defining technological and engineering literacy

by Marie Hoepfl

Standards for Technological and Engineering Literacy (STEL) is designed to reflect changes in both the technological and the educational landscape, and to do so in a way that will accommodate future developments in both arenas.

With the release of *Standards for Technological and Engineering Literacy: The Role of Technology and Engineering in STEM Education*, ITEEA has redefined the knowledge, skills, and habits of mind that constitute literacy within technology and engineering. By examining the meaning of literacy, as well as its function, we can better understand the role played by disciplinary standards in shaping educational experiences at the PreK-12 level.

A Broad Definition of Literacy

The National Academies, in the 2016 report *Science Literacy: Concepts, Contexts, and Consequences*, provided a helpful discussion of the word literacy:

> Literacy as a term and a concept has great usefulness and seemingly boundless semantic potential, such that it is used to refer to an ever-larger array of ideas, and the central concept has drifted dramatically from its original meaning. The origin is *letra*, Latin for letter, and literacy once very simply referred to

> the capacity to recognize letters and decode letter strings.… That circumscribed meaning has long been transcended. (National Academies of Sciences, Engineering, and Medicine [National Academies], 2016, p. 16).

That the definition of literacy has expanded dramatically is obvious from even the most cursory examination of the literature on literacy: digital literacy, environmental literacy, financial literacy, health literacy, spatial literacy, food literacy, and many others can now be added to more familiar disciplinary literacies such as scientific, mathematical, and technological literacy. A basic starting point to defining literacy in any field is that it represents knowledge and/or competence in a specified area. Thus, the task is to define what the elements of knowledge and competence are in the field of interest—in this case, in technology and engineering.

The National Academies (2016) report contrasted "foundational literacies"—such things as "numeracy, textual literacy, visual literacy, and understanding of graphs and charts"—from the more focused "disciplinary literacy" that is associated with knowledge within the specific domain (p. 32). Both are useful concepts, and arguably the content standards for any disciplinary field must address both types of literacy.

A broad notion of literacy, particularly within a disciplinary field, must also acknowledge that what constitutes literacy is a shifting landscape, subject to change as cultural conditions change—what some have called *situational literacy* (Fourez, 1997; National Research Council, 2002; Veldhoen & Crichton, 2019; Williams, 2009). More specifically, literacy in technology and engineering contains elements that are permanent, or time-independent, as well as elements that are "constantly evolving or changing" (Krupczak et al., 2016, p. 13). The overarching message for technology and engineering education is that because technological literacy is a fluid construct, "to maintain relevance its content [must] evolve as a function of changing cultural traditions. The utility of such a literacy would depend on its ability to adapt and keep pace with constant change" (Gagel, 1997, p. 22). *Standards for Technological and Engineering Literacy* (*STEL*) is designed to reflect changes in both the technological and the educational landscape, and to do so in a way that will accommodate future developments in both arenas.

Technological Literacy

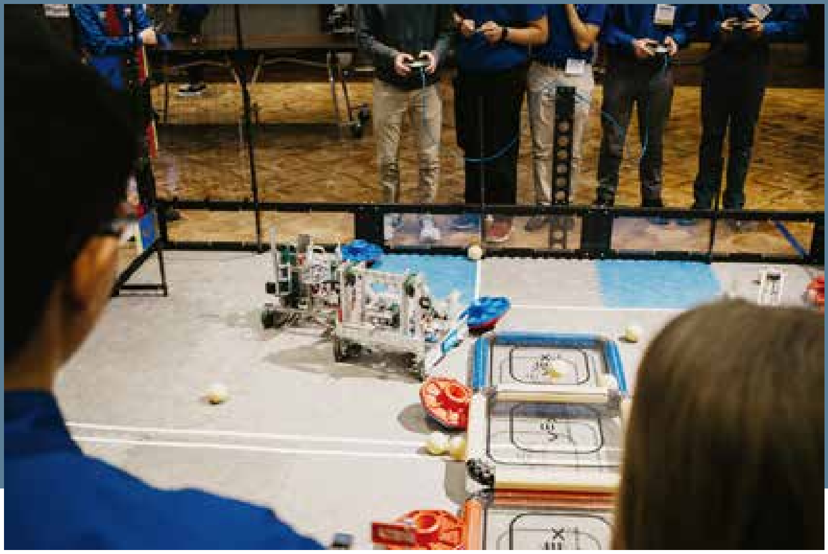
Efforts to define, and arguments about the need for, technological literacy are widespread. Yet conveying the full meaning of this literacy is difficult when many people associate the word technology only with information technologies (Fleming, 1989; Heywood, 2017; Mitchell, 2017), or when the disciplinary fields that comprise STEM are conflated into a single entity, as is widely done. It is nevertheless important to try to tease out the unique characteristics of the various STEM literacies before examining their points of overlap and complementarity.

The much-quoted definition of technological literacy provided in *Standards for Technological Literacy* (*STL*) was: "The ability to use, manage, assess, and understand technology." A technologically literate person was said to be someone who understands "what technology is, how it is created, and how it shapes society, and in turn is shaped by society" (ITEA/ITEEA, 2000, p. 9). *STL* elaborated on the content that would underpin this understanding of technology by providing a detailed list of content standards. Defining such standards poses inherent challenges, however. Determination of what is essential technological content can depend on the cultural context as well as on changes over time and across different geographical settings. To minimize the effect of these contextual variations when defining standards, some argue for an emphasis on processes and actions—in other words, on the functional or praxiological aspects of technological literacy (Gagel, 1997; Ingerman & Collier-Reed, 2011).

Gagel laid out what he called an "identity kit" for technological literacy, which would contain:

> …those effectual elements having an inherent, unchanging, and enduring quality…. that would enable one to (a) accommodate and cope with rapid and continuous technological change, (b) generate creative and innovative solutions for technological problems, (c) act through technological knowledge both effectively and efficiently, and (d) assess technology and its involvement with the human lifeworld judiciously. (Gagel, 1997, p. 25).

From this praxiological point of view, "expertise (or enhanced literacy) is developed through repeatedly acting in technology and engineering contexts, building experience in the selective application of [technology and engineering] practices" (Tang & Williams, 2018, p. 14). Examination of *STEL* will show that the benchmarks are built to encourage repeated application of core knowledge and practices in increasingly rigorous ways across the grade bands as students progress through Grades PreK-12.



The process of design has long been a hallmark of the technology education classroom (Antink-Meyer & Brown, 2019; Williams, 2009), and this process figures heavily in existing content standards in science and technology at the national level, and in science, technology, and engineering at state levels (e.g., Carr et al., 2012; Koehler et al., 2013). More recently, the term *engineering design* has seen wider use (e.g., ITEA/ITEEA, 2000/2002/2007; New York State Department of Education, 1996; NGSS Lead States, 2013). It is in the area of design activity that it becomes most difficult to differentiate technology and engineering, because both areas rightly claim design as a core function within the discipline. The concept of "technological multiliteracy" proposed by Williams (2009, p. 246) may be helpful here in that it acknowledges the many synergies between technological and other forms of literacy and highlights the breadth of technological literacy—including, very importantly, "an awareness or appreciation of the relationships between technology, society, and the environment" (Williams, 2009, p. 246). Moreover, within technology other forms of design-based problem-solving (such as industrial design, graphic design, and so on) have been embraced in addition to engineering design (ITEA/ITEEA, 2000/2002/2007).

Engineering Literacy

More so than between other disciplines within STEM, technology and engineering are often conflated (e.g., Krupczak et al., 2016) and are frequently referred to by the unified phrase "technology and engineering." Given the frequent pairing of these terms, it might seem futile to try to define engineering literacy separately from technological literacy. For example, Asunda (2012) stated that "the idea of engineering literacy is synonymous with technological literacy, since it is difficult to differentiate between the two, though engineers may argue differently" (p. 48). Technologists might also find points of contention, such as with the characterization of engineering versus technological literacy shown in Table 1, which depicts technological literacy as being focused on products and objects, rather than on actions. Krupczak et al. (2016) elaborated on their comparison of the two disciplines, noting: "If engineering literacy is viewed as having a focus directed more toward understanding the process of creating or designing technological artifacts or systems, then technological literacy includes a broader view of the products or results of the engineering process as well as the relation between technology and society" (p. 12).

Table 1. *Differentiating Engineering and Technological Literacy* (from Krupczak et al., 2016, p. 11)

Engineering Literacy	Technological Literacy
Process	Product
Verb (Actions)	Noun (Objects)
Narrow Focus	Broader Focus

Antink-Meyer and Brown (2019) wrote, "Modern engineering and technology [have] common ancestors and significantly overlap, [but] they are not identical constructs" (p. 13). These researchers identified seven features that describe the nature of engineering knowledge. According to their analysis, engineering is solution-oriented ("because it is motivated by human problems and desires" [p. 7]), contextually responsive, empirical ("evidence-based modeling is the central means of data gathering and feedback" [p. 9]), and influenced by societal and cultural factors. They noted it also has personal and social dimensions that often involve working in interdisciplinary teams.

The National Academy of Engineering laid out three general principles in its framework for engineering literacy: "K-12 engineering education should emphasize engineering design…[It] should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills…[and it] should promote engineering habits of mind…[including] systems thinking, creativity, collaboration, and communication" (National Academy of Engineering [NAE], 2010, p. 45).

The extent to which engineering content and practices have been adopted by states was examined by both Carr et al. (2012) and Koehler et al. (2013). Koehler and colleagues specifically analyzed how much engineering content was written into states' science standards, whereas Carr and his team looked more broadly at all content standards. Koehler et al. found that

New England, the Mid-Atlantic, and Great Lakes regions reflected the greatest amount of engineering content in their state science standards, and noted that some states "have used [the Science, Technology, and Society approach] as the bridge between the disciplines of science and technology" (Koehler et al., 2013, p. 10). Taking a broader census, Carr et al. found that 36 U.S. states had a "strong presence of engineering" in their educational standards (p. 549), with 11 states having explicit engineering standards and another six presenting engineering in the context of technological design.

Scientific Literacy

As with other forms of literacy, there are differing thoughts about what constitutes scientific literacy. According to a 2016 National Academies report on the topic, scientific literacy was broadly defined as having "some level of familiarity with the enterprise and practice of science" (National Academies, 2016, p. 1). A central theme of the National Academies' work on this topic is that scientific literacy should be considered a characteristic not only of individuals, but also of communities and societies (National Academies, 2017). As early as 1971, the National Science Teachers Association declared scientific literacy to be "the most important goal of science education" because it allows individuals to use scientific understanding and values to "make everyday decisions" (National Academies, 2019, p. 27).

The National Academies' report *Science Literacy* (2016) noted that the definition of scientific literacy has changed over the years as ideas about science have changed. The report summarized definitions of scientific (or science) literacy by identifying seven elements that were evident across the multiple definitions they examined to create "a sort of theoretical common ground… [of what] many scholars expect would be useful or valuable" in relation to scientific knowledge (National Academies, 2016, p. 137). These included foundational literacies; content knowledge ("scientific terms, concepts, and facts"); understanding of scientific practices (broadly speaking, "how scientists do science"); identifying and judging scientific expertise; epistemic knowledge ("how the procedures of science support the claims made by science"); cultural understanding of science (which "acknowledged the interrelationships of science and society"); and dispositions and habits of mind (which might include "inquisitiveness, open-mindedness, a valuing of the scientific approach to inquiry, and a commitment to evidence") (pp. 32-33).

These seven elements were operationalized neatly in the following definition found in the 1996 *National Science Education Standards*:

> Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (National Academy of Sciences, 1996, p. 22).

In the current *Next Generation Science Standards* (*NGSS*), scientific literacy is still seen as a compelling need, although the term isn't explicitly defined as in past science standards documents. *NGSS* is based, in part, on the National Academy of Sciences report, *A Framework for K-12 Science Education* (National Research Council, 2012). This report made a much more concrete connection between science and engineering, notably structuring the discussion about science education around three "dimensions" that are echoed in *NGSS*. "Dimension 1 describes scientific and engineering practices. Dimension 2 describes crosscutting concepts… those having applicability across science disciplines. Dimension 3 describes core ideas in the science disciplines and of the relationships among science, engineering, and technology" (National Research Council, 2012, p. 29). As these dimensions suggest, at the same time that the door was opened more widely to engineering (and, to a lesser extent, to technology), an effort was made to pare down the "cornucopia of information" to a manageable set of ideas that could represent "core knowledge" (p. 31).

The disciplinary core ideas that form the principal share of *NGSS* are largely based around the conventional subcategories of science education, encompassing the physical, life, and earth sciences. However, these also include elements related to the engineering design process. Similarly, the crosscutting concepts include one that focuses on the interdependence of science, engineering, and technology and another on the influence of engineering, technology, and science on society and the natural world.

Toward a Broader STEM Literacy

The past 10 to 20 years have seen a marked expansion of interest in interdisciplinary STEM approaches, with the acronym STEM becoming a common part of the conversation among educators and members of the public (e.g., National Governors Association, 2007; Zollman, 2012). ITEA (now ITEEA) expanded its name to include the word engineering in 2010. *NGSS* and its precursor reports, including *Project 2061* (American Association for the Advancement of Science [AAAS], 2007), embraced the connections between the STEM disciplines. STEM is seen as an "interdisciplinary area of study that bridges the four areas of science, technology, engineering, and mathematics. STEM literacy does not simply mean achieving literacy in these four strands or silos" (National Governors Association [NGA], 2007, p. 7). Yet, because it is a relatively new term and because effective interdisciplinarity dictates working beyond and outside of these silos, "STEM literacy" has still not been precisely defined (Cencelj et al., 2019; Zollman, 2012), and the wide-ranging definitions of STEM and its component parts "present an obstacle for the field to have meaningful conversation revolving around STEM literacy" (Tang & Williams, 2018, p. 2). Two points seem clear, however: (1) STEM is a unitary force that must be reckoned with; and (2) technology and engineering must better establish their roles in this disciplinary quartet, including better articulating the core elements of their respective disciplinary literacy.

With respect to the first point, Zollman (2012) articulated a vision for how we might think about STEM literacy that detailed a model for STEM as a unified entity, even as it suggested that the core content areas contain their own specific educational objectives:

> In education, we need to view STEM literacy as a dynamic process, spotlighting the three strata in the STEM literacy process: educational objectives of the content areas; cognitive, affective, and psychomotor domains from learning theory; and economic, societal, and personal needs of humanity. Such a vision allows us to evolve from focusing on *learning for STEM literacy* to using *STEM literacy for continued learning* (Zollman, 2012, p. 18).

This dualistic vision of STEM literacy was described by Tang and Williams (2018), who wrote: "STEM literacy is more than the sum of its parts. What STEM literacy provides that the independent disciplines do not, is also a holistic understanding of how concepts, processes, and ways of thinking can be integrated and applied to the design of a solution to a real-world problem. These 'wicked' problems often require an interdisciplinary approach rather than a singular disciplinary approach" (p. 18). These authors proposed that, because there are specific skills and knowledge reflective of each disciplinary area, we might better use the phrase "S.T.E.M. literacies" (p. 18) to refer to the kind of literacy we wish to emphasize. The idea of "STEM literacies" was also promoted by Cencelj et al. (2019), who said, "While science, mathematical, engineering, and technological literacy may well refer to competences sharing common roots and a set of common attributes, they are ultimately different kinds of literacy competences, which serve different goals, lead to different results, and must therefore be developed systematically, each of them separately" (p. 133). In spite of this recognition that the STEM fields have different goals and disciplinary content, and in the face of inconsistent models for how to best integrate STEM into the K-12 school curriculum, there is some agreement that an interdisciplinary approach will lead to the kind of functional literacy required to solve our pressing societal needs (Heywood, 2017; Mitchell, 2017). Educators who use *STEL* will note that the ancillary resources provided as part of the development work include crosswalks with science, math, English/Language Arts, and information technology standards that highlight the connection points between the disciplines.

With respect to the second point, that technology and engineering need to better articulate their roles in STEM, the National Governors Association called for increased support for emerging work on the "'T' and 'E' of STEM," as a key strategy to "increase the relevancy of STEM to students' lives" (NGA, 2007, p. 19), and U.S. schools must do more to incorporate technology and engineering in their curricula (Mitchell, 2017). Even in the absence of standards that focus solely on K-12 engineering education, engineering content features prominently in both *NGSS* and *Standards for Technological and Engineering Literacy*, a trend that is likely to be expanded in the coming years as states modify their educational standards and through the development of the Technology and Engineering Literacy component of the National Assessment of Educational Progress (Institute of Education Sciences/National Center for Education Statistics, 2019). Through careful integration of content and processes associated with diverse fields of study, including mathematics and science, technology and engineering education can embody the kind of STEM literacy that enables students to tackle "wicked" problems.

The task for any standards document is to provide "sufficient unpacking of how literacy is conceptualized or operationalized" within the given disciplinary field (Mirra & Garcia, 2019, p. 2). Ultimately, standards must lay out a coherent path to guide educational experiences that will prepare young people for successful participation in a future that will certainly contain new challenges, new questions, and new opportunities.

References

American Association for the Advancement of Science and National Science Teachers Association. (2007). *Atlas of science literacy: Project 2061.* Washington, DC: Author. www.project2061.org/publications/sfaa/

Antink-Meyer, A. & Brown, R. (2019). Nature of engineering knowledge: An articulation for science learners with nature of science understandings. *Science & Education* (online). https://doi.org/10.1007/s11191-019-00038-0

Asunda, P. (2012). *Standards for technological literacy* and STEM education delivery through career and technical education programs. *Journal of Technology Education, 23*(2), 44-60.

Carr, R., Bennett, L., & Strobel, J. (2012). Engineering in the K-12 STEM standards of the 50 U.S. states: An analysis of presence and extent. *Journal of Engineering Education, 101*(3), 539-564.

Cencelj, Z., Abersek, M., Bersek, B., & Flogie, A. (2019). Role and meaning of functional science, technological and engineering literacy in problem-based learning. *Journal of Baltic Science Education, 18*(1), 132-146. https://doi.org/10.33225/jbse/19.18.132

Fleming, R. (1989). Literacy for a technological age. *Science Education, 73*(4), 391-404.

Fourez, G. (1997). Scientific and technological literacy as a social practice. *Social Studies of Science, 27*, 903-936.

Gagel, C. W. (1997). Literacy and technology: Reflections and insights for technological literacy. *Journal of Industrial Teacher Education, 34*(3), 6-34.

Heywood, J. (2017). Why technological literacy and for whom? In Heywood et al. (2017), *Philosophical and educational perspectives on engineering and technological literacy, IV* (pp. 2-9). Iowa State University. https://lib.dr.iastate.edu/ece_books/4/

Ingerman, A. & Collier-Reed, B. (2011). Technological literacy reconsidered: A model for enactment. *International Journal of Technology and Design Education, 21*, 137-148. doi: 10.1007/s10798-009-9108-6.

Institute of Education Sciences/National Center for Education Statistics. (2019). *Technology and engineering literacy.* https://nces.ed.gov/nationsreportcard/tel/

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

Koehler, C., Faraclas, E., Giblin, D., Moss, D. M., & Kazerounian, K. (2013). The Nexus between science literacy & technical literacy: A state-by-state analysis of engineering content in state science standards. *Journal of STEM Education, 14*(3), 5–12.

Krupczak, J., Blake, J., Disney, K.A., Hilgarth, C., Libros, R., Mina, M., & Walk, S. (2016). Defining engineering and technological literacy. In Blake et al. *Philosophical and educational perspectives on engineering and technological literacy, III* (pp. 8-14). Iowa State University. https://lib.dr.iastate.edu/ece_books/3/

Mirra, N. & Garcia, A. (2020). In search of the meaning and purpose of 21st-century literacy learning: A critical review of research and practice. *Reading Research Quarterly* (advanced publication version). doi:10.1002/rrq.313.

Mitchell, T. (2017). *Examining the relationship between technology & engineering instruction and technology & engineering literacy in K-8 education* (Doctoral dissertation, Duquesne University). https://dsc.duq.edu/etd/179

National Academy of Engineering [NAE]. (2010). *Standards for K-12 engineering education?* Washington, DC: The National Academies Press.

National Academy of Sciences. (1996). *National science education standards.* Washington, DC: The National Academies Press.

National Academies of Sciences, Engineering, and Medicine. (2016). *Science literacy: Concepts, contexts, and consequences.* Washington, DC: The National Academies Press. doi:10.17226/23595.

National Academies of Sciences, Engineering, and Medicine. (2017). *Communicating science effectively: A research agenda.* Washington, DC: The National Academies Press. doi: 10.17226/23674.

National Academies of Sciences, Engineering, and Medicine. (2019). *Science and engineering for grades 6-12: Investigation and design at the center.* Washington, DC: The National Academies Press. https://doi.org/10.17226/25216

National Governors Association. (2007). *Innovation America: Building a science, technology, engineering, and math agenda.* Washington, DC: Author.

National Research Council. (2002). *Investigating the influence of standards: A framework for research in mathematics, science, and technology education.* Washington, DC: National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press.

New York State Department of Education. (1996). *Learning standards for mathematics, science, and technology.* www.nysed.gov/common/nysed/files/programs/curriculum-instruction/mststa1_2.pdf

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

Tang, K. & Williams, P. (2019). STEM literacy or literacies? Examining the empirical basis of these constructs. *Review of Education, 7*(3), 675-697. https://doi.org/10.1002/rev3.3162

Veldhoen, K. & Crichton, S. (2019). *Expanding notions of literacy: Developing creative commons resources to cultivate 21st century literacies.* Paper presented at the Pan-Commonwealth Forum, Edinburgh, Scotland. http://dspace.col.org/handle/11599/3294

Williams, P. (2009). Technological literacy: A multiliteracies approach for democracy. *International Journal of Technology and Design Education, 19*, 237-254. doi: 10.1007/s10798-007-9046-0.

Zollman, A. (2012). Learning for STEM literacy: STEM literacy for learning first. *School Science and Mathematics, 112*(1), 12-19.

Marie Hoepfl, Ed.D., *is Professor and Associate Dean at Appalachian State University in Boone, NC. She can be reached at hoepflmc@appstate.edu.*

This is a refereed article.