Students can explore emerging technologies and develop the skills to evaluate their potential impacts in a systematic, objective, and ethical manner. They should learn to reason and make informed decisions based on asking critical questions. The goal is to equip them with the knowledge and habits of mind to examine technology's impacts and justify their conclusions regarding technology's value to themselves and society. For example, students could look at how communication devices have shaped (or changed) the way they connect with others. They could explore the larger societal effects coming from the resulting culture of constant, almost instantaneous communication. Students could evaluate the environmental impact on resource consumption stemming from the push marketing approach used by mobile phone manufacturers to increase consumer demand.

Furthermore, high school students can use diverse knowledge to more fully understand technological impacts on broader issues such as social justice, equity, and sustainability. For example, advances in medical technologies can augment human capabilities in ways that blur the line between human and machine (e.g., cochlear implants, prosthetics integrated with human nervous systems, implantation of computer chips in the brain). Is this desirable?

To demonstrate their understanding of the impacts of technology, students in Grades 9-12 should be able to:

STEL-4P. **Evaluate ways that technology can impact individuals, society, and the environment.** A variety of approaches and resources can be used by students when asked to evaluate given technologies. These include technology assessment, cost-benefit analysis, risk assessment, environmental impact analysis, and case studies, among others. By applying evaluative techniques, students can analyze the relationships between resources and technology to improve sustainability efforts. This process should be accompanied by an understanding of the importance of evaluating technologies in a holistic manner.

STEL-4Q. **Critique whether existing and proposed technologies use resources sustainably.** By applying the evaluative tools described above, students can investigate ways that resources used to create and operate a given technology can be improved to enhance the sustainability of the technology. For example, they could evaluate how students are currently transported to and from school and devise ways to reduce fuel use. Strategies could include promoting bike riding by installing covered bike racks, re-routing vehicles to avoid long wait times, shifting school bus schedules to prevent extended idling times, and so on.

STEL-4R. **Assess a technology that minimizes resource use and resulting waste to achieve a goal.** By focusing on a "wicked problem"—one that is complex, has multiple possible solutions, and requires consideration of various perspectives—students can be challenged to go through a process of problem finding/defining, investigation, and design to find technological solutions that are more beneficial for society and the environment.

STEL-4S. **Develop a solution to a technological problem that has the least negative environmental and social impact.** Students can be challenged to engage in problem identification, analysis, investigation, and design to find technological solutions that improve people's living conditions or that improve the well-being of individuals or members of a group.

STEL-4T. **Evaluate how technologies alter human health and capabilities.** Evaluative tools can be used to examine existing or proposed technologies to assess their positive and negative effects on humans. For example, CRISPR-Cas9 technology has been hailed as a tool for modifying human genetic material to reduce the risk of inherited disease. At the same time, there are medical and ethical concerns surrounding application of this technology to humans.

Standard 5: Influence of Society on Technological Development

Societies influence technological development. Societies are characterized by common elements such as shared values, differentiated roles, and cultural norms, as well as by entities such as community institutions, organizations, and businesses. To grasp the vast societal influences on technological change one would need to analyze historical and contemporary advancements in technology and engineering, a landscape that is constantly converging and fluctuating. Technological development often occurs because of changes in education, transportation, communication, agriculture, and other areas related to human existence. Technology and engineering will continue to alter the way humans live in the future. Student understanding of this force needs to go beyond learning historical timelines, dates of key inventions, and the names of prominent innovators.

Three key ideas provide a foundation for student understanding and capabilities related to the influence of society on technological development. The benchmarks that follow all link back to these key ideas, with increasing levels of specificity and complexity across the grade bands. One key idea is that **the needs and wants of society often shape technology and engineering more than individual needs and wants.** Technological innovations are molded and influenced by cultures, organizations, and the citizens who use them. Governmental regulations, subsidies, and financial incentives can favor some technologies and hinder the progress of others. For example, transport of individuals in the United States was heavily influenced by governmental policies that supported adoption of the private automobile; these policies included the Interstate Defense and Highways Act of 1956. As a result, interest in and funding for other public transportation options waned in many areas of the country over the decades that followed.

A second key idea is that **the values and beliefs of societies shape attitudes toward technology.** If a technology is considered useful or desirable by a society, it is likely to be used and further developed. The development of a product or system is related to the wants, interests, and acceptance of individuals, but is often shaped by collective values and beliefs. These values and beliefs are often reflected in the laws, policies, and procedures a society adopts to control and regulate technological products, systems, and processes. Sometimes, an industry is capable of delivering a product or system, but because of misunderstanding, fear, or caution, the product or system is not developed. For instance, genetically modified crops are more widely accepted in the United States than in Europe, where uncertainty about the safety of these foods has restricted their use.

A third key idea is that **societies are at different stages of development, which affects the diffusion of technological innovation.** A technology that has been adopted in an advanced society may not be appropriate for a developing society. Appropriate technology is the concept that a technology must be suitable to the social and economic conditions of a society, and that it also promote sustainability (i.e., sound environmental practices and self-sufficiency among those using it). The United Nations has developed seventeen sustainable development goals to address global challenges, many that deal with technological inequities between societies.

Grades PreK-2

Young children are interested in learning about various technological developments and systems that can satisfy their own needs and wants. This interest is a segue to teach how products and systems are designed. Young children might explore how the desire to see after dark and the need for safer, more reliable sources of light led to the use of fire, candles, and eventually the electric light bulb. The light bulb displaced the candle and gas lamp as a primary source of indoor lighting because it had several desirable characteristics: it was cleaner, less likely to cause a fire, and provided a brighter, steadier, and more natural light. This example demonstrates that preferred characteristics help shape product development using mathematics, science, and engineering.

To demonstrate their understanding of the influence of society on technological development, students in Grades PreK-2 should be able to:

STEL-5A. **Explain the needs and wants of individuals and societies.** Basic human needs include food, water, and shelter. Beyond these, children can discuss other needs and wants that have resulted in new technologies. This helps them to begin to see that other people's thoughts, feelings, needs, and wants may differ from their own.

STEL-5B. **Explore how technologies are developed to meet individual and societal needs and wants.** For example, people need clean, safe water, so systems are developed to provide water to homes and schools. Human-made technology requires some knowledge of the natural world and uses materials from it as well.

STEL-5C. **Investigate the use of technologies in the home and community.** Children learn to use their senses to gather data and make observations about technologies in their everyday environment. Toasters, microwaves, stoves, and refrigerators may be used to create breakfasts before going to school in western cultures. In other societies, different food storage and preparation technologies are used for this same purpose.

Grades 3-5

Students in Grades 3-5 learn that societal needs and wants directly influence the development of technology. Inventions and innovations are driven by societal demand. If a society believes a technological development is valuable, the product or system will remain in demand. If people lose interest in a certain product or system, companies will not develop it and it may be removed from the marketplace.

Students at this level can begin to see how consumer product development and marketing affect them personally. If a new cereal is marketed on television or on other popular communication devices, children naturally share their interest with their friends and parents, leading to increased sales. When a new toy becomes a hot item during the holiday season, exploding demand can result in producers being unprepared for the increased sales orders, leading to newspaper stories of parents fighting over the last toys in a store or traveling to remote locations to purchase the special toy. When the toy goes out of style factories may be over-producing them, which results in falling prices and overstocks being shipped to discount outlets. Parents and teachers can talk to children about the implications of marketing and these boom-and-bust consumer cycles.

To demonstrate their understanding of the influence of society on technological development, students in Grades 3-5 should be able to:

STEL-5D. **Determine factors that influence changes in a society's technological systems or infrastructure.** Individual, family, and community values as well as environmental and economic factors may expand or limit the development of technologies. Students should recognize that products and systems are designed and marketed for a variety of purposes, including to generate profit. Sometimes these changes come at the expense of human and environmental health.

STEL-5E. **Explain how technologies are developed or adapted when individual or societal needs and wants change.** More useful and efficient technologies are developed when society identifies a need. When something changes in the environment, technologies are developed in response to the new conditions. For example, if a local water source runs dry, solutions must be designed for alternative water purification and transport. Engineers improve existing technologies by designing and creating to meet new constraints and requirements.

Grades 6-8

Although technology changes society, society also plays a critical role in the development and use of technology. Students in Grades 6-8 learn that inventions and innovations are created to help meet the demands and interests of individuals and communities. They should have opportunities to discuss and explore technological developments that have significantly impacted society. These developments occur in the contexts of automation, artificial intelligence, computers, robotics, transportation, construction, manufacturing, energy and power, biotechnology, agriculture, and other areas.

Societies focus on improvements to make things faster, stronger, more efficient, and less costly. Consumers expect these improvements to continue to make their lives easier and more cost effective, but sometimes the improvements lead to new problems needing solutions. For example, improvements in transportation systems have made it easier to travel the world but have overwhelmed historical locations with tourists and spread diseases worldwide. When problems like this arise, leaders often look globally to see if other societies have encountered and solved similar problems.

To demonstrate their understanding of the influence of society on technological development, students in Grades 6-8 should be able to:

STEL-5F. **Analyze how an invention or innovation was influenced by its historical context.** Characteristics of technologies are the result of the circumstances in which they are developed. Economic, political, cultural, and environmental drivers create historical contexts and determine the design of technology and its level of acceptance. For example, over the past decade, lighting technology has evolved considerably, with LED bulbs largely replacing both incandescent and compact fluorescent lighting as a result of people seeking more efficient, long-lasting, and more environmentally benign lighting solutions.

STEL-5G. **Evaluate trade-offs based on various perspectives as part of a decision process that recognizes the need for careful compromises among competing factors.** Technological developments come with both benefits and consequences. A trade-off is a compromise in which one thing is given up in order to get something else that is desired. Students should recognize that a society's expectation for new and unique products contributes to design for obsolescence and to unsustainable rates of consumption.

Grades 9-12

Technology is influenced by society's institutions, including governmental, business, and educational institutions, among others. These societal institutions impact how people learn, live, work, and play. Students in Grades 9-12 need to realize the influence of society on technology and how societal decisions can directly affect the development of a product or system.

Students should study how public opinion directly affects the marketplace. When a product or system is not regarded favorably, the developers must decide whether to continue, to modify, or to halt its development. Moral and ethical considerations also play a role. Acceptance or rejection by society often determines the success or failure of new technologies.

To demonstrate their understanding of the influence of society on technological development, students in Grades 9-12 should be able to:

STEL-5H. **Evaluate a technological innovation that arose from a specific society's unique need or want.** As engineers modify technological systems, materials are often chosen based on local environmental factors, locally available materials, and cost. Modes of transportation differ depending upon population density, availability, safety, speed, geography, and cost. Energy sources are chosen based on considerations such as proximity to source, cost-effectiveness, and environmental impact.

STEL-5I. Evaluate a technological innovation that was met with societal resistance, impacting its development. Throughout history, societies have made moral, ethical, and political decisions impacting the development of technological solutions and innovations. Sometimes those decisions are controversial and multifaceted. Societies differ in their norms and methods for resolving the problems that arise when conflicting values preclude consensus. For example, Germany made the decision to phase out all use of nuclear power due to public opposition to this energy source.

STEL-5J. Design an appropriate technology for use in a different culture. High school students can benefit from examining relationships to technology in other cultures, such as the access (or lack of access) to technologies in specific cultures. For example, people in many locations around the world lack ready access to clean water. Strategies to address this problem will vary according to the resources and circumstances of a given location.

Standard 6: History of Technology

The first technologies were very simple tools: rocks or other natural items that were modified to better serve their maker's purpose. As time passed, humans became more sophisticated at making tools, and also learned to process raw materials into forms that did not exist in nature—bronze and steel, ceramics, glass, paper, and ink. These new materials opened the way to improving existing tools and creating entirely new technologies. People learned to put individual parts together to create systems—the wheel and axle, the lever, and the bow and arrow—that could perform jobs no single component could. The division of labor allowed people to become specialists and to cooperate in making products that were more complicated and sophisticated than individuals were likely to achieve working on their own.

Three equally important key ideas provide a foundation for student understanding and capabilities related to the history of technology. The benchmarks that follow all link back to these key ideas, with increasing levels of specificity and complexity across the grade bands. One key idea is that technological knowledge accelerated along with other fields of endeavor during the Renaissance. Scientific and mathematical knowledge opened the way to a new type of design, one not only based on trial and error but also on being able to model and predict how something should work even before it was built. Additionally, the visual and performing arts expanded to create a greater appreciation for aesthetics that influenced product design, and global exploration created cultural exchanges of knowledge, tools, and materials.

A second key idea is that historical eras are often defined by technological advancements. History has seen at least three great transformations that were driven by technology. The development of agriculture some 14,000 years ago was the first. By providing a stable food supply, agriculture allowed societies to grow and flourish in one place, which in turn led to the first great flowering of civilization. The second transformation came in the eighteenth century with the development of interchangeable parts, the steam engine, the harnessing of fossil fuels, and the establishment of the first factories. These changes ushered in the Industrial Age, a time of mass production. The creation of an interconnected system of suppliers, manufacturers, distributors, financiers, and inventors revolutionized the production of material goods, making them widely available at low cost and high quality. The most recent transformation—the development of powerful computer networks—has taken place over the past few decades. These technologies have achieved for the field of information and communication what the previous two revolutions did for food and material goods.

A third key idea is that the history of technology chronicles positive and negative aspects of humanity. Knowing the history of technology helps people understand the world around them by seeing how inventions and innovations have evolved and how they, in turn, steered the world to how it exists today. There are many triumphs in agriculture, manufacturing, transportation, medicine, the built environment, and other areas, but there are also negative aspects of technology such as cybercrime, pollution, and overuse of natural resources. In studying the major eras, along with specific events, innovators, and milestones, one begins to see patterns that can help in anticipating the future. In this way, the study of technology equips students to make more responsible decisions about technology and its place in society.

Grades PreK-2

Studying the history of technology in the early grades is important because it provides young children with a basic foundation of how the human-made world developed. This foundation will play a significant role in their academic progression by connecting technology to other subjects.

Young children will learn how technology has evolved from early civilizations when the first humans created primitive tools by chipping away the edges of flint stones. Making and using tools were the first steps in technological development. Tools were, and still are, a means to extend human capabilities and to help people work more comfortably. Students will realize that humans evolved from toolmakers to strategic designers capable of creating products and systems. Over time, people have improved their capability to create products or systems for providing shelter, food, clothing, communication, transportation, leisure, health, and culture.

To demonstrate their understanding of the history of technology, students in Grades PreK-2 should be able to:

STEL-6A. Discuss how the way people live and work has changed throughout history because of technology. Once people learned to provide shelter for themselves—first with simple huts and later with houses, castles, and skyscrapers—they were no longer forced to seek natural shelter, such as caves. The invention of the plow and other agricultural technologies, along with such simple devices as fish hooks and the bow and arrow, made it easier for people to feed themselves, freeing up time for other pursuits. People's ability to communicate with one another over space and time has been improved by the use of tools and processes like smoke signals, alarms, papermaking, printing, telephones, and the internet.

Grades 3-5

Throughout history, people have developed various products and systems to help meet their needs and wants. To understand this concept, students in Grades 3-5 might study, for instance, the evolution of construction. They could trace the development of structures from the earliest people to Egyptian pyramids, Roman aqueducts, and homes, to modern day skyscrapers. In this way, students will come to see how the history of civilization has been closely linked to technological developments.

Assessing activities from a historical perspective can help students learn how people improved conditions, and subsequently, promoted their culture. For example, to develop an understanding of the evolution of communication, students could replicate different forms of communication, starting with pictographs and carvings and moving on to maps and charts, then to photography and printing presses. They could trace the progression of a communication device, focusing on the criteria and constraints that helped the technology come to fruition and also reasons the technology was not sustainable or is no longer used.

By the time they complete the elementary grades, students will have gained a perspective on the importance of technology from a historical context. In addition, they will have gained an understanding of the importance of tools and machines throughout history.

To demonstrate their understanding of the history of technology, students in Grades 3-5 should be able to:

STEL-6B. Create representations of the tools people made, how they cultivated food, made clothing, and built shelters to protect themselves. Historical technological products and systems did not always work and often many attempts and variations were tested before an idea became a reality. For example, the development of pottery stretched over 10,000 years. People learned to mix various clays to make stronger items and they learned to fire pottery in ovens to harden the clay more quickly. Various containers, such as jugs, vases, and cups were designed and developed for holding things such as water, milk, seeds, and grains. Not all of the designs worked, and variations may be seen in every ancient civilization. Representations developed in the classroom could include sketches, dioramas, models, photographic slide shows, and so on.

Grades 6-8

In the middle level grades, students will learn about many of the technological milestones in human history. They will recognize the ways in which technology affected people in different historical periods—how they lived, the kind of work they did, and the decisions they made. Seeing the history of technological developments in the broader context of human history will enable students to understand how the impact of technology on humankind has changed over time. One way to understand past technologies is to reverse engineer technologies from those eras.

Teachers can inspire students' curiosity about the history of technology in a variety of ways. They might, for example, have students explore various structures that provide shelter and investigate how their climate control systems, such as heating and cooling, have made life indoors more comfortable and enjoyable. In conducting their research students could draw from such sources as books, the internet, and older members of the community to learn about life before homes were air conditioned and centrally heated. Once gathered, the students could present their information to the class in various formats, such as building a model, making a presentation, or producing a video. Any number of other topics, including food, clothing, communication, transportation, sports, and health, could also serve as the basis for such an exercise. By investigating the major inventions and innovations from various times in history, students will be able to draw conclusions about how society and culture influence technological development, and vice versa.

To demonstrate their understanding of the history of technology, students in Grades 6-8 should be able to:

STEL-6C. Compare various technologies and how they have contributed to human progress. For example, students can examine maps in a historical context and decipher how geography and availability of natural resources often determined the materials humans used for shelter.

STEL-6D. Engage in a research and development process to simulate how inventions and innovations have evolved through systematic tests and refinements. For example, in 1879 the first light bulb burned for only 13 hours. Since that time there have been many innovations and design changes to Edison's light bulb. Students can research the timeline of a given technology, noting the significant changes and what those changes have meant to society and the environment.

STEL-6E. Verify how specialization of function has been at the heart of many technological improvements. For example, the early steam engine was originally designed with a single chamber in which steam expanded and then was condensed—thus performing both of the two very different functions of the steam engine. Fifty years later, by isolating the functions of the cylinder and steam condenser into separate components, James Watt created a more efficient steam engine. Fields such as industrial design have evolved to carefully incorporate aesthetics and ergonomics in the design of technological products and systems in addition to other technical improvements.

Grades 9-12

Students in Grades 9-12 should learn that sometimes technological changes are abrupt and obvious but more often they are evolutionary and subtle. The effects of technological advancements can also be very powerful, irreversible, and global.

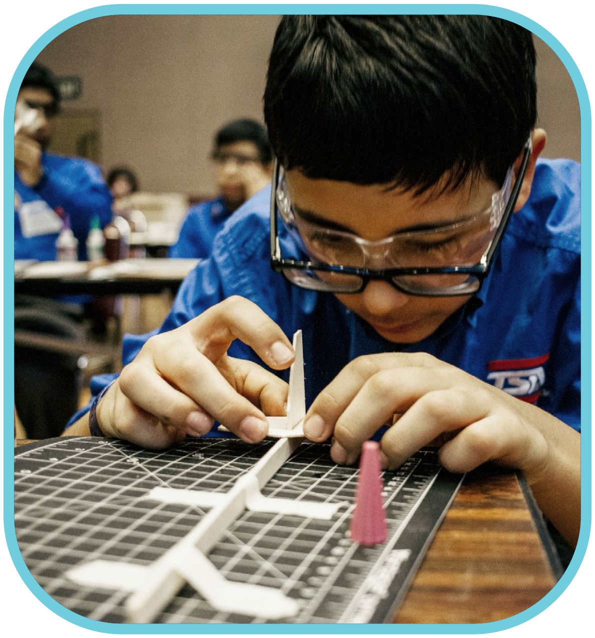
To develop an understanding of the history of technology, students at these grade levels should learn about the origins and history of various inventions and innovations as they relate to particular periods of time. Historical periods have been defined and named in terms of the dominant products or systems of the time. For instance, students learn that the Stone Age began with the development of chipped-stone tools, which later evolved into hand axes, blade tools, spears, and the bow and arrow, and that fire was also harnessed at this time. Other historical periods have been characterized by significant technological developments—the wheel, the use of certain resources (e.g., the Iron Age), the printing press, mass production, and the computer, to name a few.

Without question, key developments in technology have pushed civilization forward and laid the foundation for the present era. Over the past 200 years, technological and scientific growth have become closely linked with the idea of progress. A common thread throughout history is that the design process was used to refine and improve our technological capabilities. Students should make connections between technologies and the various eras and develop an understanding that studying the history of technology is also studying the process of change. Furthermore, students should understand that while history tends to be told in terms of heroes and individual inventors, in reality many people with different backgrounds have often worked together over time to develop technology.

To demonstrate their understanding of the history of technology, students in Grades 9-12 should be able to:

STEL-6F. **Relate how technological development has been evolutionary, often the result of a series of refinements to basic inventions or technological knowledge.** For example, the development of the pencil was a long and tedious process. Engineers, designers, and technicians developed many different techniques and processes and used a variety of materials in order to develop the best pencil possible. Agricultural techniques were developed to improve the cultivation of food and its supply. Other developments included better ways to communicate through the development of paper, ink, and the alphabet; to navigate with boats; to understand human anatomy; and to provide access to clean drinking water.

STEL-6G. **Verify that the evolution of civilization has been directly affected by, and has in turn affected, the development and use of tools, materials, and processes.** The Stone Age started with the development of stone tools used for hunting, cutting, and pounding vegetables and meat and progressed to the harnessing of fire for heating, cooking, and protection. The Bronze Age began with the discovery of copper and copper-based metals. The wide application of new agricultural technologies such as the sickle, plow, windmill, and irrigation enabled farmers to grow more food. Sustained technological advancement caused many people to migrate from farms to developing towns and cities. Other influential developments in this age included weaving machines and the spinning wheel, which advanced the making of cloth. The invention of gunpowder and guns was an improvement over previous weapons for both hunting and protection.



STEL-6H. **Evaluate how technology has been a powerful force in reshaping social, cultural, political, and economic landscapes throughout history.** Communication, agriculture, and transportation, for example, have evolved out of the political, economic, and social interests and values of the times. The Middle Ages saw the development of many technological devices that produced long-lasting effects on technology and society, such as the waterwheel and the magnetic compass. In some form all of these devices are still being used today, although they have been greatly modified from earlier designs. The Renaissance was also an important era of development in the history of technology. The camera obscura, silk knitting machines, the telescope, the submarine, the hydraulic press, and the calculating machine were all developed during this time period. The study of the history of technology helps us understand the context surrounding social and political events and to determine possible scenarios for the future.

STEL-6I. Analyze how the Industrial Revolution resulted in the development of mass production, sophisticated transportation and communication systems, advanced construction practices, and improved education and leisure time. Major developments of this period included the continuous-process flour mill, power loom and pattern-weaving loom, steam engine, electric motor, gasoline and diesel engines, vulcanized rubber, airplane, telegraph, telephone, radio, and television. The concepts of Eli Whitney's interchangeable parts and Henry Ford's movable conveyor added to advances in the production of goods. Extended free time was possible for some people as a result of increased efficiency and updated labor laws, and eventually led to more widespread access to education.

STEL-6J. Investigate the widespread changes that have resulted from the Information Age, which has placed emphasis on the processing and exchange of information. The development of binary language, transistors, microchips, and an electronic numerical integrator and calculator (ENIAC) led to an explosion of computers, calculators, and communication processes to quickly move information from place to place. Holography, cybernetics, xerographic copying, the breeder reactor, the hydrogen bomb, the lunar module, communication satellites, prefabrication, and gene editing have all been major developments during this time period.

Standard 7: Design in Technology and Engineering Education

Humans design for enjoyment and to solve problems, extend human capabilities, satisfy needs and wants, and improve the human condition. Without design—the purposeful development of a plan of action—a product or system cannot be made effectively. Design is the foundation for all technology and engineering activity. Eight equally important key ideas provide a foundation for student understanding and capabilities related to design. The benchmarks that follow all link back to these key ideas, with increasing levels of specificity and complexity across the grade bands.

One key idea is that design is a fundamental human activity. Design in technology and engineering is a distinctly human process with several defining characteristics. It is purposeful, open-ended, based on certain requirements, iterative, creative, and results in many possible solutions. This means that even though we talk about the technology and engineering design process, there is not just one process. Technology and engineering design addresses criteria or constraints defined by the needs of the users and/or by policies or regulations (e.g., building codes). Young students should start with simpler, well-defined design problems with fewer criteria and constraints to build their knowledge and skills. Older students should be challenged with broader, ill-defined design challenges that require different and more complex design approaches.

Design in technology and engineering is by nature a creative process. Sometimes innovative solutions use resources in unique and unexpected ways and students learning to use design in technology and engineering will be challenged to generate creative solutions to design problems. The open-ended nature of technology and engineering design allows for multiple pathways leading to a solution, and for creation of multiple solutions. Therefore, a second key idea is that **there is often no single, correct solution in technology and engineering design; furthermore, designs can always be improved and refined.** These fundamental attributes are central to the design and development of any product or system.

Few products and systems today are developed by trial and error or come about simply by accident. This is the third key idea: **design in technology and engineering is iterative.** Almost any design is the result of a circular process that revisits developmental steps as an idea is transformed into a final product or system. Technologists and engineers often return to earlier stages of the design process to re-evaluate whether criteria and constraints are being met and whether solutions will be sufficient. This process involves an in-depth understanding of a problem and the resources available, a comprehensive search for solutions, and careful evaluation and refinement.

Effective technology and engineering design demands the application of knowledge from a range of disciplines and an appreciation of the effects of a design on society and the environment. Use of this process provides opportunities to enhance and promote necessary skills in students, often referred to as the 21st Century Skills. However, there are additional skills promoted through the technology and engineering design process. The fourth key idea is that **there is a range of skills needed to carry out technology and engineering design**, including communication, creativity, collaboration, critical thinking, computational thinking, visualization, resourcefulness, innovation, ideation, abstract thinking, civic-mindedness, perseverance, learning from failure, accepting and providing feedback, spatial thinking, project and time management, and self-directed learning, among others.

A fifth key idea is that **there are universal principles and elements of design.** The principles of design are balance, rhythm, pattern, emphasis, contrast, unity, and movement. The elements of design are line, shape, space, value, form, texture, and color. Furthermore, within technology and engineering many designs take physical forms, to which a range of additional design factors often apply, including ergonomics, energy efficiency, reliability, durability, safety, ease of manufacture, aesthetics, and more. These widely-accepted principles, elements, and factors are used together in varying ways to create physical objects that meet desired goals and have utility and aesthetic value.

A sixth key idea is that **making is an inherent part of technology and engineering design.** Design in technology and engineering also requires specific physical making skills. These include, but are not limited to, sketching and drawing, measuring, tinkering, computer-aided designing, computer programming, manipulating materials, modeling and prototyping, and effectively using hand and power tools.

The title *technology and engineering design* is used here to embrace both technological design and the engineering design process. The term *technology* in this context refers broadly to a process for technological development by creating plans for converting resources into products or systems that meet human needs and wants. The term ***engineering*** design is used to represent a process that requires the collection and analysis of scientific and numerical data to make informed decisions about design solutions. Engineering design uses data collected while testing prototypes to best predict performance. This is the seventh key idea: design optimization is governed by criteria and constraints. Engineering design is an ideal STEM integrator by creating an informed design approach that uses scientific knowledge, engineering science, and mathematical predictive analysis to optimize the final solution. The purposeful blend of technology and engineering design approaches allows students to learn the benefits of informed engineering design to promote STEM learning while engaging in making technological design solutions. Technology design embraces and often requires making prototypes for testing and design refinement. Technology design alone and engineering design alone do not capture the necessary benefits of both approaches; therefore, the term *technology and engineering design* is the preferred and chosen term for use in these standards. Other design approaches, such as graphic design and industrial design, also play a role in technology and engineering laboratory-classrooms.

A carefully structured educational program will intentionally include these key ideas, which contribute to the development of technological and engineering literacy. Design embodies humans' innate ability and inclination to improve the human condition. As students progress, they will have the knowledge and skills to demonstrate the eighth key idea, that there are many approaches to design. When appropriate, students will learn to use other design approaches such as participatory design, ecological design, and user-centered design, among others.

Grades PreK-2

As young children explore the world around them, they begin to understand that some elements of their world are human-made. Making systems or products requires careful planning, and this planning involves a process called design. Children at this age start to understand that there are many people who contribute to the designed world. They engage in the design process naturally through their play and begin to investigate properties of materials and the use of tools as they learn to create their own design solutions. Children at this level can learn that designs have requirements in order to meet the needs and wants of the end user and begin to describe designs by listing key design elements. When exploring different design solutions, students learn that there are no perfect designs. For example, young children can compare and contrast toys, eating utensils, or other familiar items to begin to differentiate characteristics of products. Through technology and engineering design, students begin to acquire skills that are essential to this process. Often, design activities occur during play, exploration, and tinkering, which results in the development of basic making skills.

To demonstrate their ability to design in technology and engineering education, students in Grades PreK-2 should be able to:

STEL-7A. Apply design concepts, principles, and processes through play and exploration. Design experiences build on young children's natural curiosity, desire to explore, and persistence. Familiar materials, tools, and environments will enhance these experiences.

STEL-7B. **Demonstrate that designs have requirements.** Young children recognize that all designs must meet certain expectations. These expectations are related to the purpose, function, and requirements of a solution.

STEL-7C. **Explain that design is a response to wants and needs.** Young children begin to understand that design is driven by wants and needs. These wants and needs often derive from familiar environments such as home, school, and community.

STEL-7D. **Discuss that all designs have different characteristics that can be described.** Young children recognize and categorize basic features of design, which represent principles and elements of design. In drawing, they begin to differentiate between lines, colors, and shapes. In thinking about early ideas on design, they might brainstorm with other children, draw sketches, and see how well their ideas worked out.

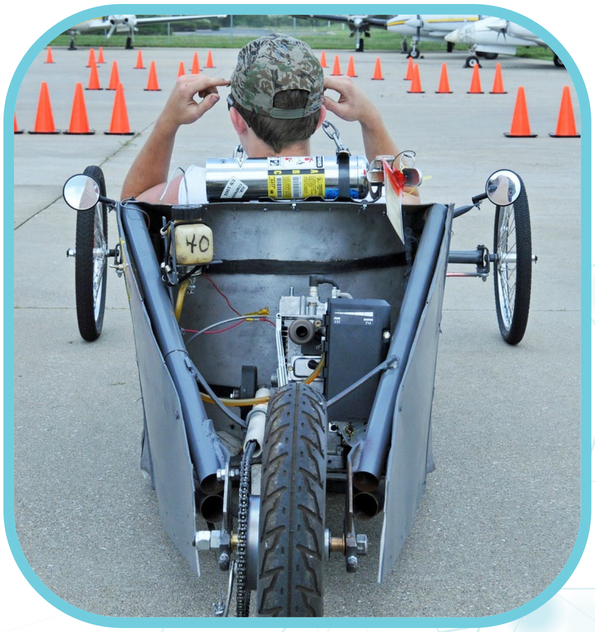
STEL-7E. **Illustrate that there are different solutions to a design and that none are perfect.** Young children recognize that there is more than one plausible solution to a design challenge.

STEL-7F. **Differentiate *essential skills* of the technology and engineering design process.** Young children identify that there are some essential skills, such as creative thinking, building, and testing, that are required to succeed in technology and engineering design.

STEL-7G. **Apply skills necessary for making in design.** Providing opportunities to use tools and manipulate materials can facilitate making skills in young children. Structuring design experiences at this age may take the form of tinkering and play.

Grades 3-5

Building upon the knowledge of the PreK-2 level, students in Grades 3-5 begin to have a deeper understanding of, and capacity to engage in, technology and engineering design. They begin to understand that there are various approaches to designing, and that technology and engineering design requires revisiting some steps. This iterative process can include such things as defining the problem, ideation, research, analysis, modeling and predicting, prototyping, testing and evaluating, refining the solution, decision making, documenting, and communicating. Grades 3-5 students begin to engage in technology and engineering design by learning about constraints and criteria as they develop design ideas. They learn that design is an approach to improve the human condition and creates possibilities to improve the quality of life. Students will begin to expand their technology and engineering design vocabulary and identify key design elements and principles of "good" design. Additionally, students begin to analyze existing designs and learn to identify strengths and weaknesses. Students at this level understand that design solutions have limits and that no design solution is perfect.



To demonstrate their ability to design in technology and engineering education, students in Grades 3-5 should be able to:

STEL-7H. **Illustrate that there are multiple approaches to design.** Design approaches are determined by the context, the individual, the available resources, and the intended purpose of the design.

STEL-7I. **Apply the technology and engineering design process.** Design in technology and engineering may include defining the problem, ideation, conducting research, analysis, modeling and predicting, prototyping, testing/evaluating, refining, decision making, documenting, and communicating. Students identify and engage with this range of actions in technology and engineering design in a non-linear way, revisiting certain steps as needed, and documenting their actions in their engineering notebooks or portfolios.

STEL-7J. **Evaluate designs based on criteria, constraints, and standards.** Students in this grade band develop an appropriate vocabulary to identify and discuss design parameters or requirements. They can recognize that purposeful design decisions are based on criteria and constraints.

STEL-7K. **Interpret how good design improves the human condition.** Students expand their scope of understanding by identifying wants and needs associated with the human condition beyond their immediate surroundings. Students recognize the potential impacts of design on the quality of life.

STEL-7L. **Apply universal principles and elements of design.** Students develop the necessary vocabulary to identify, describe, and begin to apply the principles and elements of design. Students can appreciate the impact of these principles and elements on design quality.

STEL-7M. **Evaluate the strengths and weaknesses of existing design solutions, including their own solutions.** Students can evaluate a range of potential solutions by analyzing their relative strengths and weaknesses. Using criteria and constraints, students acknowledge the limitations caused by one solution and continue to explore a range of ideas.

STEL-7N. **Practice successful design skills.** Continued opportunities to experience and develop essential design skills will improve students' design experiences. Students engage in developmentally appropriate experiences to develop these essential skills, which will often be teacher-driven.

STEL-7O. **Apply tools, techniques, and materials in a safe manner as part of the design process.** Students understand that designers practice the making skills necessary to successfully complete a design. Continued opportunities to explore tools, techniques, and materials will result in refining the skills necessary to successfully design. Students can begin to select appropriate tools and materials for an identified purpose.

Grades 6-8

Students in Grades 6-8 continue to develop their abilities in the creation of design solutions and begin to appreciate and experience the benefits of various approaches to technology and engineering design. Students recognize the limits of using only one approach to design and learn to avoid fixating on one approach and/or one design solution. They seek to locate the best approach to meet the needs of the end user. Students understand that design is a human endeavor and work to locate design solutions with human factors in mind. Through exploration of technology and engineering design processes, students learn that design involves a series of tradeoffs and learn to optimize solutions that best address constraints and criteria (requirements). At this level, students begin to learn how to evaluate their own and their classmates' design solutions based on identified criteria and constraints. Additionally, students begin to realize the limits to their own design solutions; these learning experiences will often happen through failure, which is an inherent part of the design process.

To demonstrate their ability to design in technology and engineering education, students in Grades 6-8 should be able to:

STEL-7P. **Illustrate the benefits and opportunities associated with different approaches to design.** A characteristic of design is weighing the benefits and opportunities associated with the approach a designer selects.

STEL-7Q. **Apply the technology and engineering design process.** Students intentionally use the technology and engineering design process to iteratively solve design challenges. Students begin to recognize the value of revisiting steps in the design process to avoid fixation on one solution.

STEL-7R. **Refine design solutions to address criteria and constraints.** Students design within provided criteria and constraints and recognize trade-offs associated with optimization.

STEL-7S. **Create solutions to problems by identifying and applying human factors in design.** Students acknowledge that the process of design is influenced by human factors and broaden their ability to identify and apply human factors such as ease of use and ergonomics. Students become increasingly aware of the relationship between humans and the designed environment.

STEL-7T. **Assess design quality based upon established principles and elements of design.** Students assess quality in designs based in part upon the principles and elements of design. With teacher guidance, students in this grade band can articulate reasons why they believe some designs are more effective than others.

STEL-7U. **Evaluate the strengths and weaknesses of different design solutions.** Students engage in self- and peer-evaluation of design through a recognition of trade-offs associated with design decisions.

STEL-7V. **Improve essential skills necessary to successfully design.** Students recognize the value of these essential skills and identify opportunities to develop these skills. Metacognition drives student experience in recognizing and learning from failure in design.

Grades 9-12

By Grades 9-12, students experience the full spectrum of technology and engineering design. They have had opportunities, to experience multiple design activities, and, as a result, they have a deeper understanding of technology and engineering design processes. At this level, students have learned several approaches to technology and engineering design, which enhances their ability to select the best approach to design for a given design problem or opportunity. Students at this level understand how to select and engage in a design process and how to provide a rationale for their design decisions as they work through the process. Students in Grades 9-12 learn to optimize their designs based on established criteria and constraints, parameters that are often defined by the designer. They learn to collect evidence from tests and collect data from these tests to analyze the performance of design solutions. At times, tests and data indicate that current design ideas will not meet the needs of the client or end user; in such cases, students learn to seek additional

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solutions. Students learn that sometimes the best solutions happen as designers combine key features from multiple design ideas. At this level of learning students begin to self-reflect upon the essential skills necessary for successful technology and engineering design process. Additionally, students expand their ability to apply a broad range of making skills to create design solutions, and to seek additional training to advance their knowledge and skills.

To demonstrate their ability to design in technology and engineering education, students in Grades 9-12 should be able to:

STEL-7W. Determine the best approach by evaluating the purpose of the design. Trade-offs occur as designers choose the approach to design that provides the most optimal solution.

STEL-7X. Document trade-offs in the technology and engineering design process to produce the optimal design. Students evaluate aspects of the technology and engineering design process and select optimal approaches for their design solutions. Students at this level should be able to articulate a rationale for design decisions.

STEL-7Y. Optimize a design by addressing desired qualities within criteria and constraints. Students optimize designs through critical evaluation of design decisions based on provided parameters.

STEL-7Z. Apply principles of human-centered design. Students consider the relationship between humans and the designed environment while designing. Students will synthesize their understanding of human-centered design through critical evaluation of design decisions and their appropriateness for the intended users.

STEL-7AA. Illustrate principles, elements, and factors of design. Students independently select, evaluate, and implement principles, elements, and other factors to improve their designs. The principles of design are balance, rhythm, pattern, emphasis, contrast, unity, and movement. The elements of design are line, shape, space, value, form, texture, and color. Additional design factors that can be applied to physical objects include ergonomics, energy efficiency, reliability, durability, safety, ease of manufacture, aesthetics, and more

STEL-7BB. Implement the best possible solution to a design. Students should be able to express a rationale, based on testing and analysis of evidence, to support their selection of a design solution that optimizes criteria and constraints. Identifying strengths and combining key features may enhance design solutions.

STEL-7CC. Apply a broad range of design skills to their design process. Students engage in meaningful discourse about the essential skills they have applied when engaged in successful design activity. These include creativity, collaboration, resourcefulness, ideation, learning through failure, and many other essential skills of design.

STEL-7DD. Apply a broad range of making skills to their design process. Students independently identify and safely use appropriate tools and processes to complete a design-making task. Students recognize their own knowledge and skill gaps, pursue opportunities to develop necessary skills, and become more confident and competent in making.

Standard 8: Applying, Maintaining, and Assessing Technological Products and Systems

Everyone uses technological products and systems—vehicles, televisions, computers, household appliances, and so on—but not everyone uses technologies well, safely, or in the most efficient and effective manner. Many of the problems associated with the use of technological products and systems result from the rapid pace of technological change. New technologies appear so frequently that it can be difficult to become comfortable with one before the next has taken its place.

Three equally important key ideas provide a foundation for applying, maintaining, and assessing technological products and systems. The benchmarks that follow all link back to these key ideas, with increasing levels of specificity and complexity across the grade bands. One key idea is that technologically literate people are better equipped to learn about and use technological products and systems than those individuals who lack prior technological experience. In order for students to be technologically literate in the application, maintenance, and assessment of technological products and systems they need to be exposed to a variety of technologies and be given opportunities to develop their knowledge and skills for mastering their use. Students should learn to select appropriate technologies for a given situation.

Students should be able to analyze technological malfunctions and come up with appropriate responses and remedies. A second key idea is that maintenance of a technological product, system, or process is crucial to keeping it in proper working order, and when malfunctions do occur, appropriate repair is necessary. Troubleshooting, testing, and diagnosing are important processes in maintaining and repairing a product or system. As a problem-solving process, troubleshooting is aimed at identifying the cause of a malfunctioning system. Effective troubleshooters are systematic in eliminating various possible explanations as they focus on the source of the problem. This process is known as one-variable testing.

A third key idea is that people should gather, synthesize, and analyze information before drawing conclusions when assessing a technological product, system, or process. To assess a technology in this way, students should be encouraged to acquire new abilities. These include testing, reasoning from past experiences, anticipating possible consequences, modeling and developing scenarios, and determining benefits and risks. These skills will enable students to assess how a product or system will affect individuals, society, and the environment. At the same time, students should realize that technological activities inevitably involve trade-offs, as well as a certain amount of risk.

Grades PreK-2

Technology plays an important part in young children's lives, providing them with shelter, physical comfort, toys, clothing, and food. Young children are interested in everything they see around them and ask questions about how things work, why things are a certain way, and how things came to be. They should be encouraged to investigate, perhaps by deconstructing and comparing various products to discover how they work and to better understand their use and purpose.

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Young children should collect information about everyday products and systems by asking questions. This questioning is important in developing an ability to make decisions about the use of technology and in evaluating its effectiveness or using troubleshooting to isolate and correct technological problems. The concept of data collection as a means of decision making should be introduced in Grades PreK-2 when students are studying data collection in science and mathematics. Using easily observable requirements (e.g., numbers, size, texture, weight, and motion), students will identify, categorize, and compare different kinds of technologies.

Employing products and systems often requires students to use common tools, such as staplers, rulers, scissors, and clamps. Although many students will have used tools before, they may not know how to use them correctly. Others may have no experience with a given tool and will require thoughtful introduction to its purpose and its effective, safe use. Through formal and informal learning activities and teacher-led demonstrations, students will learn the best and safest way to use a variety of tools.

Symbols are important because they communicate information and directions in an efficient manner. Young children should recognize that symbols are all around them, from icons on appliance controls to warning signs on roads. At the PreK-2 level, students should have basic recognition and understanding of symbols that communicate information, especially regarding safety.

To demonstrate their understanding of how to use and maintain technological products and systems, students in Grades PreK-2 should be able to:

STEL-8A. Analyze how things work. This can be done by safely and carefully taking something apart and then putting it back together. The ability to observe, analyze, and document is vital to successfully accomplishing this task.

STEL-8B. Identify and use everyday symbols. Symbols are used as a means of communication in the technological world. Examples include road signs, symbols for persons with disabilities, and icons on a screen.

STEL-8C. Describe qualities of everyday products. Technology assessment, or the ability to critically analyze a technology's effectiveness, is a skill that should be introduced early and consistently. Is a lunchbox hard or soft, metal or plastic, insulated or not? Is there enough space inside for the items brought for lunch?

Grades 3-5

Building upon knowledge from Grades PreK-2, students will learn more about how to use products and systems. At this level, students will deconstruct and analyze a product or system and reconstruct it to better understand technological systems and the relationships between parts. The knowledge gained in such exercises will help them to safely use and troubleshoot other products, systems, and processes.

Given many opportunities to use tools, students should become proficient in selecting the most appropriate tool for a given task. Students must also be taught to keep safety foremost in their minds when using tools. Tools that help students access, organize, and evaluate information should receive special attention.

In addition, students should understand and be able to use various symbols in different settings. These symbols could include signs in the community and icons on computers. In classroom activities, students may be challenged to create new symbols that could be used in the home, school, or community. They can begin to understand the need for symbols and how they aid in communicating key ideas quickly, and that some symbols are universal regardless of people's native language.

Students in Grades 3-5 will have an opportunity to assess technology from multiple viewpoints (e.g., personal, family, environmental, economic). In assessing technology, students take a step toward becoming self-reliant and independent thinkers. Furthermore, in learning to assess technology, students will develop skills in contrasting and classifying data used to make decisions.

Gathering information involves making investigations and observations about the use of technology and then recording the observations in an appropriate manner. Knowing how to gather data requires students to apply and access interdisciplinary skills such as scientific observation, statistical analysis, and language arts skills such as note taking, outlining, and informative writing.

Students should explore how technology influences individuals, families, communities, and the environment. As students study the significant events that helped shape their communities, they lay the groundwork for discussing and learning about the development and future use of technological products, systems, and processes. Students should learn to recognize and weigh the trade-offs implicit in any technology and consider whether the advantages will outweigh the consequences.

To demonstrate their understanding of how to use and maintain technological products and systems, students in Grades 3-5 should be able to:

STEL-8D. Follow directions to complete a technological task. Skill development typically starts with guided instruction, and many tasks require following a specific sequence of steps.

STEL-8E. Use appropriate symbols, numbers, and words to communicate key ideas about technological products and systems. Most of these symbols are found in everyday life, such as the alphabet, numbers, punctuation marks, or commercial logos. There are technical symbols to be aware of as well, including hazardous material symbols, caution signs, and the recycling logo.

STEL-8F. Identify why a product or system is not working properly. Technological systems and products do not last forever. For elementary students this can be unsettling when they expect everything to work every time. A chain coming off a bike gear becomes a teachable moment on how things function and how to get them working again. This concept is important for all students to learn. Teachers can ask questions to identify why the technology is not working properly, what could be a logical explanation of the problem, and what might be the easiest solution to address the problem.

STEL-8G. Examine information to assess the trade-offs of using a product or system. To assess technologies, information such as cost, function, durability, and warranties could be collected on products such as toys, food, games, health products, school supplies, and clothes to assess the costs, benefits, and trade-offs of these products or systems.

Grades 6-8

Students in the middle grades will explore, use, and properly maintain a variety of tools and machines, consumer products, and technological systems. Students will continue to practice proper safety procedures and follow directions or other protocols to ensure a safe and effective working environment. In these grades, students use appropriate tools to collect data and analyze information to help them determine whether a system is operating effectively. In addition to correcting problems, students will be taught to be proactive and to establish proper maintenance schedules that will keep their technological products operating efficiently. Tools at this level are used primarily for the purpose of designing and making products.

At the middle grades level, students will work toward solutions to more complicated and demanding technological problems. For example, students should realize that designing something using a set of constraints requires a different problem-solving process than determining why a device does not work.

To deal with technologies that have become inefficient or have failed, students will learn the skills of diagnosing, troubleshooting, maintaining, and repairing. They should be able to recognize when a system malfunctions, isolate the problem, test the faulty component or module, determine whether they can correct the problem, and decide if they require outside help.

Controlling technological systems and products is primarily done through feedback from electronic or mechanical sensors. These sensors can communicate to people whether a system is operating within safe operational parameters. The measurements taken by sensors can include temperature, number, distance, time, and other factors. Controls are found across a range of systems including transportation devices, energy systems, homes, and many others.

Students will be able to use instruments for gathering data. They will collect and analyze data to create knowledge, make sound decisions about technology, and evaluate and monitor the consequences of technological activity. Students can be introduced to ideas about intellectual property and legal protections such as patents, copyrights, and trademarks. By combining critical thinking and information gathering regarding technology, students will be able to effectively evaluate and assess products and systems.

To demonstrate their understanding of how to use and maintain technological products and systems, students in Grades 6-8 should be able to:

STEL-8H. Research information from various sources to use and maintain technological products or systems. Written and graphical information is helpful in learning how to use a product and determining if it works properly. In addition, many manuals provide tips on how to troubleshoot a product or system.

STEL-8I. Use tools, materials, and machines to safely diagnose, adjust, and repair systems. For many consumer products, federal and state laws require safety information. Safety procedures should be learned through formal education and teacher demonstration. Tools are used by students for diagnosis, adjustments, and repair. For example, when the cutting bit on a computer numerically-controlled (CNC) lathe wears down, adjustments need to be made to the alignment of the cutting bit to the raw stock.

STEL-8J. Use devices to control technological systems. Students should be familiar with and use sensors to control technological systems such as robotic devices, alternative energy vehicles, and other technologies. Many machines are equipped with other types of safety devices to protect the user.

STEL-8K. Design methods to gather data about technological systems. Examples include devices designed to test water or air quality, performance tests to assess things like accuracy or speed, destructive testing to analyze strength and durability of materials, and so on.

STEL-8L. Interpret the accuracy of information collected. Developing specific criteria for what information is useful is important in making these judgments. Sometimes determining accuracy is easy—taking information from physical measuring devices like a water-purity tester, for example. At other times, accuracy is more difficult to determine, as when assessments are based on public opinion, which can differ greatly from group to group.

STEL-8M. Use instruments to gather data on the performance of everyday products. Students should use evidence to make more complex technology assessment decisions. For example, monitoring the power produced by a photovoltaic system will allow students to determine if the system is operating according to its rated output.

Grades 9-12

By the time students graduate from high school, they should be able to use and maintain various types of products and systems—a key element in technological and engineering literacy. Some students will also have developed strong personal interests and abilities in technology or engineering and will be ready to pursue further education in these fields. Students should be able to articulate and communicate their thoughts regarding technological and engineering products and systems.

Students should be capable of diagnosing, troubleshooting, analyzing, and maintaining systems. These abilities become central to keeping systems in good condition and in working order. Students should understand the importance of preventive maintenance schedules, in addition to learning about troubleshooting and engaging in research and development (R&D).

As has been stressed at other grade levels, the safe and effective use of tools and machines is an important part of technological and engineering literacy. Students should be given many opportunities to use various tools to retrieve, monitor, organize, diagnose, maintain, interpret, and evaluate data and information that can then be used in solving technological problems. Safe use of tools is expected in all stages of design and making of products.

Students will learn to synthesize data and to use this to design and control technological systems. Collecting and synthesizing data is invaluable for making informed technological decisions. For example, people who are interested in buying a product or system may research how comparable products fare in

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the marketplace and if meaningful trends are discernible. Is market share increasing for a particular product because it operates better or is less costly than competitors? Is product failure an increasing complaint? Once information has been accumulated and evaluated, the final step in assessing a product or system is deciding whether using it is appropriate. In making such a decision, students should come to understand the benefits and risks, costs, limits, potential, and trade-offs of technological developments.

To demonstrate their understanding of how to use and maintain technological products and systems, students in Grades 9-12 should be able to:

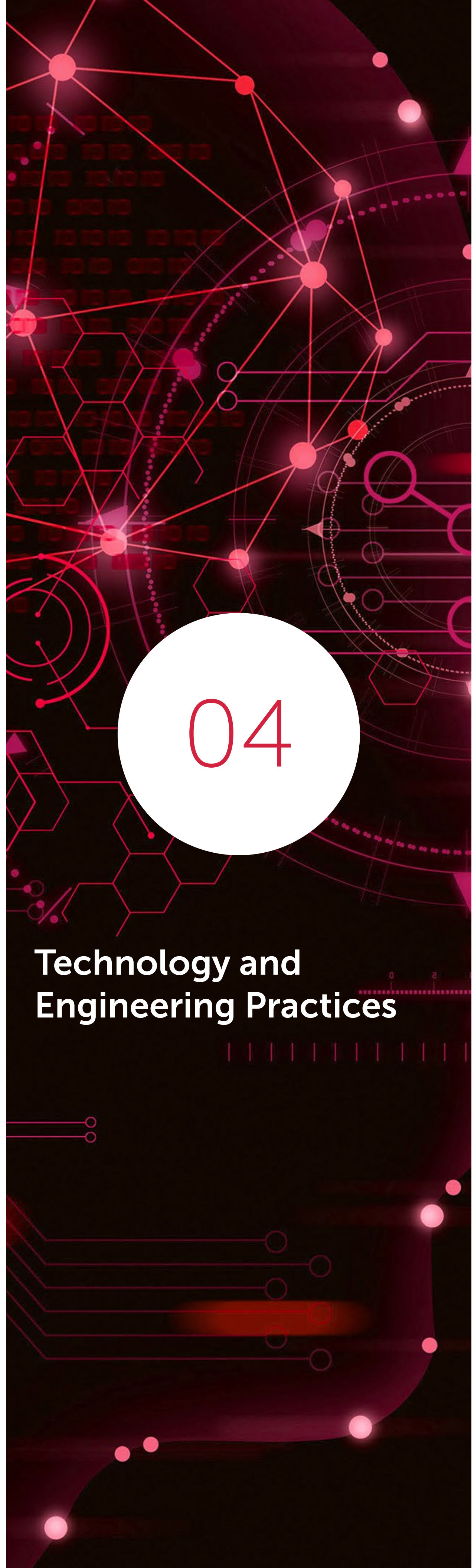
STEL-8N. Use various approaches to communicate processes and procedures for using, maintaining, and assessing technological products and systems. Examples of such techniques include flow charts, drawings, graphics, symbols, spreadsheets, graphs, time charts, and web pages. The audiences can be peers, teachers, local community and business members, and the global community.

STEL-8O. Develop a device or system for the marketplace. Research on specific topics of interest to the government or business and industry can provide more information on a subject, and, in many cases, can provide information needed to create an invention or innovation. R&D helps to prepare a product or system for final production. Product development of this type frequently requires sustained effort from teams of people having diverse backgrounds.

STEL-8P. Apply appropriate methods to diagnose, adjust, and repair systems to ensure precise, safe, and proper functionality. For many consumer products, federal and state laws require safety information. Tools are used by students for diagnosis, adjustments, and repair. Monitoring the operation, adjusting the parts, and regular maintenance of a system are part of keeping systems in good working order and maintaining safety.

STEL-8Q. Synthesize data and analyze trends to make decisions about technological products, systems, or processes. Deductive thinking and synthesis techniques can assist in this process. Students should consider historical events, global trends, and economic factors, and they should evaluate and consider how to manage the risks incurred by technological development.

STEL-8R. Interpret the results of technology assessment to guide policy development. Laws, regulations, and policies shape the development and use of technology. Students should understand, in increasingly sophisticated ways, how technology assessment impacts policy development.



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Technology and Engineering Practices

As students acquire the knowledge, skills, and dispositions defined by the core standards in *STEL*, they will repeatedly make use of a set of behaviors that are consistent with technology and engineering activity. Depending on the source, such behaviors are referred to variously as “practices[1],” “engineering habits of mind[2],” and “21st Century Skills[3],” among other titles.

[1]*Next Generation Science Standards* (NGSS Lead States, 2013)
[2]National Academy of Engineering (2019b)
[3]Partnership for 21st Century Skills (2019)

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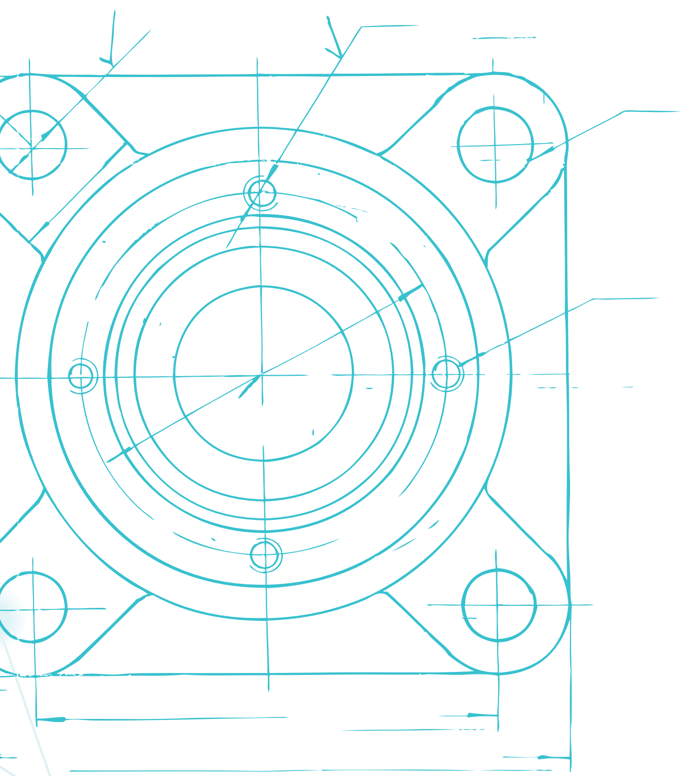
Technology and Engineering Practices



As applied in technology and engineering education contexts, these technology and engineering practices comprise abilities and dispositions that are seen as fundamental to student success. Technology and engineering practices 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 practices are equally important from an interdisciplinary context, as seen in the connections to science, mathematics, and the humanities outlined in Chapter 1. This chapter will define eight technology and engineering practices, describe the functions of each practice by grade band, provide some guiding principles for their implementation, and give an overview and example for each practice. The eight technology and engineering practices are described in the following ways:

TEP-1. 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.

TEP-2. Creativity is the use of investigation, imagination, innovative thinking, and physical skills to accomplish goals, including design goals.

TEP-3. Making and Doing are at the heart of what makes technology and engineering education 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.

TEP-4. 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.

TEP-5. 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.

TEP-6. Collaboration refers to having the perspectives, knowledge, capabilities, and willingness to seek out and include team members when working on design challenges.

TEP-7. Communication in technology and engineering education can be considered 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.

TEP-8. Attention to Ethics is at the core of being a human in society. In technology and engineering education, 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.

These eight student-centered practices are equally important, and their order in the list should not be considered hierarchical. They help students develop the knowledge, skills, and dispositions to successfully apply the core disciplinary standards in the different context areas. To accomplish this, curriculum developers and teachers should apply the following guiding principles.

Guiding Principles for Teaching Technology and Engineering Practices

Students in all grade bands should use these eight technology and engineering practices in a variety of contexts. These practices have been identified as essential skills for an individual's technological and engineering literacy and in a complementary way are as important as the core disciplinary standards. *STEL* does not prescribe how teaching of these practices is to occur; rather, that is left up to curriculum developers and teachers. However, these should not be taught as isolated practices. Their repeated use in a variety of contexts will allow students to apply these practices at an increasing level of proficiency.

Practices become more complex across the grade bands (PreK-2, 3-5, 6-8, and 9-12). Table 4.1 outlines student expectations for all eight practices by grade band. This table demonstrates how engagement with these practices grows over time. However, it should not be assumed that older students have mastered the abilities from prior grade bands. Likewise, younger students may have experiences that allow them to function at higher levels within a given technology and engineering practice. Therefore, curriculum developers and teachers should use summative and formative evaluations to gauge students' abilities with regard to technology and engineering practices.

Technology and engineering practices are connected and overlapping. In fact, it would be almost impossible to teach a practice in isolation. The background and examples given for each practice in this chapter attempt to describe how integrated these eight practices are, and to illustrate how the practices might be applied in classroom settings.

Table 4.1. Technology and Engineering Practice Expectations by Grade Band

Grade Bands	TEP-1: Systems Thinking	TEP-2: Creativity	TEP-3: Making and Doing	TEP-4: Critical Thinking	TEP-5: Optimism	TEP-6: Collaboration	TEP-7: Communication	TEP-8: Attention to Ethics
PreK-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 and Engineering Practice 1 (TEP-1): 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 takes into account all of 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" (para. 9). What do these definitions have in common, and why is systems thinking considered an essential technology and engineering practice?

Systems thinking can promote the kind of interdisciplinary work that is integral to STEM education. 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* looks first at 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 product or 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

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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, if included; 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 of the information being gathered and decisions being made.

Technology and Engineering Practice 2 (TEP-2): 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 Academy 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 and Engineering Practice 3 (TEP-3): 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 education. 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. It also provides ample opportunities for addressing the overlapping *STEL* core concepts, practices, and applications.

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 within STEM education.

Safely making and doing are central to technology and engineering education. 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 education 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 education apart from other subject areas in today's PreK-12 schools, and is one of the reasons students find these programs so meaningful.

Students could potentially use all eight of the practices identified in this chapter within the context of making and doing. They perform systems thinking (TEP-1) as they design or construct items. Using their creativity (TEP-2) and critical-thinking skills (TEP-4), students must analyze the requirements of a situation or problem and consider how they can ethically design a solution to address the situation (TEP-8). Students are able to realize at a young age that their designs often improve (Practice 5) when collaborating with others (TEP-5) 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 STEM 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 some STEM classrooms. In the past, students often built furniture from pre-designed 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 STEM concepts in their making and doing.

Technology and Engineering Practice 4 (TEP-4): 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 student 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 has a technology and engineering teacher ask *Foundations of Technology* 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 on line. 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 would they change.

Technology and Engineering Practice 5 (TEP-5): 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 (TEP-4) and attention to ethics (TEP-8). 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 (TEP-1), 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 and Engineering Practice 6 (TEP-6): 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.

Take, for example, the *STEM⁴: The Power of Collaboration for Change* document (Advance CTE et al., 2018). Texas Instruments, a large and influential technology company, was concerned that the United States was "falling short in preparing students for college majors or careers" in STEM (Advance CTE et al., 2018, p. 1). The company gathered STEM leaders and worked with them to produce a document illustrating "the need for systematic change in STEM policies and practices in order to serve the nations' children, close opportunity gaps, and address systemic inequities" (p. 6). The resulting *STEM⁴* report was only made possible through collaboration between Advance CTE, the Association of State Supervisors of Mathematics, the Council of State Science Supervisors, the International Technology and Engineering Educators Association, and Texas Instruments. Without this collaborative effort, the important guidance found in the *STEM⁴* document would not exist.

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 the opportunity to collaborate 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 education. Working in collaborative teams is also common in technology and engineering education, but can be expanded upon. Students, particularly those with limited project collaboration experience, will benefit from guidance on how to structure 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 bring in other disciplinary perspectives. Teleconferencing tools have also made it possible to rethink what a classroom boundary is, 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 PreK-2 grade level could learn

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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.

A high school *Advanced Applications in Technology* class is 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 and Engineering Practice 7 (TEP-7): 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 PreK 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 will begin. 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.

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Technology and Engineering Practice 8 (TEP-8): 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.

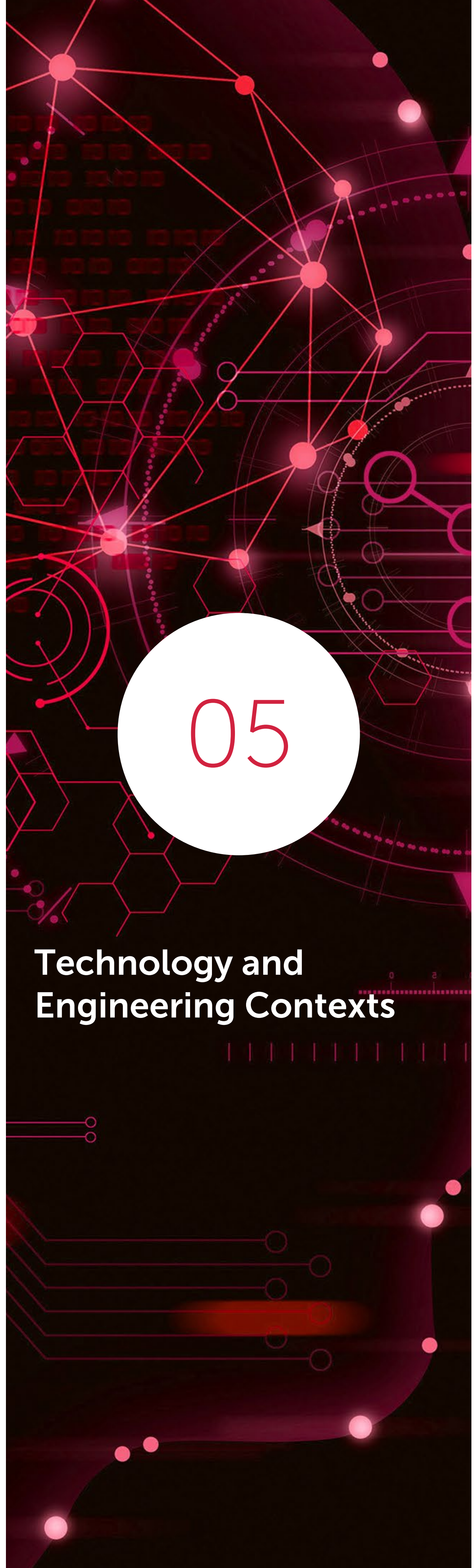
Any technology or system designed by technologists and engineers should be evaluated for its potential impact on people, society, and the environment. Sometimes, unintended consequences and impacts don't become apparent until after production and distribution have been initiated. Furthermore, these impacts 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 with 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 promote gender equity and 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.

In a high school *Advanced Applications in Technology* 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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Technology and Engineering Contexts

The most appropriate setting for teaching the eight core disciplinary standards is a technology and engineering laboratory-classroom with a certified technology and engineering teacher. Technology and engineering classrooms and laboratories can vary greatly depending upon the state, district, region, province, or country in which programs are located. In *Standards for Technological and Engineering Literacy*, these settings are referred to as technology and engineering contexts.

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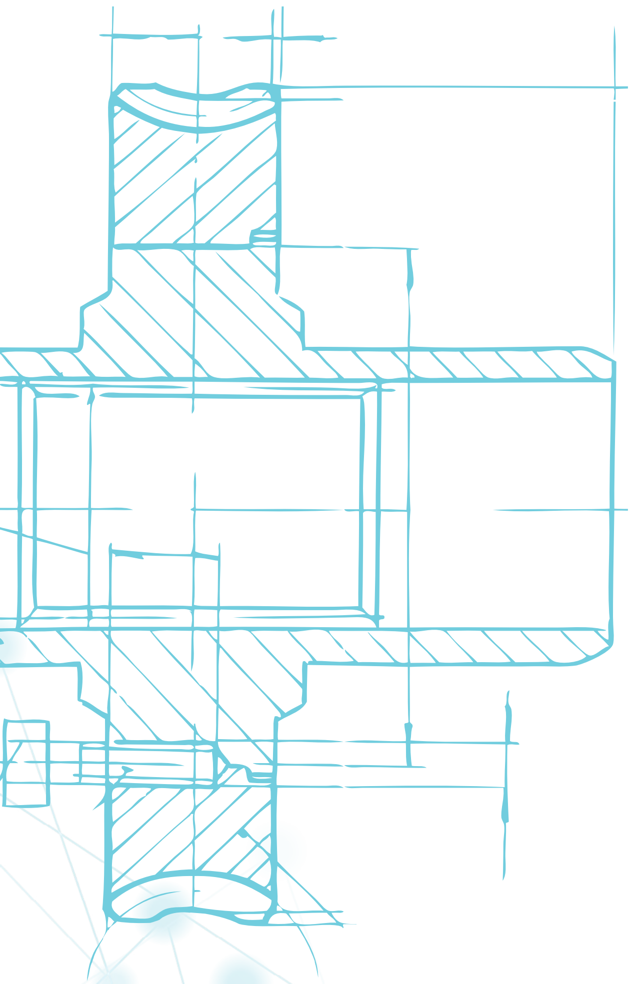
Technology and Engineering Contexts



The disciplinary contexts do not necessarily imply a specific course or program. Many of these contexts could be represented as units within a technology and engineering or core course, or as field trips, engineering challenges at museums, makerspaces in libraries, or activities within a student organization (e.g., Technology Student Association [TSA]), competitive event, or statewide STEM organization.

The technology and engineering contexts are grouped into eight areas that broadly represent the breadth of technological activity. Most current technology and engineering courses will fit within one or more of these contexts:

TEC-1: Computation, Automation, Artificial Intelligence, and Robotics
TEC-2: Material Conversion and Processing
TEC-3: Transportation and Logistics
TEC-4: Energy and Power
TEC-5: Information and Communication
TEC-6: The Built Environment
TEC-7: Medical and Health-Related Technologies
TEC-8: Agricultural and Biological Technologies

In this chapter, these technology and engineering contexts are described and linked to the core disciplinary standards and how they can be taught. The technology and engineering contexts are vehicles for teaching and applying the core disciplinary standards and technology and engineering practices.

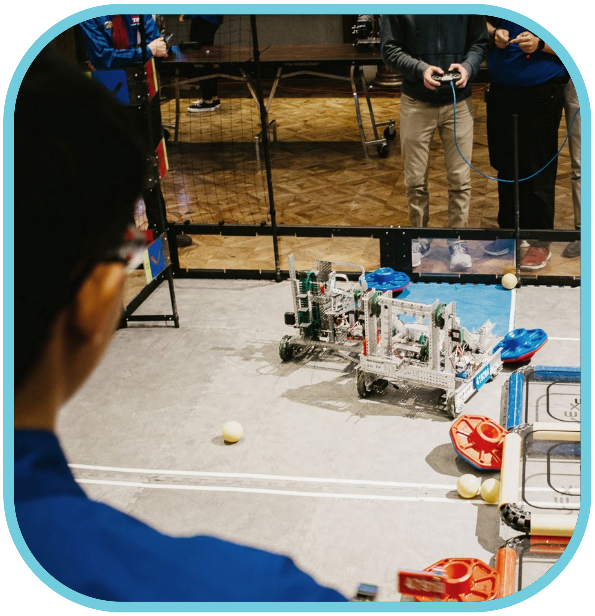
Each of the eight contexts described in this chapter includes:

- A description of the context within technology and engineering education and STEM education.
- A sampling of courses offered by state/provincial or national curricula.

- Suggested examples on how grade-band benchmarks can be linked to courses, projects, course objectives, and technology and engineering practices in the United States and other countries. In many of these examples, one could readily envision engaging students in use of all eight practices. For the purposes of *STEL*, we will only reference one in each example. These are stand-alone examples and are not intended to illustrate coverage of a specific topic across the PreK-12 spectrum.

When implementing *Standards for Technological and Engineering Literacy*, students and teachers should focus primarily on the core disciplinary standards and benchmarks and, secondarily, on the technology and engineering practices. The courses and programs mentioned in the examples provided here are from selected current national and state-level courses in specific grades. Because these course titles and activities change over time, they are referred to using generic titles, not by name. Teachers in need of prescriptive objectives in these contexts should refer to their state/province/country curriculum frameworks.

Each of the eight technology and engineering contexts provides rich opportunities for acquisition of the knowledge, skills, and dispositions detailed in the standards, and for application of the technology and engineering practices described in Chapter 4. Moreover, each of these contexts contains unique knowledge that is specific to that field of endeavor. For example, within the context of energy and power concepts such as energy conversion, energy transmission, power calculations, and much more may be taught. Because the breadth of technological activity is so vast and ever-changing, *STEL* focuses on the core knowledge, skills, and dispositions that might apply *regardless of the specific context* and in this way reinforces these aspects of technological literacy across the PreK-12 spectrum. However, it must be emphasized that technological and engineering activity requires a context. The structure of *STEL* allows local, state/provincial, and national curriculum developers to select those contexts that are most meaningful and appropriate given their own specific needs, resources, and goals.



Technology and Engineering Context 1 (TEC-1): Computation, Automation, Artificial Intelligence, and Robotics

Overview

Computation is often thought of as a mathematical process. Computational thinking can be defined more broadly as a systematic approach to planning, problem solving, and creating. In *STEL* the term computation is used to describe contexts where computational thinking and design processes are used in technology and engineering education. For example, cybersecurity is one setting that could be linked directly to the context of computation. Computation consists of several elements, including:

- Breaking down problems, processes, and/or data into smaller pieces
- Recognizing patterns via identification of trends, commonalities, and anomalies discovered through observation and troubleshooting
- Generating general principles or ideas from abstract data
- Designing algorithms that provide processes and approaches for accomplishing a task
- Applying algorithms through designing, programming, testing, and revising within physical applications

Within technology and engineering education, computational thinking is inherently tied to designing, making, and programming physical devices, a process commonly referred to as physical computing. While other fields (e.g., computer science) are also engaged in computational thinking practices, the unique approach of technology and engineering is connected to the automation of physical devices and systems that result in, from, or through design. Computation is seen in a multitude of application areas including, but not limited to, automation, artificial intelligence, and robotics. Computational thinking is needed in all of the other contexts, particularly material conversion and processing, transportation and logistics, and information and communication technology. Additionally, it is a part of multiple technology and engineering practices.

Automation is the operation and control of equipment and processes through programmable systems. As humans developed a greater understanding of the natural world around them, automation facilitated faster, easier, and more precise mechanization of processes. Automation also influenced the creation of new technologies and the advancement of existing technologies. Throughout history, technology has had many positive and negative outcomes, both intended and unforeseen. Automation is no different; it has been both praised and criticized as it has evolved. Automation in its very simplest form appeared through inventions like Eli Whitney's cotton gin, which helped to automate the process of separating cotton fibers from their seeds. More modern examples include automated assembly in vehicle production and other manufacturing areas. While this advancement in technology has increased the accuracy and number of products produced, it has also decreased the number of jobs previously performed by people. As a result, workers have needed to shift their roles and be retrained to program and service these automated systems. Instruction on the skills to design and automate these systems must consider various factors (e.g., safety, maintenance, efficiency, and trade-offs). Students should experience design-based automation applications in various contexts, like those described in this chapter.

Similar to automated devices, artificial intelligence, or AI, has also been and continues to be a controversial topic. AI can be defined as human-like knowledge and skills exhibited by a manufactured device or system. AI has allowed humans and computers to collect data and information to improve living and working conditions. AI has been criticized for infringing on privacy due to the potential for inappropriate tracking of personal information about individuals' behaviors and habits. Beneficial applications of collected information could be used to help make a person's daily life easier by automating tasks completed every day at the same time. For example, by predicting what time a person usually arrives home, a thermostat could adjust the temperature to be more comfortable based on outside weather conditions. This would help conserve energy, cutting down on non-renewable energy usage and electric costs. On the other hand, this data could be misused to track human actions for negative outcomes. For example, personal assistant devices in homes or cars can forward conversations and preferences back to companies for the purpose of making more tailored marketing pitches to individuals. When tasked with developing AI systems, students must also be prompted to consider these trade-offs. Designing a security or safety measure to protect the end user is just one consideration when developing AI applications. AI applies computational thinking by identifying and replicating patterns. Coding and programming, microcontrollers, electronic sensors, and other tools and methods can be used to integrate these patterns into a given technological system.

Artificial intelligence is an application of computational thinking that can be closely connected to a student's life. Students should be taught to recognize patterns using computational thinking skills and design solutions to improve those tasks using AI and various technologies. Some examples of AI in various contexts to improve our daily lives include intelligent traffic signals, facial recognition for security and identification purposes, fraud identification, email filters and reminders, product purchasing recommendations, music recommendations, navigation systems, and smart vehicles.

Robotics has long been a core component of technology and engineering programs; however, robotics and the associated applications have advanced dramatically in recent years and are expected to continue to do so. For example, robots were traditionally used as a means to make manufacturing more efficient (e.g., assembly, CNC manufacturing). However, advances in robotics have allowed this technology to be used in more refined ways for greater benefits, such as medical robotic devices used to perform difficult surgeries. Robots can be defined as mechanical devices that can perform tasks automatically or with varying degrees of direct human control. As robotic technologies continue to advance, students will be able to apply robotics to new applications and in contexts for safer and more precise outcomes. Robotic tools can also be automated to carry out repetitive tasks or tasks that would have required many hours for a human worker to perform.

Multiple technologies and content areas may be integrated to develop advanced systems involving robotics. Design of the robotic system, and the steps used to perform a task as safely and efficiently as possible, should be major points of emphasis in this context. Examples of robotic applications could include designing and programming a small assembly line, controlled and autonomous navigation of vehicles and Unmanned Aerial Systems (UAS) to transport people and products, simulated safety applications such as a robot to survey an

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area prior to sending people into a hazardous situation, high-efficiency agricultural practices, and many other applications.

Programs in Technology and Engineering

There are many ways to implement the newer contexts of automation, computation, artificial intelligence, and robotics in PreK-12 classrooms. Many states and local districts implement stand-alone courses in automation, computation, artificial intelligence, and robotics technology at the middle and high school level, but these key ideas can also be introduced to students in the earlier grades. In addition, national curriculum developers provide courses on automation, computation, artificial intelligence, and robotics. The examples below contain lessons from computation, automation, IA, and robotics contexts at different grade levels. They showcase the links between the *STEL* benchmarks, technology and engineering practices, and technology and engineering contexts.


Photo credit: Julie Sicks-Panus.

Grades PreK-2 Technology and Engineering Context in Computation, Automation, Artificial Intelligence, and Robotics: PreK children can apply STEL-3A: Apply concepts and skills from technology and engineering activities that reinforce concepts and skills across multiple content areas by identifying patterns within technology, mathematics, or scientific contexts and attempting to predict how those patterns may continue or change based on recognized variables. This may be accomplished during a unit or activity on toys and products. This activity of exploring and describing motion prepares students to look for patterns that are an essential component of computational thinking. This example can be linked to TEP-4: Critical Thinking. First-grade students can apply STEL-2A: Illustrate how systems have parts or components that work together to accomplish a goal in basic electronic circuit design and function. Students in a national curriculum on light and sound can be guided to follow the path of electricity in a simple series circuit that turns on an alerting device such as a light or buzzer using a switch and power source. This example can be linked to TEP-1: Systems Thinking.

Grades 3-5 Technology and Engineering Context in Computation, Automation, Artificial Intelligence, and Robotics: Third graders can apply STEL-4F: Describe the helpful and harmful effects of technology in a national curriculum on stability and motion that includes programming. These students identify technologies in their world that use automation or artificial intelligence and discuss both positive and negative impacts that could result. To elicit further thinking, students should identify these impacts and suggest potential solutions when designing a system that would utilize automation or artificial intelligence. This example can be linked to TEP-7: Communication.

Fifth graders can apply STEL-8E: Use appropriate symbols, numbers, and words to communicate key ideas about technological products and systems to control a simple microcontroller or robot in a national robotics and automation course unit. Students should be able to use a graphical programming system, such as blocks, to develop a program that allows a microcontroller or robot to perform a desired task (e.g., turn on a light or sound a buzzer when motion is sensed). This example can be linked to TEP-2: Creativity.

Grades 6-8 Technology and Engineering Context in Computation, Automation, Artificial Intelligence, and Robotics: Sixth-grade students could apply STEL-5G: Evaluate trade-offs based on various perspectives as part of a decision process recognizing the need for careful compromises among competing factors to design an automated home in a national curriculum course on automation. Students would need to design, test, and automate various sensors that rely on input and output, to interact seamlessly and control functions in the house such as temperature, lighting, and security. This example can be linked to TEP-3: Making and Doing.

In a United Kingdom-based program in Design & Technology, students in Grades 6-8 can apply STEL-2S Defend decisions related to a design problem. In the unit YF 3 *Understanding Needs and Wants*, students learn about the relationship between needs and wants and think about why people buy certain products and services. When theoretically dropped into a forest and later a seaside, they are asked to reflect and respond to critical-thinking questions related to being cut off from modern resources. This example can be linked to TEP-6: Collaboration.

Grade 8 students could apply STEL-1J: Develop innovative products and systems that solve problems and extend capabilities based on individual or collective needs when they are introduced to various physical challenges faced by military veterans. Providing middle school students with the opportunity to design, test, build, and automate a device that performs an important function for these veterans could help students practice using knowledge of sensors, motors, controllers, materials, and techniques as they work to automate a solution that extends the capabilities of individuals. This activity aligns with an objective to *Integrate proper body mechanics, ergonomics, safety equipment, and techniques to prevent personal injury to patients and clients* and can be linked to TEP-8: Attention to Ethics.

Teams of middle school students apply STEL-2P: Create a closed loop system that has a feedback path and requires no human intervention during an aircraft manufacturing company-sponsored innovation challenge on developing robotic rescues. Students are given a scenario of a flooded area that needs supplies delivered and people extracted. They design and build an Unmanned Aerial Vehicle (UAV), or drone, to deliver a payload of ping pong balls to a target. Students must include a preliminary design report. This example can be linked to TEP-5: Optimism.

Grades 9-12 Technology and Engineering Context in Computation, Automation, Artificial Intelligence, and Robotics: Tenth grade students can apply STEL-7DD: Apply a broad range of making skills to their design process in a course on electronics when they create, construct, and control an advanced microcontroller robot or automated system. Students should be able to write the programming language required to control these items to perform desired tasks,

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identify patterns, and make adjustments based off of recognizing those patterns (e.g., design and program a small-scale assembly line that can recognize defective products and collect data on the frequency of those unwanted products to improve the safety and efficiency of the products produced by the assembly line). This can be linked to TEP-1: Systems Thinking.

Twelfth graders can apply STEL-6J: Investigate the widespread changes that have resulted from the Information Age, which has placed emphasis on the processing and exchange of information to identify and predict patterns in the exchange of information within a complex system in a robotic applications capstone course. This activity includes the use of mathematical equations and algorithms. An example would be examining the routes of a transportation system and how recognizing patterns in traffic flow or other issues could allow for a more efficient route to be communicated to the controller or system. Students may also consider planning how to safely automate the communication needed for this process. Furthermore, students should understand how the Information Age has provided benefits like this for more efficient processes. This example can be linked to TEP-4: Critical Thinking.

Technology and Engineering Context 2 (TEC-2): Material Conversion and Processing

Overview

Material conversion and processing is the production of physical goods. These goods can range from tools, such as kitchen appliances and computers, to products such as shoes and tennis balls, and to biological materials as well.

Material conversion and processing of goods has changed tremendously over the last century. Before manufactured goods became widely available, many goods were custom made—individuals made each product by hand, one at a time. With developments such as standardized parts, assembly lines, and automation, material conversion and processing changed dramatically. For the first time, goods became more affordable as more of them could be produced, an effect known as economy of scale. As machines became more accurate, making more complex items with interchangeable parts became more affordable. Progress continues in material conversion and processing with emerging models such as crowdfunding, open-source design, and sustainable development, among others.

All goods are made of materials, and without these material resources production is impossible. Although every material can be traced to one or more natural resources, very few materials can be used in their natural form. They must first be processed to some degree before they can be used to produce goods that are ready for market. For example, some clothing is made of cotton, but before cotton can be used to make clothing it must first be planted, grown, harvested, processed, and woven into cloth. The same is true of all materials, from steel and lumber to plastic. Materials must first be processed into standard stock, which in turn is used to make manufactured products. The processing of materials into standard stock is called primary manufacturing.

Goods can also be classified as durable or non-durable. During processing, materials may be separated, formed, combined, and conditioned to reach their final form. During the design phase, use of additive printers has resulted in quicker turnaround from ideas to finished products. With the use of robotics, computer control, and automated assemblies, these processes can be accomplished quickly and accurately. Some industries use a process called just-in-time (JIT) production, in which supplies, components, and materials are delivered just when they are needed. This process, which is designed to reduce the need to store inventory, places the burden on the suppliers to deliver quality parts and materials on an as-needed basis and can result in shortages when supply chains are disrupted. Modern manufacturing, therefore, is built to develop and produce products quickly to create new markets or stay ahead of competitors.

Product and project management is a common component of technological and engineering literacy that includes specific skill sets. Management in manufacturing includes four key actions: planning, organizing, directing, and controlling, with additional responsibilities in research and development, production, marketing, industrial relations, and financial affairs. To be a product manager one needs to be a person of many talents, and certainly must be technologically literate. Management includes system design in factory layout to efficiently move materials and inventory through manufacturing processes. Manufacturing also may involve systems for continuous improvement, including lean manufacturing, total quality management, Six Sigma, and others. In addition, manufacturing is regulated by government and professional association regulations.

We live in a global economy where products made in the United States, Portugal, Japan, China, Malaysia, Mexico, Canada, and many other countries are sold and used worldwide. Corporations may be global in scale with research and design in one country and production, marketing, and distribution in others. This globalization has led to the need for workers to be flexible and respectful of diverse cultures. Our lives have been enhanced because of material conversion and processing technology. It provides a segment of the population with jobs, is a major factor in the economy, and provides us with many products that improve the quality of life.

Programs in Technology and Engineering

There are many ways to implement manufacturing technologies in PreK-12 classrooms. Activities and units within PreK through elementary STEM courses can address material conversion and processing along with the core disciplinary standards. Many states and local districts implement stand-alone courses on material conversion and processing. In addition, national curriculum developers provide courses on material conversion and processing and engineering. Due to the development of new technologies and research, it is appropriate to teach the core disciplinary standards within these technology courses. The examples below contain lessons from material conversion and processing contexts at different grade levels. They showcase the links between the *STEL* benchmarks, technology and engineering practices, and technology and engineering contexts.

Grades PreK-2 Technology and Engineering Context in Material Conversion and Processing: Kindergarten students can apply STEL-2A: Illustrate how systems have parts or components that work together to accomplish a goal while designing and constructing an avian habitat as part of a unit within a national curriculum course. The teacher can ask the students: what would happen if there was no bottom to this structure?

What if it was made out of paper? Could they use a toy to make a bird house? Why are the holes of different sizes for birds? This activity links to TEP-4: Critical Thinking.

First graders can apply STEL-6A: Discuss how the ways people live and work has changed throughout history because of technology in constructing a product that makes and detects sounds as part of a national curriculum course unit. This links to the unit objective *Identify contributions that humans have made throughout the history of science and technology* and to TEP-6: Collaboration.

Grades 3-5 Technology and Engineering Context in Material Conversion and Processing:
Third graders can apply STEL-7N: Practice successful design skills in a national curriculum unit where student teams design a blizzard shoe that resists weather hazards. In a warm climate, how can students test their design? This engineering and scientific discovery project links to TEP-5: Optimism.

Year 4 students in a United Kingdom course can apply STEL-8D: Follow directions to complete a technological task in a unit called Treasure Box. Many children have particular small favorite items or treasures. These are precious but not necessarily valuable in monetary terms—an attractive pebble or shell, a small toy figure, a tiny doll, an old coin, an unusual button, a buckle from an old shoe. Usually these items are associated with a fond memory—a holiday, a visit, a lucky find—and sometimes they involve friendships. A difficulty with these items is that they can easily get lost. One solution to this problem is to design and make a special container, one that can hold the item safely and from its appearance reflect the importance of the contents. The children's task is to identify one, or a few, small items that are precious and to make a suitable "treasure" box. Students might plan an octagonal box and design the cutting pattern on a material such as cardstock. After building the treasure box, students decorate the box to personalize. This unit links to TEP-2: Creativity.

Fifth graders can apply STEL-2K: Describe requirements of designing or making a product or system in a national curriculum where students study mechanical design and computer programming in order to design an automated guided vehicle for delivering supplies in a hospital setting. Students can test their designs in the classroom and then go to a local hospital on a field trip to try out their final designed vehicles. This project links to TEP-3: Making and Doing.

Grades 6-8 Technology and Engineering Context in Material Conversion and Processing:
Eighth graders in a national curriculum on technological systems can apply STEL-8I: Use tools, materials, and machines to safely diagnose, adjust, and repair systems as they learn to maintain

technological systems. Systems need to be adjusted or repaired and tools and equipment must be used safely. This objective and activity addresses material conversion and processing safety as well as OSHA safety requirements in school labs. It can be linked to TEP-1: Systems Thinking.

Middle school students can apply STEL-3G: Explain how knowledge gained from other content areas affects the development of technological products and systems when using mathematics to precisely measure in English and metric measurement when laying out parts in a manufacturing design process. This project pairs American student teams with teams from a Caribbean island to develop a tennis racket for children. Different measuring systems are used, so part of the instruction is conversion of measurements. This links to TEP-7: Communication.

Grades 9-12 Technology and Engineering Context in Material Conversion and Processing: High school students taking a national course on computer integrated manufacturing (CIM) can apply STEL-4Q: Critique whether existing and proposed technologies use resources sustainably. In this course, students design and create a product using Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) software to transform raw materials into a unique shape on a computer numerical control (CNC) milling machine. Part of the discussions that occur focus on manufacturing and industrial waste. This links to TEP-8: Attention to Ethics.

High school students in a national curriculum on additive manufacturing and materials can apply STEL-5H: Evaluate a technological innovation that arose from a specific society's unique need or want while studying new materials for use in advanced additive manufacturing. Societal resistance to the impacts of using combinations of materials in home and school printers resulted in a focus on materials product standards and safety measures. This links to TEP-8: Attention to Ethics.

Tenth graders apply STEL-8O: Develop a device or system for the marketplace by working in a team to design and use a programmable logic controller (PLC) to control a device that did not previously include an electronic control system (e.g., a toy car). During the project, the student teams will apply the controller, troubleshoot malfunctions, and evaluate the overall performance of the control system. This project supports TEP-3: Making and Doing.

Technology and Engineering Context 3 (TEC-3): Transportation and Logistics

Overview

People view transportation as one of life's basic needs. Transportation systems take individuals to work, offer them convenient access to shopping, allow them to visit with their friends and family, provide opportunities for recreation, and carry the material goods of society.

The overall transportation system is a complex network of interconnected components that operate on land, on water, in the air, and in space. Many of the subsystems of the transportation system, such as highways, ports, airports, pipelines, and others, are dependent upon other subsystems, and each, in turn, is made up of yet smaller components that are themselves interlinked and interdependent. For many years people have used various forms of transportation—such as ships, boats, jets, helicopters, elevators, and escalators—while newer forms of transportation are used in limited areas or are still in experimental stages.

Logistics is the management of physical and information flows starting at the source of supply and ending at the consumption point. Logistics often involves data-driven decision-making through data management and analytics. With the increased speed of digital computing, advances in logistics are allowing transportation systems to react quickly to changes in data. This is known as a data-driven innovation cycle, in which data generation and analysis works to improve transportation capabilities and meet unexpected challenges. One example of logistics in urban automobile systems is the optimization of traffic signals for the purpose of reducing traffic congestion. Another example of logistics is the transport of goods from a manufacturing site in India to a retail business in the United States. The order must be processed through shipping companies that deal with international tariffs and rules, translation of information, and different transportation means (e.g., railways, ships, containers, trucks) through distribution centers.

The more complex life and work become, the more indispensable transportation and logistics systems are. Throughout history, transportation systems have brought different parts of the world closer together. In the early twentieth century, for example, an airplane flight across the United States would take approximately 26 hours. Now, through advances in technology, the same trip can be accomplished in five hours or less.

Because transportation is such an integral part of life, people often take it for granted or consider it an ordinary part of the world. As transportation advances, society becomes increasingly dependent upon types of transportation. Autonomous vehicles are delivering products and people through sophisticated software applications. Today there is arguably more consideration given to the environmental consequences and other effects of rapid expansion of transportation technologies. Future use of transportation systems should consider ways to reduce energy consumption and air pollution while promoting economic development and supporting international commerce.

Children have experienced various forms of transportation throughout their lives and typically consider transportation only in terms of individual devices, such as cars, buses, trains, or bicycles. They know that a car uses roads and highways, but they may not understand that roads and highways are part of a larger road system. Asking what might happen if a particular subsystem were not working (or was missing) could lead students to reflect on the interdependence of systems in transportation. Students should recognize the different subsystems of the transportation system (e.g., structural, propulsion, suspension, guidance, control, and support) and recognize how they work together.

Students' understanding of the transportation system should expand to encompass concepts such as intermodalism, which provides an effective system to move people and goods. Students should also learn about the vital role that transportation plays in manufacturing, construction, communication, health and safety, recreation and entertainment, and agriculture. For example, the movement of goods in dynamic just-in-time (JIT) manufacturing is directly dependent on the global transportation system. Many industries use materials and prefabricated parts from far-away locations. These goods arrive just as they are needed (instead of being inventoried and used at a later time) to be used to manufacture products such as cars and clothing. The transportation system is key to the use of JIT manufacturing, which helps in the reduction of storage needs and resource costs.

Programs in Technology and Engineering

There are many ways to implement transportation and logistics technologies in PreK-12 classrooms. Units within PreK through elementary STEM courses can address these key ideas about transportation and logistics and the core disciplinary standards. Many states and local districts implement stand-alone courses on transportation. In addition, national curriculum developers provide courses on transportation and logistics. Due to the development of new technologies and research, it is appropriate to teach the core disciplinary standards within transportation technology courses. The examples below contain lessons from transportation and logistics contexts at different grade bands. They showcase the links between the *STEL* benchmarks, technology and engineering practices, and technology and engineering contexts.

Grades PreK-2 Technology and Engineering Context in Transportation and Logistics: Kindergarteners can apply STEL-4E: Design new technologies that could help improve their daily lives in a unit on investigating our world when they explain how transportation technologies help them travel to school. This meets the course objective *Record a list of issues/ concerns and solutions about your local/global community* and links to TEP-7: Communication.

Second graders apply STEL-3B: Draw connections between technology and human experiences in a national curriculum on materials science and properties of matter with a challenging activity of keeping ice pops frozen during transportation from one part of the school to an area outside. Students are introduced to the science of states of matter and the challenges of transporting perishable foods. This links to TEP-4: Critical Thinking.

Grades 3-5 Technology and Engineering Context in Transportation and Logistics: Third graders can apply STEL-7I: Apply the technology and engineering design process through a space flight activity. This national curriculum on stability and motion with a science of flight activity has students compare and contrast different transportation systems for efficiency. Students apply the design process to the logistics of delivering aid to an area where supplies must be airlifted in and dropped to the ground from an aircraft. This project links to TEP-3: Making and Doing.

Fourth graders in a unit on power may apply STEL-5D: Determine factors that influence change in a society's technological systems or infrastructure as they evaluate the impacts of mass transportation on their town. This national curriculum has a transportation objective to *Use evidence to construct an explanation relating the speed of a process to the energy of that process*. Students compare the efficiency of vehicles powered by different systems: solar, battery, hard-wired electric, fuel cell, and gas-powered. This activity also links to TEP-8: Attention to Ethics.

Grades 6-8 Technology and Engineering Context in Transportation and Logistics: Sixth graders in a fundamentals of transportation course can apply STEL-1J: Develop innovative products and systems that solve problems and extend capabilities based on individual or collective needs and wants when they are asked to describe which type of transportation is most efficient to move a designated item through water. The teacher poses divergent questions regarding problems that could crop up in marine travel (e.g., port cranes are shut down, propellers caught in surface plastic debris, and bad weather). This meets the course objective to *Discuss various propulsion systems for maritime vessels* and links to TEP-4: Critical Thinking.

Seventh graders in a course apply STEL-2N: Illustrate how systems thinking involves considering relationships between every part, as well as how the system interacts with the environment in which it is used when they illustrate how subsystems of a delivery drone vehicle work together to make the transportation vehicle move, reach a destination, deliver a payload, and return to base. Students create a matrix in their design journal that explains the functions of structural, propulsion, suspension, guidance, control, and support subsystems. This links to TEP-1: Systems Thinking.

Grades 9-12 Technology and Engineering Context in Transportation and Logistics: Tenth graders can apply STEL-6G: Verify that the evolution of civilization has been directly affected by, and has in turn affected, the development and use of tools, materials, and processes in a transportation course. In a problem-based activity, students can assess how the development and use of composite materials has increased people's abilities to travel. Students must work in small teams to present their findings and defend their conclusions. This meets a course objective to *Describe the operation of devices used to convert various forms of energy or power into other forms of energy or power* and links to TEP-6: Collaboration.

High school students apply STEL-8Q: Synthesize data and analyze trends to make decisions about technological products, systems, or processes when they design an intelligent transportation system that incorporates sensors for safer travel. The students run their autonomous vehicle on an obstacle course and successfully sense and avoid barriers to reach the end point. Each obstacle avoidance is measured for accuracy and time. This meets the state curriculum standard *Define the different types of process controls* for this transportation operations pathway course and links to TEP-5: Optimism.

Technology and Engineering Context 4 (TEC-4): Energy and Power

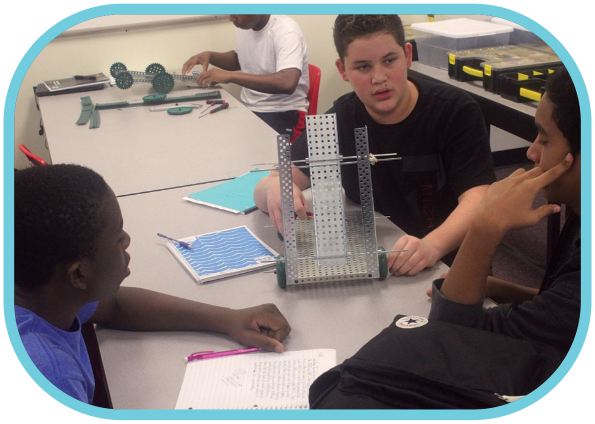
Overview

Energy is the ability to do work. Large supplies of energy are a fundamental requirement of the technological world. Although the terms energy and power are often used interchangeably, they should not be—each has unique characteristics that differentiate them. Energy is the capacity to do work. Power is defined as the rate at which work is done. Energy and power technologies encompass many specific expressions and terms that are used to describe phenomena and units of measure, as well as formulas used to make calculations. Understanding the laws of thermodynamics (including entropy), energy efficiency, embedded energy, energy conservation, fossil fuels, carbon emissions, and waste would be expected in this context.

Technological products and systems need energy that is plentiful, affordable, and easy to control. Thus, the processing and controlling of energy resources, often called fuels, have been key features in the development of technology. This energy can be transformed, stored, retrieved, and transported.

Energy drives the technological products and systems used by society. The quality of life is sometimes associated with the amount of energy used by a society. Choices about which form of energy to use influence our society and the environment in various ways, and there are always trade-offs to consider. Many energy and power systems can pollute the environment. Some sources of energy are non-renewable—once they are used, they will no longer be available—while others are renewable, such as fuel made from biomass like corn or wood. Currently, many of our energy needs are met by burning fossil fuels. Nuclear energy provides a source with less air pollution and no carbon dioxide buildup, but nuclear waste is more dangerous over longer periods of time than waste from other energy sources. In recent years the use of non-depletable energy resources like solar and wind has expanded dramatically in many areas of the world.

The ability to harness energy and power to accomplish work and complete tasks is ubiquitous in modern society and often goes unnoticed until failures occur. It is the responsibility of all citizens to conserve energy resources to ensure that future generations will have access to these natural resources. To decide what energy resources should be further developed, people must critically evaluate the positive and negative impacts of the use of various energy resources. Human decisions about energy and power exploitation and usage have long-term impacts and reflect our societal values.



Programs in Technology and Engineering

There are many ways to study energy and power technologies in PreK-12 classrooms. Units within a course focusing on electricity or energy and power can address these key ideas. Some states and local districts implement stand-alone courses and units related to energy and power. These courses might include elementary STEM, state-supported technology and engineering courses, and programs from national organizations. The examples below contain lessons from power and energy contexts at different grade levels. They showcase the links between the *STEL* benchmarks, technology and engineering practices, and technology and engineering contexts.

Grades PreK-2 Technology and Engineering Context in Energy and Power: PreK children can apply STEL-2A: Illustrate how systems have parts or components that work together to accomplish a goal by identifying how life would be different without human-designed energy and power systems. For example, how would they cook food without being able to use their family stove or microwave? How would they receive light? How would they listen to music? This project supports TEP-4: Critical Thinking.

Second graders can apply STEL-1A: Compare the natural world and the human-made world by conducting an audit of all the energy sources they used during their morning routine. This would include electricity in their home or school, perhaps natural gas if the stove was used to prepare breakfast, gasoline for the bus/automobile, or opening window shades to let in natural sun light. The students would present their findings to the class. This links to TEP-7: Communication.

Grades 3-5 Technology and Engineering Context in Energy and Power: Third-grade students can learn to apply STEL-4H: Classify resources used to create technologies as either renewable or non-renewable by creating a chart of all energy systems that they use during the typical day and then classifying them as either renewable or non-renewable. This project supports TEP-1: Systems Thinking.

Fifth-grade students can apply STEL-3C: Demonstrate how simple technologies are often combined to form more complex systems by safely building a simple direct current motor using a battery, copper wire, and a magnet. During the small group project, student teams will discuss the relationship between magnetism, electromotive force, and rotary motion. This project links to TEP-6: Collaboration.

Grades 6-8 Technology and Engineering Context in Energy and Power: Seventh graders apply STEL-7S: Create solutions to problems by identifying and applying human factors in design by working in a team to design and safely create a model of an energy or power-related invention that will solve a common problem faced by most middle school students (e.g., how to recharge their communication device batteries) in an uncommon situation (e.g., they are out at sea or in the desert). During the project, the students will practice using the engineering design process to find a solution for an ill-structured problem. This project supports TEP-2: Creativity.

Eighth graders can apply STEL-5F: Analyze how an invention or innovation was influenced by its historical context by conducting research on an off-grid house design where students identify the economic, political, cultural, and environmental impacts of the design. The students must account for solutions for alternative energy, heating and cooling, water accessibility, building materials, energy efficient appliances, and food. The student teams design a scale model of the off-grid home and give a class presentation. This project links to TEP-8: Attention to Ethics.

Grades 9-12 Technology and Engineering Context in Energy and Power: Eleventh graders apply STEL-7BB: Implement the best possible solution to a design by working as a team to design and safely create a pneumatic engine that utilizes compressed air to transition reciprocating motion to rotary motion to complete a common task. During the project, the student teams will apply energy and power transmission systems to safely control fluid flow, motion, speed, and exhaust. They will also troubleshoot malfunctions and evaluate the overall performance of the pneumatic engine. This project links to TEP-3: Making and Doing.

High school students can learn to apply STEL-7W: Determine the best approach by evaluating the purpose of the design by working on a microbial fuel cell or mud battery. Students build a sediment- or mud-based battery and learn how bacteria can convert chemical energy, like that in wastewater, into electrical energy. They are also introduced to the fundamental principles surrounding energy conversion, microbial metabolism, and electricity. This project supports TEP-5: Optimism.

Technology and Engineering Context 5 (TEC-5): Information and Communication

Overview

People have long used various technologies to communicate over distances. The invention of movable type provided the means for a transfer of knowledge via printed material to people all over the world. Since that time a wide variety of communication technologies that record, store, manipulate, analyze, and transmit data have been developed and present important areas of study within the technology and engineering classroom.

Data, information, and knowledge have become the fuel that runs the communication technology engine. This change was enabled by the ability to record and store all sorts of data in a digital format as "bits"—strings of zeros and ones, or offs and ons—that can represent letters and numbers, colors on a computer monitor, notes in a Beethoven sonata, and many other types of information. Information and communication technologies include computers and related devices, graphic media, electronic transmitters and receiving devices, entertainment products, and various other systems. Information and communication technologies also include the areas of computer-aided design (CAD), video production, podcasting, graphic design, augmented reality, and the internet.

Powerful technologies that deal with information in a digital form—computers, cloud-based storage, fiber-optic cables, and others—have revolutionized society's information-handling capacity. This has led to a new era: The Information Age. Information itself is a valuable commodity that has become more widely available than in the past. Advanced computing technologies have allowed for the collection, storage, and analysis of vast amounts of data that can be used to inform technological activity in virtually every area of human endeavor, yet these same capabilities pose significant security and privacy challenges. The development of the internet has greatly expanded individuals' access to information but at the same time made it easier for deleterious effects such as propaganda, invasion of privacy, cyber bullying, and actions damaging to democracies.

Communication systems have unique characteristics. The design of a communication is influenced by the intended audience, the medium used to communicate, and the nature of the message. All communication systems involve the fundamental tasks of encoding, transforming, transmitting, storing, retrieving, and decoding information in some fashion. Information and communication systems can influence social and cultural norms as they are used to inform, persuade, entertain, control, manage, and educate. Equitable access to communication networks and devices is important for ensuring individuals' ability to participate in the social, economic, and political functions of the global society.

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Programs in Technology and Engineering

In many states, courses in information and communication technology make up one of the largest areas of enrollment in technology and engineering. Whether units or courses in CAD, TV Production, Web Design, Print Graphics, Game Art Design, Computer Programming, or introductory classes, this content area is popular with students at all levels. Some states and local districts implement stand-alone courses and units related to information and communication technology. These courses might include elementary STEM, state-supported technology and engineering courses, and programs from national organizations. The examples below contain lessons from information and communication contexts at different grade levels. They showcase the links between the *STEL* benchmarks, technology and engineering practices, and technology and engineering contexts.

Grades PreK-2 Technology and Engineering Context in Information and Communication:

Kindergarten students will apply STEL-2E: Collaborate effectively as a member of a team while solving a challenging problem with multiple solutions within a unit from a national kindergarten curriculum that includes the direction to communicate ideas and solutions about building a toy through discussion, writing, drawing, and presentation. This activity links to TEP-7: Communication.

First graders in a national curriculum apply STEL-3A: Apply concepts and skills from technology and engineering activities that reinforce concepts and skills across multiple content areas when they participate in an activity where they use products from a backpack to communicate using light and sound over a distance with their fellow classmates. The teacher can ask the first graders to send a variety of messages. This links to TEP-6: Collaboration.

Grades 3-5 Technology and Engineering Context in Information and Communication:

Fourth graders are introduced to a technology and society unit that allows them to apply STEL-5D: Determine factors that influence change in a society's technological systems or infrastructure. In the technology and engineering education setting, students identify examples of common technological changes, past to present, in communications that have had positive and negative impacts on society or the environment. They can discuss the nature of the changes, the effects of those changes, and how the communication systems might have been modified or improved. This unit links to TEP-8: Attention to Ethics.

In a fifth-grade technology education program, students apply STEL-7I: Apply the technology and engineering design process as they learn how to develop a unique numeric code language to encode a message, transmit the message, and allow another student to decode with a student-developed decoding key. This links with TEP-3: Making and Doing.

Grades 6-8 Technology and Engineering Context in Information and Communication: In an exploring technology course, students can apply STEL-4O: Hypothesize what alternative outcomes (individual, cultural, and/or environmental) might have resulted had a different technological solution been selected. Students are asked to brainstorm ideas as they prepare an engineering design journal to document team activities using narratives and sketches from their class project. This links to TEP-4: Critical Thinking.

In a computer science principles course developed as a national curriculum model, students can apply STEL-8K: Design methods to gather data about technological systems in a lesson in which student teams develop mobile applications. Development of applications for smartphones and tablets increases student engagement and motivation. This links to TEP-3: Making and Doing.

Middle school students in Japan apply STEL-6D: Engage in a research and development process to simulate how inventions and innovations have evolved through systematic tests and refinements in an open discussion moderated by their technology education teacher. The teacher prompts the students by asking an open-ended, critical-thinking question such as: "When you were a baby, television channels were either broadcast or delivered via cable. Streaming services have now become the norm. What factors do you think have led to this change? What modifications could improve streaming services?" The students submit new ideas about their daily life by thinking outside the box to come up with fresh innovations. These ideas are summarized in engineering journals. This discussion links to TEP-2: Creativity.

Grades 9-12 Technology and Engineering Context in Information and Communication: Students can apply STEL-1N: Explain how the world around them guides technological development and engineering design in an information technology unit from a national curriculum during a challenge to unjam urban traffic using spreadsheets and animation software. The context for teaching this lesson could be the impact on society and systems of condensed rush hour windows. The preparation of smart signal systems in many cities has reduced vehicle bottlenecks. This activity links to TEP-1: Systems Thinking.

Students can apply STEL-2T: Demonstrate the use of conceptual, graphical, virtual, mathematical, and physical modeling to identify conflicting considerations before the entire system is developed and to aid in design decision making in a course on photo imaging through use of the brush tool for image creation and correction. Although this might be considered a prescriptive job skill, the teacher could provide more open-ended challenges related to different purposes of the message for teaching this technological skill. A question that could be posed is why magazine publishers use these tools to change someone's face on a magazine cover. This supports TEP-4: Critical Thinking.

Students in a national course with a unit on modeling skills can apply STEL-7Y: Optimize a design using desired qualities within criteria and constraints. During this unit, students develop three-dimensional graphical models of products and then create the physical models using additive manufacturing. The teacher identifies the criteria and constraints the students must adhere to. The students should articulate how information has been encoded, transmitted, and

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decoded within these linked tasks. This project links to TEP-5: Optimism.

Technology and Engineering Context 6 (TEC-6): The Built Environment

Overview

Humans have been building structures for millennia. The Chinese erected the Great Wall, the ancient Egyptians built pyramids, the Greeks constructed elaborate temples, and the Romans created a vast system of roads and aqueducts. Many of the same principles for building structures used centuries ago are still being applied today. Principles related to siting the structure, the type of foundation needed, the materials to be used, and the characteristics of the structure that give it strength and make it attractive are still very much a part of constructing the built environment in current practice. The built environment is bigger than just individual structures and construction. City planners look at the efficiency and purpose of a total city as a built environment when making choices about future changes. The built environment encompasses how buildings and roads are organized and their relationship to one another. Towns and cities rely on good planning to develop healthy environments for their citizens.

The processes involved in designing and making structures are typically referred to as construction. People from many different professions work in the construction industry—including architects, engineers, builders, estimators, carpenters, plumbers, concrete workers, and electricians—to create what is broadly referred to as the built environment. In some cases, structures are designed primarily to provide shelter and a place to live. Other structures are used for entertainment and recreation, such as concert halls, amusement parks, and football stadiums. Still others are primarily for work, such as factories and office buildings. Another major class of structures includes those that support transportation, such as bridges, roads, and marine terminals. Structural integrity, safety, and sustainability are important factors that must be considered when planning and constructing the built environment.

Some structures are temporary, while others are permanent. Structures such as scaffolding, cofferdams (a temporary structure used to create a dry space in water so that a pier or bridge foundation can be built), and forms for pouring concrete are deliberately designed to last for only brief periods at a given location. Permanent structures are those that are designed and constructed to last for a long time. Examples include parking garages, water towers, school buildings, bridges, fences, dams, pools, apartment complexes and structures in space like the International Space Station. Even permanent structures, however, will eventually wear out or become obsolete.

As with other contexts, resources are needed as inputs into the construction process. These resources include tools and machines, materials, information, energy, capital, time, and people. Maintenance is an important concept in the safety and longevity of structures. Human activities cause wear and tear on such things as buildings, roads, and bridges. Weather also contributes to deterioration, and regular maintenance is important for structures to last.

Students should have opportunities to safely design, use, and assess structures and materials. This process can provide a meaningful way for them to develop spatial relationships. They should understand that structures have subsystems that are used to do specific things. For example, the electrical system is used to light the building, and heating and air conditioning systems provide comfortable temperatures. There are many types of materials needed in a construction job that are used to provide form, decoration, protection, and strength. Materials can be natural (rocks, timber) or engineered (bricks, asphalt, concrete, and steel). The choice of materials can substantially influence the structure's environmental impact and its efficiency, issues of greater concern in the modern day.

Programs in Technology and Engineering

There are many ways to implement study of the built environment in PreK-12 classrooms. These could entail units within the elementary curriculum that teach about measurement by involving students in the design of a structure such as a playhouse. Middle grades students engage in activities such as building and testing towers, which helps them learn about forces. High school students may have access to stand-alone courses in construction technology. In addition, curriculum developers provide courses on construction and the built environment that provide appropriate opportunities to teach the core disciplinary standards within the built environment context. The examples below contain lessons from the built environment context at different grade levels. They showcase the links between the *STEL* benchmarks, technology and engineering practices, and technology and engineering contexts.

Grades PreK-2 Technology and Engineering Context in the Built Environment: Pre-kindergarten children in a national curriculum life science course may apply STEL-1A: Compare the natural world and human-made world as they design, build, and test an animal shelter for a classroom hamster. Students must observe the hamster and decide which natural and human-made elements would need to work together to provide safety, shelter, and nourishment. This links to TEP-6: Collaboration.

Kindergarten students may apply STEL-4C: Compare simple technologies to evaluate their impacts during a unit where they design and build a niche habitat for an animal. A foam core model could be designed and built first. The teacher could then ask the class to predict whether the selected animals would use this shelter. Selecting appropriate classroom tools, the students would then construct their niche habitat. This links to TEP-3: Making and Doing.

Grades 3-5 Technology and Engineering Context in the Built Environment: Fourth graders may apply STEL-5D: Determine factors that influence change in a society's technological systems or infrastructure through the study of changes to structures based on history. This meets specific state benchmarks *Describe how the history of civilization is linked closely to technological development* and *Understand that structures rest on foundations and that some structures are temporary, while others are permanent*. As part of a discussion on the historical context of buildings constructed in different eras, a critical-thinking question can be posed to determine the defining features of these structures and how their era or times influenced their features. This project supports TEP-4: Critical Thinking.

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Fifth graders in a national curriculum course apply STEL-8D: Follow directions to complete a technological task when they are directed to build an innovative structure to move water from source to end point without loss of water. The students work together to brainstorm ideas about how this could be accomplished underground, on the earth's surface, underwater, or in space. This links to TEP-2: Creativity.

Grades 6-8 Technology and Engineering Context in the Built Environment: Seventh graders in a national curriculum course may apply STEL-6E: Verify how specialization of function has been at the heart of many technological improvements in a space structure project. Students design and build a scale-model space exploration environment and living habitat for our moon. Due to the distance from Earth and extreme working conditions, students must consider every purpose, access to materials, and what skilled structural building work must be done. This project links to TEP-1: Systems Thinking.

In a middle school course on fundamentals of architecture and construction, students apply STEL-7U: Evaluate the strengths and weaknesses of different design solutions as they apply the course benchmark on sustainability related to design, construction, and maintenance of the built environment. Students build a scale (¾″ = 1′) model balsawood house with poured concrete basement. The structure must account for a varying topography and address the impact on landscaping. This challenging project lasts for 12 weeks and requires student cooperation and team persistence. It links to TEP-5: Optimism.

Grades 9-12 Technology and Engineering Context in the Built Environment: Eleventh-grade architecture and construction students apply STEL-2Y: Implement quality control as a planned process to ensure that a product, service, or system meets established criteria as they design, plan, manage, build, and maintain the built environment through design and construction of tiny houses for Federal Emergency Management Agency (FEMA) emergencies. The emphasis is on the importance of meeting critical shelter needs safely, cost effectively, and in compliance with local zoning laws. The project involves working with individuals with diverse areas of expertise necessary to ensure that a structure is built correctly and on time. This may include architects, engineers, technicians, urban planners, tradespeople, and many others. This project links to TEP-8: Attention to Ethics.

High school students in a course on structural systems may apply STEL-3J: Connect technological progress and to the advancement of other areas of knowledge, and vice versa by using infrared cameras to identify building heat loss and devise ways to minimize heat loss and optimize energy use. This meets two course objectives: *Interpret, evaluate, and adjust design and construction project plans and schedules to respond to unexpected events and conditions and apply measurement skills to accurately lay out and construct materials according to specifications*. Students present their findings to the class and are therefore introduced to the importance of TEP-7: Communication.

Technology and Engineering Context 7 (TEC-7): Medical and Health-Related Technologies

Overview

People use technological tools, devices, medicines, and systems to address health problems, protect living organisms from disease and death, and improve quality of life. As new technologies are developed, their application can be applied or adapted for a variety of health-related products, devices, and services for diagnosis, treatment, and prevention.

Innovation is key to medical technology. It delivers better lives for patients and more efficient health care systems. Medical miracles are often cited in the news—the reattachment of a limb or the saving of a life through a medical procedure made possible by a new device or system. New ways of studying how the human body functions are being introduced at rapid rates. Devices and systems are being designed to check, evaluate, and operate with computerized and electronic controls in order to extend human capabilities and help improve human health. Assistive technologies, including orthotics and prosthetics, are designed to maintain or improve individuals' functioning and independence. Medical devices are designed and developed for an intended medical use but may also find new uses that were unexpected or unplanned.

The development of good nutrition and preventive medicine has played a critical role in helping individuals live better lives. Medical advances such as vaccines and genetically engineered drugs are developed to help healthcare providers do their work more efficiently and effectively, thus improving the delivery of medical care. Today, technologies such as telemedicine and personal medical devices are being designed and developed to provide easier access to medical expertise, to integrate geographically dispersed services, to improve the quality of care, and to gain maximum productivity from expensive medical and technical resources. Medical and health-related technologies have the potential to extend human potential through devices, medicines, systems, and other products that can replace, repair, and supplement biological tissue and systems.

With the increased use of technologies in the medical industry, it is important to consider the consequences that accompany them. Technologies like pharmaceuticals and life support systems have helped protect and improve human health. However, the use of these products and systems has raised questions about things such as the length of time a person should remain on a life-support system, who has access to life-saving procedures, and the side effects of medicines.

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Conditions relating to public health, clean drinking water, and waste management are vital to health and wellness. The issues surrounding the use of many technologies may conflict with each other or with the opinions and ethics of those affected by their use. Access to accurate information is therefore essential for making sound health-related decisions.

Programs in Technology and Engineering

There are many ways to implement medical and health-related technologies in PreK-12 classrooms. Units within existing technology and engineering or health-related courses can address this context. Due to the development of new technologies and research, it may be most appropriate to teach the core disciplinary standards within these related technology courses. However, some states and local districts implement stand-alone courses and units related to medical and health-related technologies. The courses might include elementary STEM, state-supported technology and engineering courses, and programs from national organizations. The examples below contain lessons from the medical and health-related technologies context at different grade levels. They showcase the links between the *STEL* benchmarks, technology and engineering practices, and technology and engineering contexts.

Grades PreK-2 Technology and Engineering Medical and Health-Related Technologies: First graders can apply STEL-1B: Explain the tools and techniques that people use to help them do things by recalling examples of assistive or medical technologies in a media clip or story that features medical devices or assistive technologies. Assistive technologies, including orthotics and prosthetics, are designed to maintain or improve individuals' functioning and independence. This supports TEP-8: Attention to Ethics.

Second graders can apply STEL-3B: Draw connections between technology and human experiences in a health unit lesson by discussing how science is used to develop medicines and vaccines and how technology provides a way to distribute them to people. This discussion can include ideas such as that many diseases are preventable and that vaccines are not always available to the people who need them. Students give in-class presentations about their ideas. This links to TEP-7: Communication.

Grades 3-5 Technology and Engineering Medical and Health-Related Technologies: Third graders may apply STEL-2G: Illustrate how, when parts of a system are missing, it may not work as planned in a national third-grade curriculum unit on space when students design a solution to a medical problem in space. In a moon habitat, one of the people gets sick and there isn't a known solution available. It will take four weeks for the next supply ship to arrive, so the astronauts must work with physicians on earth to use supplies on hand to create a solution. With teacher prompts, students brainstorm ideas to address this problem. This links to TEP-6: Collaboration.

Fifth graders can apply STEL-6B: Create representations of the tools people made, how they cultivated to provide food, made clothing, and built shelters to protect themselves in a unit on humans and the environment. The discussion could focus on early systems for water and sanitation. Students in teams develop a diagram of the sanitation system designed for Paris in the mid-1800s by Eugène Belgrand and based on archaeological findings below the streets of the city. The activity on water quality links to a science benchmark *Understand that scientific investigations may result in new ideas for study, new methods or procedures for an investigation,* *or new technologies to improve data collection* and supports TEP-4: Critical Thinking.

Grades 6-8 Technology and Engineering Medical and Health-Related Technologies: Sixth graders may apply STEL-8K: Design methods to gather data about technological systems in an Exploration of Health Science course where they demonstrate applied mathematical abilities on health-related tests. Students take readings on blood pressure, pulse, and temperatures of their classmates and then make generalizations from the data collected. This links to TEP-3: Making and Doing.

Middle schoolers can apply STEL-7Q: Apply the technology and engineering design process in a national curriculum unit, students will act as medical detectives while they investigate a disease outbreak. The teacher poses the problem of an outbreak of chickenpox on an island. Students work to understand the underlying causes (e.g., island lifestyle, religious beliefs, social aspects, impact of tourists, the habitation of the island, access to healthcare, and so on) and how to contain the outbreak. This unit links to TEP-1: Systems Thinking.

Grades 9-12 Technology and Engineering Medical and Health-Related Technologies: Tenth graders applied STEL-4T: Evaluate how technologies alter human health and capabilities in a biomedical engineering lesson as they designed assistive technologies and appropriate medical and scientific equipment for a classmate who was born with a shortened right arm. The student's arm ended about an inch and a half below the elbow, with the joint intact and functional, and had four tiny fingertips on the end stump. The teacher challenged the students to make a preliminary mechanical model hand out of cardboard, straws, and rubber bands. The culmination of this lesson was 3D printing an arm that was customized for the student. At the student's request, the class printed a pink and glitter-blue prosthetic arm. The prosthetic limb wrapped around her bicep with Velcro, making her right arm the same length as her left. The limb was controlled by 100-pound fishing line when she either bent her elbow or flexed her bicep, allowing her to grasp and pick up objects. This activity focused on empathy, user-centered design, and prototyping to develop real solutions for a classmate, and was linked to TEP-5: Optimism

Twelfth graders in a state curriculum may apply STEL-6F: Relate how technological development has been evolutionary, the result of a series of refinements to basic inventions or technological knowledge as they design and build a hemodialysis device from readily available plumbing parts. The project links to mathematics and science objectives and was developed as a college program called INSPIRES (Increasing Student Participation, Interest, and Recruitment in Engineering and Science). This activity links to TEP-2: Creativity.

Chinese senior high schools are required to offer an elective project named "traditional and practical arts reservation and innovation" in order to inspire students' interest as well as to preserve traditional culture. Traditional Chinese medicine is a branch of medical care that is said to be based on more than 3,500 years of medical practice that includes various forms of herbal medicine, acupuncture, massage, and other treatments. A high school affiliated with a Chinese university implemented a project with tenth-grade students in which they applied STEL-7Z: Apply principles of human-centered design. One student invented a portable human meridian detector (for acupuncture) and won a silver medal at the Geneva International Invention Exhibition. Other students invented the point massager, massage clothes, and Chinese herbal medicine grinders. This project links to TEP-3: Making and Doing.

Technology and Engineering Context 8 (TEC-8): Agricultural and Biological Technologies

Overview

Approximately 14,000 years ago the Agricultural Revolution transformed society by allowing humans for the first time to produce more food than they needed. The development of a variety of agricultural tools and practices, such as the plow and irrigation, improved productivity and made it possible for fewer people to feed an entire society, thereby freeing up some members of society for other tasks. Further advances in agricultural technology since that time have continued that pattern. It is estimated that less than 2% of the United States population today is directly employed in agriculture.

Agriculture is the growing of plants and animals for food, fiber, fuel, chemicals, or other useful products. Many technological processes and systems are used in agriculture. One example of a simple process is the saving of seeds from the end of one growing season to plant at the beginning of the next. Another is the use of fertilizers to enhance plant growth and herbicides to control weeds. Breeding plants and animals in order to produce offspring with desired traits is yet another example of agricultural technology. There is a long line of evolutionary change in agricultural tools and machinery—from pointed sticks used to scratch a line in the soil for planting seeds to today's most advanced precision farming techniques such as the use of drones, automated milking machines, and GPS-guided systems. Technology has improved the yield and quality of food and has also made it possible for farmers to adjust to changing circumstances in the environment, such as weather-related changes, water shortages and floods, and overused soil.

Biological technology applications, both classical and modern, have long been a driving force in the field of agriculture. Biotechnology is defined as the use of living organisms, or parts of organisms, to make or modify products or to improve plants or animals. The phrase "agricultural and biological technologies" encompasses a broader spectrum of purposes that can range from changing the form of food or improving health to disposing of waste or using DNA to store data. Biological processes include propagating, growing, maintaining, adapting, treating, and converting biological materials to transform them for creation of new and improved products and systems for living organisms.

Although the phrase has a modern ring to it, agricultural and biological technologies have been used for at least 8,000 years. Around 4000 BCE, Egyptians learned how to use yeast in making bread. Scientists today are proficient at manipulating cells and living tissue and are able to use and manipulate the genetic codes of living organisms. The use of agricultural and biological technologies is opening the door to improving the fight against human and animal diseases, promoting human health, fighting hunger by increasing crop yields through resisting plant diseases, and helping the environment by reducing pesticide use. New products and services will continue to emerge from bio-related technology advances in the future.

Agricultural and biological technologies raise ethical and social issues. How safe are bioengineered crops? How is the use of chemicals impacting quality of life in the areas of food, water, and soil? What level of bioengineering should be allowed on humans? Today we must address such issues as soil depletion, inadequate water supplies for irrigation, increased frequency of droughts, and pollution of drinking water from farm land and livestock. The ability to modify the genetic structure of biological organisms, including plants, animals, and humans, presents humankind with significant ethical questions. If society is to answer such questions responsibly, its members must have a basic understanding of agricultural and biological technologies and the resulting products and systems.

Programs in Technology and Engineering

There are many ways to implement agricultural and other biological technologies in PreK-12 classrooms. Units within a Career and Technical Education cluster course in Environmental, Agriculture, and Natural Resources can address these ideas. Many elementary schools incorporate plant growing and other agricultural activities into their curriculum. Some states and local districts implement stand-alone courses and units. These courses might include elementary STEM, state-supported technology and engineering courses, and programs from national organizations. The examples below contain lessons from the agricultural and biological technologies context at different grade levels. They showcase the links between the *STEL* benchmarks, technology and engineering practices, and technology and engineering contexts.

Grades PreK-2 Technology and Engineering Context in Agricultural and Biological Technologies: PreK children can apply STEL-2D: Develop a plan in order to complete a task in the application area of agricultural and biological technologies. Through an introduction to the life cycles of plants, butterflies, and frogs, plant and seed growth, and habitats, students can plan and create a collaborative terrarium project. This links to TEP-6: Collaboration.

First graders can apply the core discipline STEL-7G: Apply skills necessary for making in design in a course that includes the objective *Identify agricultural technologies that make it possible for food to be available year-round and to conserve resources*. The students design an agricultural mechanization and storage system based on the Dr. Seuss story *The Lorax*. Students collect data, analyze it, and communicate results about their solution to save the Truffula trees. This links to TEP-4: Critical Thinking.

Grades 3-5 Technology and Engineering Context in Agricultural and Biological Technologies: Third-grade students in an eight-week unit on natural hazards can learn to apply STEL-4G: Judge technologies to determine the best one to use to complete a given task or meet a need through learning about the effects of hazardous weather and extreme conditions on humans and animals. The class holds a discussion on the ethical treatment of animals. Students design and test methods for helping an animal withstand cold weather, which links to TEP-8: Attention to Ethics.

At an elementary STEM academy, fourth graders may apply STEL-3D: Explain how various relationships exist between technology and engineering and other content areas as they work on designing an apparatus using a balloon to spread seeds for planting. Student teams design and construct a mechanism that uses air pressure to move across the planting zone on a fishing line. The mechanism must disperse seeds evenly over the target area. Science concepts are applied through analyzing multiple solutions in patterns to transfer information and mathematics is used to classify the spread of the seeds by distance and intervals of time. In this STEM classroom, the student work links to TEP-2: Creativity.

Grades 6-8 Technology and Engineering Context in Agricultural and Biological Technologies: Eighth-grade students in a pre-engineering course can apply STEL-4M: Devise strategies for reducing, reusing, and recycling waste caused from the creation and use of technology to a water crisis challenge. Student projects focus on the design and safe construction of recirculating hydroponic systems for use in urban areas to help alleviate water scarcity. This meets TEP-3: Making and Doing.

In a middle school course, seventh graders can apply STEL-6D: Engage in a research and development process to simulate how inventions and innovations have evolved through systematic tests and refinements to meet a course objective *Demonstrate an understanding of the effects of technology on the environment*. This will be accomplished through student work on management of waste and how technologies can be used to repair damage caused by natural disasters. This project is based on the environmental disaster at Fukushima, Japan in 2011 from earthquake-generated tsunami waves. Research considerations include the tectonic plates in the Pacific, the shape of Japan's coastline, the lack of flat ground for building in this mountainous country, and the design of structures next to the ocean shore. This project links to TEP-1: Systems Thinking.

Grades 9-12 Technology and Engineering Context in Agricultural and Biological Technologies: High school seniors in a unit within an advanced applications course can apply STEL-5H: Evaluate a technological innovation that arose from a specific society's unique need or want to use principles of ecosystem interactions and buoyancy to design and produce fishing lures that mimic the behaviors of aquatic insects to attract fish. This strategy is known as biomimicry. Students observe natural environments, form testable hypotheses on likely fish prey, create a buoyant model using an additive printer with parametric modeling software, and test the success of their custom-made lure. All work is captured in an engineering design portfolio. This links to TEP-5: Optimism.

High school students in an environmental sustainability course can apply STEL-1Q: Conduct research to inform intentional inventions and innovations that address specific needs and wants to use science, mathematics, and technology to find solutions to problems of clean and abundant water, food supplies, and renewable energy by working on a gravity-fed water cleaning unit to remove oil from water through use of physical systems and biological materials. Students present their apparatus and reflect on improvements that could be made to their cleaning unit based on test results. This supports TEP-7: Communication.

A

STEL Benchmark Curriculum Development Resources

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Appendix A – *STEL* Benchmark Curriculum Development Resources

The interactive *STEL* website includes three curriculum development resources that will be particularly helpful to teachers: (1) a compendium that lists the benchmarks at the grade band level; 2) a crosswalk matrix that links *STEL* standards and benchmarks to *Next Generation Science Standards (NGSS)*, Common Core Mathematics (CCSS-Math) benchmarks, and Common Core English Language Arts (CCSS-ELA) benchmarks; and (3) a verb matrix that aligns benchmarks to the cognitive, affective, and psychomotor domains.

STEL Benchmarks by Grade Band Compendium

For classroom teachers and curriculum developers working on lesson plans at specific grade levels, the compendium collates all grade band benchmarks in one place for easy access. This resource is located on the *STEL* Resources webpage and is being provided in MS Word for teacher retrieval. Table A.1 is a screenshot of a portion of the Compendium of PreK-2 level benchmarks from the first three standards.

Table A.1 Example Compendium of PreK-2 Benchmarks from Standards 1-3

Grade Bands	STEL Benchmark
	STEL-1: Nature and Characteristics of Technology and Engineering
PreK-2	1A. Compare the natural world and human-made world.
PreK-2	1B. Explain the tools and techniques that people use to help them do things.
PreK-2	1C. Demonstrate that creating can be done by anyone.
PreK-2	1D. Discuss the roles of scientists, engineers, technologists, and others who work with technology.
	STEL-2: Core Concepts of Technology and Engineering
PreK-2	2A. Illustrate how systems have parts or components that work together to accomplish a goal.
PreK-2	2B. Safely use tools to complete tasks.
PreK-2	2C. Explain that materials are selected for use because they possess desirable properties and characteristics.
PreK-2	2D. Develop a plan in order to complete a task.
PreK-2	2E. Collaborate effectively as a member of a team.
	STEL-3: Integration of Knowledge, Technologies, and Practices
PreK-2	3A. Apply concepts and skills from technology and engineering activities that reinforce concepts and skills across multiple content areas.
PreK-2	3B. Draw connections between technology and human experiences.

STEL Benchmark Comparison to Other Academic Benchmarks

The benchmark crosswalk matrix is designed to provide linked academic benchmarks from *NGSS*, CCSS Math, and CCSS ELA that teachers and curriculum developers can add to their lesson plans once they have identified the *STEL* benchmark they intend to teach. In many cases, a teacher could use that benchmark as a starting point. For example, a teacher may determine that they will focus on STEL-7Y: Optimize a design by addressing desired qualities within criteria and constraints. The linked CCSS ELA benchmark is ELA-Literacy.RST.9-10.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text. The teacher may plan for their students to have a critical-thinking discussion at the conclusion of the lesson, in which case the teacher would likely pick additional ELA benchmarks in speaking and listening (e.g., *SL.9-10.1.c* and *SL.9-10.1.d*).

Table A.2 contrasts three example *STEL* benchmarks with the matched benchmarks from other academic areas. These were determined via a research study in which two separate teams of educators (consisting of university professors, state supervisors, and classroom teachers) scored the linked benchmark matches on a scale from 1-5, where 5 represented the strongest linkage. The cut score for inclusion in the crosswalk matrix was set at 3.0/5.0 total mean, and where no individual team mean was more than .5 from the total mean. This resulted in 119 matches between *STEL* and *NGSS*, 79 to CCSS Math, and 119 to CCSS ELA. For the entire list, visit the interactive *STEL* page on the ITEEA website to select your grade band and context. Abridged versions in MS Word of *NGSS*, CCSS Math, and CCSS ELA will be accessible there for teachers to select additional benchmarks for their lesson plans.

Table A.2 Three Example Matches Between STEL and NGSS, CCSS Math, and CCSS ELA

Grade Band	STEL	NGSS	CCSS Math	CCSS ELA
PreK-2	**STEL-1A.** Compare the natural world and human-made world.	**K-2-ETS1-1.** Ask questions based on observations to find more information about the natural and/or designed world(s).	**K.MD.2.** Directly compare two objects with a measurable attribute in common, to see which object has "more of"/ "less of" the attribute, and describe the difference.	**ELA-Literacy.SL.K.3.** Ask and answer questions in order to seek help, get information, or clarify something that is not understood.
6-8	**STEL-5G.** Evaluate trade-offs based on various perspectives as part of a decision process that recognizes the need for careful compromises among competing factors.	**ETS1.A.** Defining and Delimiting Engineering Problems: The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.	**7.SP.7.** Develop a probability model and use it to find probabilities of events. Compare probabilities from a model to observed frequencies; if the agreement is not good, explain possible sources of the discrepancy.	**ELA-Literacy.W.8.9.** Draw evidence from literary or informational texts to support analysis, reflection, and research.
9-12	**STEL-7Y.** Optimize a design by addressing desired qualities within criteria and constraints.	**HS-ETS1-3.** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.	**S-IC.2.** Decide if a specified model is consistent with results from a given data-generating process, e.g., using simulation.	**ELA-Literacy.RST.9-10.3.** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

STEL Benchmark Verb Alignment to Cognitive, Affective, and Psychomotor Domains

Curriculum developers and classroom teachers often need to make sure they are teaching and assessing students at the appropriate levels of the cognitive, affective, and psychomotor domains. The *STEL* benchmarks are written with active verbs to target different levels of these domains.

In addition, curriculum developers and classroom teachers want to know whether the benchmarks are at the factual, conceptual, procedural, or metacognitive level of knowledge. The second resource being provided on ITEEA's interactive *STEL* website will identify these factors for all 142 *STEL* benchmarks. This tool was developed to help ensure the alignment of the three domains to the technology and engineering dimensions and to student outcomes. This relationship is depicted in Table A.3.

Table A.3 Alignment of the Three Domains of Learning to the Technology and Engineering Dimensions and to Student Outcomes

Domain		T & E Dimensions		Student Outcomes (as defined by Benchmark verbs)
Cognitive	→	Knowing & Thinking	→	Knowledge
Psychomotor	→	Doing	→	Skills
Affective	→	Knowing, Thinking, and Doing	→	Dispositions

For the three examples provided in Table A.2, the domains, domain levels, and knowledge dimensions are provided in Table A.4. This information will be available for each benchmark in the interactive online tool. Table A.4 has columns for each domain and the applicable levels have been identified for each benchmark. The levels for each domain are:

Cognitive Domain (Anderson & Krathwohl, 2001)

- Remember
- Understand
- Apply
- Analyze
- Evaluate
- Create

Affective Domain (Krathwohl, Bloom, & Masia, 1964)

- Receiving
- Responding
- Valuing
- Organization
- Characterization by Valuing

Psychomotor Domain (Bixler, 2011)

- Observing
- Imitating
- Practicing
- Adapting

Levels of Knowledge

- Factual
- Conceptual
- Procedural
- Metacognitive

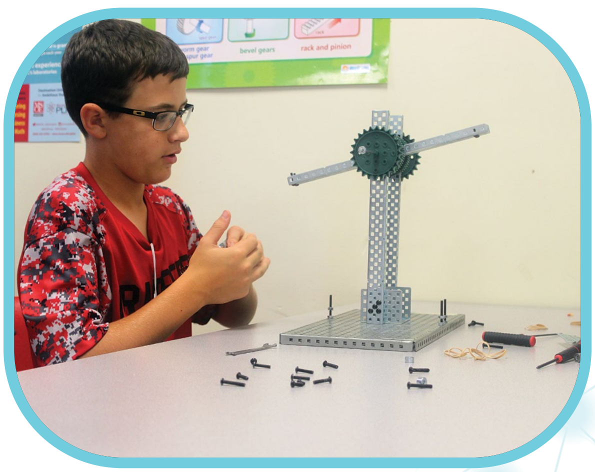

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Table A.4 STEL Benchmark Verb Alignment to Domain and Knowledge Dimensions

STEL Benchmark	Cognitive Domain	Affective Domain	Psychomotor Domain	Knowledge Dimension
1A. Compare the natural world and human-made world.	Analyze		Observing	Conceptual
5G. Evaluate trade-offs based on various perspectives as part of a decision process that recognizes the need for careful compromises among competing factors.	Evaluate	Responding		Conceptual
7Y. Optimize a design by addressing desired qualities within criteria and constraints.	Analyze		Adapting	Procedural

B

Brief History of the Standards Revision Project

B

Appendix B – Brief History of the Standards Revision Project

The original *Standards for Technological Literacy (STL)* document was published in 2000 by the International Technology Education Association (ITEA, now ITEEA). The *STL* standards were slightly revised in 2002 and 2007.

In 2011 and 2012 ITEEA, along with the American Society for Engineering Education (ASEE), National Academy of Engineering (NAE), and Biological Sciences Curriculum Study (BSCS), applied for (but did not receive) National Science Foundation (NSF) Advanced Technological Education (ATE) funding to revise the standards.

In March 2016, ITEEA's Council on Technology and Engineering Teacher Education (CTETE) had internal discussions about the possibility of developing its own accreditation entity and program standards. It was further discussed by the CTETE Accreditation Committee that a first step needed to be revision of *STL*. These discussions continued for two years.

In June 2018, the CTETE Executive Committee committed to the special project of revising *Standards for Technological Literacy*. Council members teamed with ITEEA staff to prepare and submit a new proposal for funding to the NSF in Fall 2018. Funding was awarded in early 2019.

Standards Revision Project Timeline

Summer 2018:

- Initial drafts of ITEEA member survey developed by CTETE leader team to collect input regarding current use of *STL*

Fall 2018:

- Developed a Joint Planning Team between CTETE and ITEEA

- Selected eight *STL* Revision Project Leaders
- Developed process for reviewer qualifications and applications
- Created ITEEA website page for project
- Applied for National Science Foundation ATE Grant
- Distributed survey to 60,000 ITEEA members and stakeholders
- Presented project to the ITEEA's 21st Century Leadership Academy cohort

Spring 2019:

- Survey results examined and reported in *Technology and Engineering Teacher* journal
- NSF ATE Grant #1904261 approved
- *STL* Revision Leadership Team takes over from Joint Planning Team at the 2019 ITEEA annual conference in Kansas City, MO
- Thirty Review Team members selected via a modified Delphi process
- A *Background and Rationale* paper was developed by Leadership Team members addressing literacies, reduction in the number of standards, a project mission and vision, and suggestions for a revised format

Summer 2019:

- Released *ITEEA Standards for Technological Literacy Revision Project: Background, Rationale, and Structure* and a survey to 30 Review Team members
- August 4-8: *STL* Revision Project writing workshop at Chinsegut Hill Retreat in Brooksville, Florida
- Chinsegut writers created Draft 1 of the eight standards and eight contexts

Fall 2019:

- Composite draft of the standards and contexts developed by the Leadership Team, based on work completed at Chinsegut
- All chapters of *Standards for Technological and Engineering Literacy: Defining the Role of Technology and Engineering in STEM Education* drafted
- First complete draft sent to the 30 members of the Chinsegut Review Team for review and feedback
- Revisions made based on input from the Chinsegut Review Team
- Second complete draft sent to 65 selected Second-Round Reviewers on November 19, 2019

Spring 2020:

- Third draft of *STEL* completed based on the Second-Round Reviewer feedback
- Composite *STEL* document posted on ITEEA website for comment by ITEEA members and stakeholders
- *Standards for Technological and Engineering Literacy* Executive Summary released in February 2020

Summer 2020:

- Final *STEL* published in early summer 2020
- Interactive *STEL* website launched

C

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Appendix C – Bibliography and References

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Note about the DTE designation above: ITEEA created the Distinguished Technology and Engineering Professional (DTE) program to provide a means for recognizing outstanding performance and professional accomplishments in the field of technology and engineering education. As one of the highest honors for professional achievement in technology and engineering education, the DTE designation recognizes the attainments of technology and engineering educators.

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Glossary

Appendix E – Glossary

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NOTE: The terms defined and described in this glossary apply specifically to *Standards for Technological and Engineering Literacy.* These terms may have broader meanings in different contexts.

Aesthetics—Consideration and application of principles related to the nature and appreciation of beauty; how humans perceive and judge the attractiveness of an object.

Agricultural and biological technologies—Term that applies to a broad spectrum of technologies related to food production and biological processes. Examples include growing and modifying food, harnessing the decomposition process for energy and byproducts that enhance soil, using biotechnology to create new or modified organisms, and much more.

Agriculture—The raising of crops and animals for food, feed, fiber, fuel, or other useful products.

Agroforestry—Land management for the simultaneous production of food, crops, and trees or the intentional designing of land through a system of planting trees, shrubs, crops, or forage in order to improve habitat, enhance access by humans and wildlife, and increase yields of woody plant products.

Alternative energy—Any sources or resources of energy that are renewable through natural or artificial processes and as a result that are regarded as practically inexhaustible. These include solar, wind, geothermal, tidal, and biomass resources. (a.k.a. renewable energy).

Alternative fuel—Transportation fuels other than gasoline or diesel. Includes natural gas, methanol, ethanol, and hydrogen.

Appropriate technology—Typically refers to the simplest level of technology that can achieve the intended purpose in a given location using fewer natural resources, emitting less pollution, and costing less. Appropriate technologies are often small-scale and make use of expertise available in the local community.

Articulation—A planned sequence of curriculum and course offerings from Grades PreK-12.

Artifact—A human-made product.

Artificial ecosystem—Human-made environment or system that functions as a replication of or that produces the functional equivalent of a natural environment.

Artificial intelligence (AI)—Human-like knowledge and skills exhibited by a manufactured device or system, typically a computer-based system (a.k.a. machine intelligence).

Assessment—(1) An evaluation technique used to analyze the benefits and risks of a technology, considering the trade-offs and then determining the best action to take in order to ensure that the desired positive outcomes outweigh the negative consequences (a.k.a. technology assessment). (2) An exercise, such as an activity, portfolio, written test, or experiment, that seeks to measure a student's skills or knowledge in a subject area. Information may be collected about teacher and student performance, student behavior, and classroom atmosphere.

Automation—The operation and control of equipment and processes by programmed systems rather than by human operators.

Batch production—The process of producing parts or components in large quantity to facilitate more efficient assembly into finished products.

Benchmark—(1) A written statement that describes the specific developmental components by various grade levels (PreK-2, 3-5, 6-8, and 9-12) that students should know or be able to do in order to achieve a content standard. (2) A criterion by which something can be measured or judged.

Biodegradable—The ability of a substance to be broken down physically and/or chemically by natural biological processes, such as by being digested by bacteria or fungi.

Bioengineering—Engineering applied to biological and medical systems, such as biomechanics, biomaterials, and biosensors. Bioengineering also includes biomedical engineering, as in the development of aids or replacements for defective or missing body components.

Biological processes—The processes characteristic of, or resulting from, the activities of living organisms.

Biomimicry—Design and production of materials, structures, and ecosystems that are modeled on biological organisms and processes.

Biotechnology—Any technique that uses living organisms, or parts of organisms, to make or modify products, improve plants or animals, or to develop microorganisms for specific uses.

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Brainstorming—A method of shared problem solving in which all members of a group spontaneously generate ideas in a guided but unrestrained discussion.

Bronze Age—The stage or level of development of human culture that followed the Stone Age and was characterized by the use of bronze tools and weapons and ended with the advent of the Iron Age; about 3000 B.C.E. to 1100 B.C.E.

Built environment—Refers to the human-made environment that includes the structures and facilities in which people live, work, and recreate. This encompasses buildings, roadways and bridges, infrastructure, cities, and other spaces. More than just individual structures and construction, it also addresses the features of the built environment that create a healthy, useful, and sustainable environment for citizens.

By-product—Something produced in the making of something else; a secondary result; a side effect.

CAD (computer-aided design or computer-aided drafting)—(1) The use of a computer to assist in the process of designing a part, circuit, building, or other system or artifact. (2) The use of a computer to assist in the process of creating, storing, retrieving, modifying, plotting, and communicating a technical drawing.

Capital—One of the basic resources used in a technological system. Refers to the accumulated finances (money) and goods devoted to the production of other goods.

Career and Technical Education—(1) Training within an educational institution that is intended to prepare an individual for a particular career or job. (2) A group of related education disciplines that provide education and skills for work and life (Agriculture Education, Business Education, Family and Consumer Sciences Education, Health Education, Marketing Education, Technology Education, and Trade and Industrial Education).

Chemical technology—Any technological process that modifies, alters, or produces chemical substances, elements, or compounds.

Citizenship—Being a member of a community; applying one's communication, critical thinking, and collaboration skills toward more effective participation within both local and global communities.

Civic-mindedness—A characteristic of individuals who are motivated by, and show concern for, the good of their community or humanity as a whole; public-spirited.

Closed-loop system—A system that uses feedback from the output to control the input and processes of the system.

Cognitive knowledge—A level of understanding beyond simple comprehension (basic understanding of meaning). This may include the application of rules, methods, concepts, principles, laws, and theories.

Collaboration—The act of having the perspectives, willingness, and capabilities to work as part of a team in which all members' inputs are valued.

Combining—The joining of two or more materials by such processes as fastening, coating, adhering, or chemically modifying.

Communication—(1) The successful transmission of information through a common system of symbols, signs, behavior, speech, writing, or signals. (2) Gaining an understanding of the wants and needs of the users of technology, and a means to develop and explain choices made in the design process.

Communication system—A system that forms a link between a sender and a receiver, making possible the exchange of information.

Complex system—A system consisting of many interconnected or interwoven parts that interact in such ways as to produce outputs that cannot always be predicted.

Component—A part or element of a whole that can be separated from or attached to a system.

Computational thinking—A systematic approach to problem solving that involves organization and analysis of data, use of modeling and simulation to represent data, and use of algorithmic thinking to identify effective and efficient solutions.

Concept—An idea or thought used to describe or categorize objects, conditions, or processes.

Conservation—The preservation and protection of the environment and the wise use of natural resources.

Constraint—A limit to the design process. Constraints may be such things as time, costs, space, materials, and human capabilities.

Construction—The systematic act or process of building, erecting, or constructing buildings, roads, or other structures.

Content standards—Standards that identify essential knowledge, skills, and dispositions that should be delivered in a discipline of study. Ideally these are sufficiently flexible and open-ended to be able to stay current with changes in the disciplinary field.

Contexts—Areas of technological activity that provide a specific focus for application of the core content knowledge and practices, as defined within the *Standards*. Contexts provide the settings within which technology and engineering activity occurs.

Control system—An assemblage of chemical, electronic, electrical, and mechanical components that commands or directs the management of a system, often by executing a planned set of actions.

Convention—A technique, practice, or procedure that is established by usage and widely accepted.

Convergent thinking—A form of critical thinking where linear steps are used to analyze a number of possible solutions to a problem to determine the one that is most likely to be successful; used in various stages of the design process.

Creative thinking—The ability to produce original thoughts and ideas based upon questioning, reasoning, and judgment.

Creativity—The use of investigation, imagination, innovative thinking, and physical skills to accomplish goals, including design goals.

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Criterion/Criteria—A desired specification (element or feature) of a product or system.

Critical thinking—The ability to acquire information, analyze and evaluate that information, and reach an informed conclusion or answer by using logic and reasoning skills.

Culture—The beliefs, traditions, habits, and values controlling the behavior of the majority of the people in a social-ethnic group.

Custom production—A type of manufacturing in which products are designed and built to meet the specific needs and wants of an individual.

Data—Raw facts and figures that can be used to draw a conclusion.

Data processing system—An arrangement of computer hardware and software designed to carry out specified computational tasks.

Decision making—The act of examining several possible behaviors and selecting from them the one most likely to accomplish the individual's or group's intention. Cognitive processes such as reasoning, planning, and judgment are involved.

Decode—To convert a coded message into understandable form using ordinary language.

Design—An iterative decision-making process that produces plans by which resources are converted into products or systems that meet human needs and wants or solve problems.

Design brief—A written plan that identifies a problem to be solved, its criteria, and its constraints. The design brief is used to encourage consideration of all aspects of a problem before attempting a solution.

Design principles—Visual elements applied in the design process to create aesthetically pleasing designs; they include rhythm, balance, proportion, variety, emphasis, and harmony.

Design process—A systematic problem-solving strategy that relies on use of defined criteria and constraints, used to develop possible solutions to a problem or need and to narrow down the possible solutions to one final choice.

Design proposal—A written plan of action for a solution to a proposed problem.

Develop—To change the form of something through a succession of states or stages, each of which is preparatory to the next. The successive changes are undertaken to improve the quality of or to refine the resulting process or product.

Developmentally appropriate—Educational programs and methods that are intended to match the needs of students in the areas of cognition, physical activity, emotional growth, and social adjustment at different stages of growth.

Dispositions—The characteristics, values, and habits of mind that are associated with professional practice within a discipline.

Divergent thinking—A form of creative thinking that explores multiple possible solutions to generate new ideas or approaches to a problem; in particular, used in the ideation phases of design and problem solving.

Doing—See "Making and Doing."

Drawing—A work produced by representing a process or outlining a figure, plan, or sketch by means of lines. A drawing is used to communicate ideas and provide direction for the production of a design.

Durable goods—An item that is designed to be used for many years (e.g., home appliances, automobiles, some sports equipment).

Educational technology—Using multimedia technologies or audiovisual aids as a tool to enhance the teaching and learning process.

Emergent—(1) Occurring as a consequence of something. (2) The process of coming into being.

Encode—To change a message into symbols or a form that can be transmitted by a communication system.

Energy—The ability to do work. Energy is one of the basic resources/inputs used in technological systems.

Engineer—A person who is trained in and uses technological, mathematical, and scientific knowledge to solve practical problems.

Engineering—The use of scientific principles and mathematical reasoning to develop and optimize technologies to meet needs that have been defined by criteria; simply put, the process of design under constraint.

Engineering (noun)—Disciplinary study undertaken in preparation for an engineering career. Sometimes referred to as "big E" Engineering, this represents a more exclusive focus on engineering and its content subfields.

Engineering (verb)—The application of design and engineering habits of mind in development of technological systems and products. Sometimes referred to as "little e" engineering, this characterization is represented in *Standards for Technology and Engineering Literacy*.

Engineering literacy—Abilities focused on understanding the process of creating or designing technological artifacts and systems.

Engineering design—The systematic and creative application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems.

Ergonomics—The study of human factors design, or how to arrange and design devices, machines, or spaces so that people and things interact safely and efficiently (a.k.a. human factors analysis or human factors engineering).

Ethics—Moral principles that govern a person's behavior or the conducting of an activity; in technology and engineering education, decision making based on ethical practices and considerations related to the development and use of technology.

Ethical—Conforming to an established set of principles or accepted professional standards of conduct.

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Evaluation—(1) The collection and processing of information and data in order to determine how well a design meets the requirements and to provide direction for improvements. (2) A process used to analyze, evaluate, and appraise a student's achievement, growth, and performance through the use of formal and informal tests and techniques.

Experimentation—(1) The act of conducting a controlled test or investigation. (2) The act of trying out a new procedure, idea, or activity.

Feedback—Using all or a portion of the information from the output and processes of a system to regulate or control the processes or inputs in order to modify the output.

Forecast—A statement about future trends, usually as a probability, made by examining and analyzing available information. A forecast is also a prediction about how something will develop, usually as a result of study and analysis of available pertinent data.

Foundational literacies—Numeracy, textual literacy, visual literacy, and understanding of graphs and charts; these are distinct from the more focused "disciplinary literacy" that is associated with knowledge within a specific content domain.

Grade level/Grade band—A stage in the development of a child's education; a generally accepted grouping of different grades in school (e.g., PreK-2, 3-5, 6-8, and 9-12).

Guidance system—A system that provides information for guiding the path of a vehicle by means of built-in equipment and control.

Human factors engineering—See "Ergonomics."

Human wants and needs—Human wants refers to something desired or dreamed of, and human needs refers to something that is required for survival.

Hydroponics—A technique of growing plants without soil, in water or sometimes an inert medium (e.g., sand) containing dissolved nutrients.

Ideation—The process of generating multiple ideas, often using design thinking strategies such as brainstorming, sketching, use of analogies, and so on. Linked with divergent thinking.

Impact—The effect or influence of one thing on another. In the use of any technological system, some impacts are anticipated and others are unanticipated.

Industrial Revolution—A period of inventive activity beginning around 1750 in Great Britain. During this period, industrial and technological changes resulted in mechanized machinery that replaced much of what was previously manual work. The Industrial Revolution was responsible for many social changes, as well as changes in the way products were manufactured.

Information—One of the basic resources used by technological systems. Information is data and facts that have been organized and communicated in a coherent and meaningful manner.

Information Age—A period of activity starting in the 1950s and continuing today in which the gathering, manipulation, classification, storage, and retrieval of information is central to the workings of society. The Information Age was enhanced by the development of the internet, which is an electronic means to exchange information broadly and at great speed.

Information system—A arrangement of elements used to receive and transfer information. Information systems may use different types of carriers, such as satellites, fiber optics, cables, and telephone lines, in which switching and storage devices are often important parts.

Infrastructure—(1) The basic framework or features of a system or organization. (2) The basic physical systems that support a country's or a community's population, including transportation and utilities.

Innovation—An improvement of an existing technological product, system, or method of doing something.

Inorganic—Lacking the qualities, structure, and composition of living organisms; inanimate.

Input—Something put into a system, such as resources, in order to achieve a result.

In-service—(1) A full-time employee. (2) Workshops and lectures designed to keep practicing professionals abreast of the latest developments in their field.

Instructional technology—The use of computers, multi-media, and other technological tools to enhance the teaching and learning process. Sometimes referred to as educational technology.

Integration—The process of bringing all parts together into a whole.

Intelligence—The capacity to acquire knowledge and the skilled use of reason; the ability to comprehend.

Intelligent transportation system—Proposed evolution of the entire transportation system whereby information technologies and advances in control electronics and automation would be embedded in the system to provide traffic control, freeway and incident management, emergency response, and other features.

Interdisciplinary instruction—An educational approach where the students study a topic and its related issues in the context of multiple academic areas or disciplines. The acronyms STEM, STEAM, and associated variations refer to this approach.

Intermodalism—The use of more than one form (mode) of transportation.

Invention—A new product, system, or process that has never existed before, created by study and experimentation.

Iron Age—The period of human culture characterized by the smelting of iron and its use in industry beginning after the Bronze Age somewhat before 1000 B.C.E. in western Asia and Egypt.

Irradiation—Treatment through the use of ionizing radiation, such as X-rays or radioactive sources (e.g., radioactive iridium seeds).

Irrigation system—A system that uses ditches, pipes, or streams to distribute water artificially.

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Iterative—Describes the repetition of a procedure or process, usually until some condition is satisfied. In design, iteration refers to revisiting stages in the process to achieve improved design outcomes.

Key idea—Concepts or ideas that have lasting impacts and are widely seen as important for all students to learn.

Kinesthetic (psychomotor) learning—educational activities in which learning occurs through physical activity that requires use of various parts of the body in a hands-on environment (a.k.a. tactile learning).

Kinetic energy—The energy possessed by a body as a result of its motion.

Knowledge—(1) The body of truth, information, and principles acquired by mankind. (2) Interpreted information that can be used.

Laboratory-classroom—The formal environment in a school where the study of technology and engineering takes place. At the elementary level, this environment will likely be a regular classroom. At the middle and high school levels, a separate laboratory with areas for hands-on activities as well as group instruction could constitute the environment.

Logistics—The management of physical and information flows starting at the source of supply and ending at the consumption point.

Making and Doing—The act of creating something; a tactile, hands-on component of technological problem solving that includes designing, making/building, producing, and evaluating. A central tenet of technology and engineering education instructional delivery.

Maintenance—The work needed to keep something in proper condition; upkeep.

Management—The act of controlling production processes and ensuring that they operate efficiently and effectively; also used to direct the design, development, production, and marketing of a product or system.

Manufacturing—The process of converting a raw material into a finished product.

Manufacturing system—A system or group of systems used in the manufacturing process to make products for an end user.

Marketing—The act or process of offering goods or services for sale.

Mass production—The manufacture of goods in large quantities by means of machines, standardized design and parts, and, often, assembly lines.

Material—The tangible substance (physical, chemical, biological, or composite) that goes into the makeup of a physical product. One of the basic resources used in a technological system.

Material conversion and processing—The production of physical goods.

Mathematician—An expert in or student of mathematics.

Mathematics—The science of patterns and order and the study of measurement, properties, and the relationships of quantities; using numbers and symbols.

Measurement—The process of using dimensions, quantity, or capacity by comparison with a standard in order to mark off, apportion, lay out, or establish dimensions.

Medical and health-related technology—Of or relating to the study of medicine through the use of and advances in technology, such as medical instruments, imaging systems, and other tools. Related terms include biomedical engineering and medical innovations.

Medicine—The science of diagnosing, treating, or preventing disease and other damage to the body or mind.

Middle Ages—The period in European history between antiquity and the Renaissance, often dated from A.D. 476 to 1453.

Model—A visual, mathematical, or three-dimensional representation in detail of a process or design, often smaller than the original. A model can be used to test ideas, make changes to a design, and learn more about what would happen to a similar, real process.

Module—A self-contained educational unit.

Multimedia—Information that is mixed and transmitted through a number of formats (e.g., video, audio, and data).

Natural material—Material found in nature, such as wood, stone, gases, and clay.

Non-biodegradable—The inability of a substance to be broken down (decomposed) and therefore retaining its form for an extended period of time.

Non-durable goods—Items that do not last and are constantly consumed, such as paper products.

Nonrenewable—A process, thing, or resource that cannot be replaced.

Nuclear power—Power, the source of which is nuclear fission or fusion.

Obsolescence—Loss in the usefulness of a product or system because of the development of an improved or superior way of achieving the same goal.

Open-loop system—A control system that has no means for comparing the output with input for control purposes. Control of open-loop systems often requires human intervention.

Optimism—Having a belief that technologies can be improved and 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.

Optimization—(1) An act, process, or methodology used to make a design or system as effective or functional as possible within the given criteria and constraints. (2) An engineering practice that is about finding the most effective solution to a problem and using the fewest resources to create the best product.

E

Output—The results of the operation of any system.

Plan—A set of steps, procedures, or programs worked out beforehand in order to complete a process or achieve goal.

Portfolio—A systematic and organized collection of a student's work that may include results of research, successful and less successful ideas, notes on procedures, and data collected.

Potential energy—The energy of a particle, body, or system that is determined by its position or structure.

Power—(1) The amount of work done in a given period of time; the rate at which work is done or energy is converted. (2) The source of energy or motive force by which a physical system or machine is operated.

Power standards—Content standards that are enduring, applicable across a wide spectrum of other standards, and required to achieve the next level of instruction

Power system—A technological system that transforms energy resources to power.

Practice—Behavior used when engaged in the three dimensions of knowing, thinking, and doing technology and engineering.

Pre-service—Undergraduate or graduate coursework taken by those preparing to work as teachers.

Problem-based learning—A student-centered instructional approach in which students learn about a subject through the experience of solving open-ended problems.

Problem solving—The process of understanding a problem, devising a plan, carrying out the plan, and evaluating the plan in order to solve a problem or meet a need or want.

Procedural knowledge—Knowing how to do something.

Process—(1) Human activities used to create, invent, design, transform, produce, control, maintain, and use products or systems. (2) A systematic sequence of actions that combines resources to produce an output.

Produce—To create, develop, manufacture, or construct a human-made product.

Product—A tangible artifact produced by means of either human or mechanical work, or by biological or chemical processes.

Product lifecycle—Stages a product goes through from concept and creation to eventual withdrawal from use.

Production system—A technological system that involves making products and systems either via manufacturing (e.g., on an assembly line) or via construction (e.g., a building on a site).

Project-based learning—An instructional approach that involves learning by doing, typically by having students focus on a real-world problem and devising practical solutions.

Propulsion system—A system that provides the energy source, conversion, and transmission of power to move a vehicle.

Prototype—A full-scale working model used to test a design concept by making actual observations and necessary adjustments.

Psychomotor (kinesthetic) learning—See “Kinesthetic learning.”

Quality control—A system by which a desired standard of quality in a product or process is maintained. Quality control usually requires feeding back information about measured defects to further improvements of the process.

Receiver—The part of a communication system that picks up or accepts a signal or message from a channel and converts it to perceptible forms.

Recycle—To reclaim or reuse old materials in order to make new products.

Renaissance—The transitional movement in Europe between medieval and modern times beginning in the fourteenth century in Italy, lasting into the seventeenth century, and marked by a flowering of the arts and literature and by the beginnings of modern science.

Renewable—Designation of a commodity or resource, such as solar energy or firewood, that is inexhaustible or capable of being replaced by natural ecological cycles or sound management practices.

Requirements—The parameters placed on the development of a product or system. Requirements may include safety needs, physical laws that will limit the development of an idea, available resources, cultural or societal norms, and functional criteria and constraints, among other things.

Research and development (R&D)—The practical application of scientific and engineering knowledge for discovering new approaches for products, processes, and services, and then applying that knowledge to create new and improved products, processes, and services that fill market needs.

Resource—The things needed to get a job done. In a technological system, the basic technological resources are: energy, capital, information, machines and tools, materials, people, and time.

Robotics—Mechanical devices that can perform tasks automatically or with varying degrees of direct human control.

Sanitation—The design and practice of methods for solving basic public health problems, such as drainage, water and sewage treatment, and waste removal.

Scale—A proportion between two sets of dimensions used in developing accurate, larger or smaller prototypes, or models of design ideas.

Schematic—A drawing or diagram of a chemical, electrical, or mechanical system.

Science—The study of the natural world through observation, identification, description, experimental investigation, and theoretical explanations.

Scientific inquiry—The use of questioning and close examination using the methodologies of science.

E

Scientific literacy—Having some level of familiarity with the enterprise and practice of science.

Scientist—An expert in or student of science and scientific inquiry.

Service—The installation, maintenance, or repairs provided or completed by a dealer, manufacturer, owner, or contractor.

Side effect—A peripheral or secondary effect, especially an undesirable secondary effect. Some side effects become the central basis for new developments.

Sketch—A rough drawing representing the main features of a process or scene and often made as a preliminary study.

Society—A community, nation, or broad grouping of people having common traditions, institutions, and collective activities and interests.

Solution—A method or process for solving a problem.

Standards for Technological and Engineering Literacy—Written statements that specify the knowledge (what students should know), skills (what students should be able to do), and dispositions (student beliefs or values) students should possess in order to be technologically and engineering literate.

Standardization—(1) The act of checking or adjusting by comparison with a standard. (2) Development of common requirements for a process or product that lay out a consistent set of expectations for its structure or performance.

STEM—A term used to group together the academic disciplines of Science, Technology, Engineering, and Mathematics and their associated content, practices, and applications.

STEM literacy—STEM literacy is more than the sum of its parts. What STEM literacy provides that the independent disciplines do not is a more holistic understanding of how concepts, processes, and ways of thinking from across these disciplines can be integrated and applied to achieve enhanced outcomes.

Stone Age—The first known period of prehistoric human culture characterized by the use of stone tools.

Structure—(1) An arrangement of parts or constituent elements that is built, constructed, or organized in a particular way. (2) Something that has been built or constructed (e.g., a bridge, house, or dam). (3) The act of organizing, arranging, or providing a systematic framework for something.

Subsystem—A division of a system that, in itself, has the characteristics of a system.

Support system—A network of personnel and/or tools that provide life, legal, operational, maintenance, and economic support for the safe and efficient operation of a system, such as a transportation system.

Suspension system—A system of springs and other devices that insulates the passenger compartment of a vehicle from shocks transmitted by the rest of the vehicle (e.g., wheels and axles).

Sustainability—(1) Of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged. (2) Relating to a human activity that can be sustained over the long term, without adversely affecting the environmental conditions (e.g., soil conditions, water quality, climate) necessary to support those same activities in the future.

Symbol—An arbitrary or conventional sign that is used to represent operations, quantities, elements, relations, or qualities, or that is used to provide directions or alert one to safety.

Synthetic material—Material that is not found in nature, such as glass, concrete, and plastics.

System—A group of interacting, interrelated, or interdependent elements or parts that function together as a whole to accomplish a goal.

Systems thinking—(1) A technique for looking at a problem in its entirety, looking at the whole, as distinct from each of its parts or components. Systems thinking attempts to consider all of the variables affecting, and affected by, a system, including both its social and technological characteristics. (2) The individual 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 systems model, consisting of inputs, processes, outputs, and feedback.

Technological design—The application of design processes, most notably engineering design, to develop a product or process or to solve a problem. Technological design is a broad term that encompasses engineering design but may also include industrial design, graphic design, user experience design, architectural design, and other design sub-specialties.

Technological and engineering contexts—Content areas that illustrate where the core standards, benchmarks, and practices could be applied. In *STEL* these include Computation, Automation, Artificial Intelligence, and Robotics; Manufacturing; Transportation and Logistics; Energy and Power; Information and Communication; The Built Environment; Medical and Health-Related Technologies; and Agricultural and Biological Technologies.

Technological and engineering literacy—The ability to understand, use, create, and assess the human-designed environment in increasingly sophisticated ways over time.

Technological and engineering practices—Key behaviors and personal qualities students in technology and engineering education programs should exhibit. In the context of *STEL*, these practices are systems thinking, creativity, making and doing, critical thinking, optimism, collaboration, communication, and attention to ethics.

Technological literacy—The ability to understand, use, create, and assess the human-designed systems and artifacts that are the product of technology and engineering activity.

E

Technological studies—See "Technology education."

Technologist—An expert in, or a student of, a particular field of technology.

Technology—(1) The modification of the natural environment, through human-designed products, systems, and processes, to satisfy needs and wants. (2) A broad reference to the tools, machines, or systems that result from this modification.

Technology and engineering education—The combined disciplinary study of the engineered (human-designed) world, the goal of which is to develop individuals with a breadth of knowledge and capabilities who see the interactions between technology, engineering, and society and can use, create, and assess current and emerging technologies.

Technology education—The disciplinary study of the human-designed world, which provides an opportunity for students to learn about the technological processes and knowledge needed to solve problems and extend human capabilities (a.k.a. "Design and Technology," "Technological Studies," and others).

Technology transfer—The process by which products, systems, knowledge, or skills, often developed under federal research and development funding, is translated into commercial products to fulfill public and private needs.

Telemedicine—The investigation, monitoring, and management of patients and the education of patients and staff using systems that allow ready access to expert advice and patient information, no matter where the patient or the relevant information is located. The three main dimensions of telemedicine are health service, telecommunication, and medical computer technology.

Thematic unit—A set of lesson presentations that organizes classroom instruction around certain materials, activities, and learning episodes related to a topic(s). A thematic unit might integrate several disciplinary content areas.

Tinkering—Making small changes to something in an unskilled or exploratory manner, particularly in an attempt to repair or improve it.

Tool—A device that is used by humans to complete a task.

Trade-off—An exchange of one thing in return for another; especially, relinquishment of one benefit or advantage for another regarded as more desirable.

Transdisciplinary—Educational or research practices that draw from multiple disciplines. Although often used interchangeably with "interdisciplinary" and "multidisciplinary," in this context it refers to approaches that transcend disciplinary boundaries to create new and more holistic understandings and solutions.

Transmit—To send or convey a coded or non-coded message from a source to a destination.

Transportation—The process by which passengers or goods are moved or delivered from one place to another.

Transportation system—An arrangement of components and/or infrastructure that provides all of the elements needed to transport goods or passengers from one place to another.

Trend analysis—A comparative study of the component parts of a product or system and the ways in which a product or system develops over time.

Trial and error—A method of solving problems in which many solutions are tried until errors are reduced or minimized (See: Tinkering).

Troubleshoot—To locate and find the cause of problems related to technological products or systems.

Universal design—The process of creating products or systems that are accessible to people regardless of their age, size, or abilities.

Virtual—Simulation of the real thing in such a way that it presents reality in essence or in effect, though not in actual fact.

Waste—Refuse or by-products that are perceived as useless and therefore must be consumed, stored, or thrown away.

Work—(1) The transfer of energy from one physical system to another, expressed as the product of a force and the distance through which it moves a body in the direction of that force. (2) Physical or mental activity done to achieve a purpose or result, especially in relation to one's job or professional commitments.

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