Journal of Pre-College Engineering Education Research (J-PEER)

Volume 5 | Issue 1 Article 5

2015

An Introduction to the Standards for Preparation and Professional Development for Teachers of Engineering

Jackson E. Reimers
Vanderbilt University, jackson.e.reimers@vanderbilt.edu

Cheryl L. Farmer
University of Texas, cheryl.farmer@mail.utexas.edu

Stacy S. Klein-Gardner
Vanderbilt University, stacy.klein-gardner@vanderbilt.edu

Follow this and additional works at: https://docs.lib.purdue.edu/jpeer

Part of the Other Teacher Education and Professional Development Commons

Recommended Citation

Reimers, J. E., Farmer, C. L., & Klein-Gardner, S. S. (2015). An Introduction to the Standards for Preparation and Professional Development for Teachers of Engineering. *Journal of Pre-College Engineering Education Research (J-PEER), 5*(1), Article 5.
https://doi.org/10.7771/2157-9288.1107

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.

This is an Open Access journal. This means that it uses a funding model that does not charge readers or their institutions for access. Readers may freely read, download, copy, distribute, print, search, or link to the full texts of articles. This journal is covered under the CC BY-NC-ND license.

An Introduction to the Standards for Preparation and Professional Development for Teachers of Engineering

Abstract

The past 30 years have yielded a mature body of research regarding effective professional development for teachers of science and mathematics, leading to a robust selection of professional development programs for these teachers. The current emphasis on connections among science, technology, engineering, and mathematics underscores the need for similar research into the nature of effective professional development for teachers of engineering. With this in mind, this paper completes a review of the literature concerning effective professional development for teachers of engineering, both as a unique discipline and as a context for teaching and learning in other subjects. The results of this review serve as the foundation for five research-based design standards for professional development initiatives in the field of engineering education, which have been published on the American Society for Engineering Education (ASEE) website along with a matrix that will enable providers and consumers of engineering professional development to determine the extent to which a given program focuses on each of those standards.

Keywords

professional development, literature review, standards

Document Type

Article

This article is available in Journal of Pre-College Engineering Education Research (J-PEER): https://docs.lib.purdue.edu/jpeer/vol5/iss1/5

Available online at http://docs.lib.purdue.edu/jpeer

Journal of Pre-College Engineering Education Research 5:1 (2015) 40–60

An Introduction to the Standards for Preparation and Professional Development for Teachers of Engineering

Jackson E. Reimers,[1] Cheryl L. Farmer,[2] and Stacy S. Klein-Gardner[1]

[1]*Vanderbilt University*
[2]*University of Texas*

Abstract

The past 30 years have yielded a mature body of research regarding effective professional development for teachers of science and mathematics, leading to a robust selection of professional development programs for these teachers. The current emphasis on connections among science, technology, engineering, and mathematics underscores the need for similar research into the nature of effective professional development for teachers of engineering. With this in mind, this paper completes a review of the literature concerning effective professional development for teachers of engineering, both as a unique discipline and as a context for teaching and learning in other subjects. The results of this review serve as the foundation for five research-based design standards for professional development initiatives in the field of engineering education, which have been published on the American Society for Engineering Education (ASEE) website along with a matrix that will enable providers and consumers of engineering professional development to determine the extent to which a given program focuses on each of those standards.

Keywords: professional development, literature review, standards

Introduction

A discussion of the nature of effective professional development for teachers is predicated on the belief that effective teaching is not an innate ability, but a skill that can be acquired. The idea of the natural-born teacher has been displaced by research that points to the positive correlation between effective professional development and improved teacher practice, which has in turn been linked to improved student performance (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009). In an educational system that prioritizes continuous improvement of student performance across subjects and grade levels, the ability to identify and implement such professional development programs has the potential to support schools in achieving important strategic objectives. Fortunately, an extensive and growing body of research into effective professional development programs, accompanied by initiatives to identify the essential elements of such programs, offers insight to guide those who are tasked with creating or selecting professional development programs for teachers across core content areas.

The authors gratefully acknowledge the support of the American Society for Engineering Education. Correspondence concerning this article should be sent to Jackson E. Reimers at jackson.e.reimers@vanderbilt.edu.

While the nature and impact of professional development for teachers of science and mathematics has been studied to great effect over the past 30 years, the current emphasis on connections among science, technology, engineering, and mathematics (STEM) requires new efforts to understand and explain the nature of professional development for teachers of engineering, both as a unique discipline and as a context for teaching and learning in other subjects. Such an understanding is exigent in light of engineering's inclusion in the Next Generation Science Standards, which will require all elementary teachers and all secondary science teachers to engage students in authentic, engineering-centered learning.

In response to this urgent need for guidance, both for providers and for consumers of professional development for K-12 teachers of engineering, Farmer, Nadelson, and Klein-Gardner have identified *standards for preparation and professional development for teachers of engineering* that are aligned with current research in professional development and teaching and learning, including significant work by Custer and Daugherty. Additionally, Farmer and Klein-Gardner have developed a matrix to illustrate how a given professional development program might address each element of each standard with high, moderate, or low emphasis. These standards and the supporting matrix, which may be found following this paper, are not intended to be used in the evaluation of professional development, but rather as a framework to aid in designing, improving, and selecting professional development experiences that will appropriately and effectively equip in-service teachers to improve their practice as teachers of engineering. This paper provides the rationale for the standards and their supporting elements.

Standard A: Professional Development for Teachers of Engineering should Address the Fundamental Nature, Content, and Practices of Engineering to Promote Engineering Content Knowledge

An extensive body of research supports the need for professional development to focus on the development of subject matter content knowledge. In particular, Desimone (2009) states that "the content focus of teacher learning may be the most influential issue" (p. 184) in designing effective professional development, while Little (1993) emphasizes the importance of teaching specific, transferable skills. In support of this, Guskey (2003) reports that one of the most frequently cited aspects of effective professional development in the literature is the enhancement of teachers' content knowledge. Furthermore, evidence indicates a positive correlation between content focus in professional development and increased teacher knowledge, improved pedagogy, and moderate increases in student achievement (Blank, de las Alas, & Smith, 2007; Cohen, 1990; Garet, Porter, & Desimone, 2001).

While enhancing participants' content knowledge is a critically important component of all professional development, strong evidence indicates that it may be especially important in the field of engineering education. Very few classroom teachers were taught engineering in their own K-12 student experiences or pre-service teacher preparation programs, making the need to enhance engineering content knowledge particularly important even when compared with mathematics or science. Research indicates a need for K-12 teachers to "become comfortable and proficient with the engineering process" (Brophy, Klein, Portsmore, & Rogers, 2008, p. 381), especially through participation in an engineering design process (Hsu, Purzer, & Cardella, 2011). Custer and Daugherty (2009) note that effective professional development programs for teachers of engineering are geared toward engaging participants in active experimentation and problem solving, encouraging them to become more familiar with the methodology of engineering and the processes of engineering design. The authors observe that many effective programs engage teachers in authentic and exploratory design challenges to teach them to use the tools of engineering comfortably and to significant effect; at the same time, their article stresses that effective programs should comprise more than simple opportunities for learning how to implement the latest pre-packaged instructional aid. Research shows that practicing strategies for success in engineering (e.g., design essentials such as collaboration and teamwork, asking questions, cooperative communication about ideas and design specifics, careful documentation) is highly effective in developing teachers' content knowledge (Custer & Daugherty, 2009; Donna, 2012; English, Hudson, & Dawes, 2013; Moore et al., 2014). Additionally, studies show benefits for including corresponding opportunities for teachers to think about how these tools and strategies would affect their students' learning, reflecting as both learners and engineering educators on multiple design experiences both within and beyond the professional development program (Custer & Daugherty, 2009; Donna, 2012).

Standard B: Professional Development for Teachers of Engineering should Emphasize Engineering Pedagogical Content Knowledge

In addition to enhancing participants' content knowledge, effective professional development must focus on the development of engineering pedagogical content knowledge. Adult learning theory indicates that adults in their thirties and forties become more reflective and context-oriented (Sheehy, 1976), making it imperative that professional development programs engage participants in both metacognitive and concrete thought as they seek to improve both conceptions of teaching and learning and actual teaching practice. With this in mind, Rogers, Abell, and Lannin (2007) stress the importance of engaging teachers in complex thought instead of simply presenting them with information in order to challenge pedagogical knowledge and confront teachers with a transformative cognitive dissonance. An exemplary development program should engage its participants beyond the point of simply sitting and listening; discussion, reflection, and critical thinking are necessary if real learning is to take place. In support of this, several studies note the benefits of encouraging teachers to reflect on the whole of their development experience and how it can be translated into the classroom (Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Rogers et al., 2007; Thompson & Zeuli, 1999). Johnson and Saylor (2014) advocate staunchly for the same emphasis on reflection in programs designed specifically for STEM teachers.

A review of the literature reveals several trends with regard to deepening pedagogical content knowledge in the field of engineering education. First, professional development must provide opportunities for participants to experience and explore the ways in which the engineering design process can be used to teach both engineering-specific concepts and concepts common to multiple STEM disciplines (Narode, 2011). In particular, Donna (2012) reports that "professional development experiences that allow interdisciplinary teams of teachers to engage in engineering design activities can help promote connections within and across STEM domains" (p. 7). Additional research points to both reasons and opportunities to address classroom management strategies for handling the unique challenges that accompany an engineering design curriculum. For instance, the STAR.Legacy Cycle (Schwartz, Brophy, Lin, & Bransford, 1999) has been proposed as a means of incorporating modern learning theory into a classroom-ready, "pedagogically sound" inquiry cycle and has been used as an effective framework for teaching engineering-design-based lessons (Corday, Harris, & Klein, 2009). Alongside this, Klein and Harris (2007) provide a "user's guide" to implementing the Legacy Cycle successfully, complete with discussions of the challenges and corresponding suggested management strategies accompanying each step in the cycle.

Also important to consider is the contextualization of professional development in the larger school culture. Since what occurs in the classroom is subject to the demands of multiple factors (e.g., state standards, school-wide reforms, the needs of various student populations), effective professional development must be embedded in and informed by the cultures of school, district, and local community (Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet et al., 2001; Stiles, Loucks-Horsley, Mundry, & Hewson, 2009). Evidence also strongly emphasizes the importance of giving engineering educators multiple chances to reflect upon their own teaching practice and how it might be informed by their professional development experience. In fact, numerous studies have found that professional development activities that encourage teachers to consider thoughtfully how their knowledge might affect their teaching have an especially high chance of influencing teacher performance and student achievement (Cohen & Hill, 2001; Desimone et al., 2002; Knapp, 2003; McGill-Franzen, Allington, & Yokoi, 1999; Supovitz, Mayer, & Kahle, 2000; Weiss & Pasley, 2006).

Beyond offering practitioners the opportunity to reflect individually on their teaching, effective professional development also supports the evolution of teachers' engineering pedagogical skills by building community between participants and other teachers (Stiles et al., 2009) as well as between participants and scientists (Cantrell, Pekan, Itani, & Velasquez-Bryant, 2006; Custer & Daugherty, 2009; Klein, 2009; Nugent, Kunz, Rilett, & Jones, 2010). These relationships have been reported to deepen teachers' understanding of scientific inquiry and to improve their delivery of inquiry-based lessons (Caton, Brewer, & Brown, 2000; Klein-Gardner, Johnston, & Benson, 2012; Odom, 2001), as well as to provide a support structure for teachers who may find themselves at schools where no other teachers adhere to the same practices (Dresner & Worley, 2006). Some authors have noted that collaboration and collegiality can just as easily be harmful in some respects and have advocated for solitary autonomy in equal measure (Clement & Vandenberghe, 2000; Guskey, 2003); however, this is not so much an indictment as it is a reinforcement, since truly effective professional development should also foster autonomous individual experience and reflection both during and after the program.

Standard C: Professional Development for Teachers of Engineering should Make Clear How Engineering Design and Problem Solving Offer A Context for Teaching Standards of Learning in Science, Mathematics, Language Arts, Reading, and Other Subjects

In light of modern learning theory, which holds that learners are not 'blank slates' and that knowledge is constructed in reference to pre-existing ideas, beliefs, and conceptions, many education professionals advocate for integrated multidisciplinary instruction, especially in the STEM disciplines. With this in mind, addressing and harnessing the potential of engineering design to serve as a versatile and powerful platform from which to teach standards of learning in multiple subjects is a highly relevant endeavor.

Many studies have found engineering design challenges to be supportive of learning in science, resulting in improvement in student academic achievement (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Klein & Sherwood, 2005; Kolodner et al., 2003). For instance, Fortus and colleagues (2004, 2005) report enhanced student understanding of science concepts after participation in an engineering design-based science curriculum, as well as increased ability to transfer this understanding to different contexts. Furthermore, Klein and Sherwood (2005) report statistically higher gains in science learning by students who have participated in an engineering-oriented, challenge-based science curriculum. Findings such as these reify the importance of equipping teachers to use engineering design-based curricula to enhance student academic achievement and to strengthen students' ability to manipulate and transfer their own understandings.

Several articles cite the need for interdisciplinary curricula that integrate engineering with not only science, but also with mathematics, the humanities, and the arts (Carson & Chiu, 2011; English et al., 2013; Katehi & Ross, 2007). Indeed, collaboration between engineering students and students of other disciplines has been shown to enhance the abilities of both groups to solve engineering design challenges. For example, Costantino, Kellam, Cramond, and Crowder (2010) found that a majority of engineering students paired with art students considered collaboration beneficial to the project and to their own learning experience. In light of this, effective professional development for teachers of engineering should prepare participants to craft design challenges that encourage interdisciplinary collaboration.

Some literature places emphasis on the need for engineering education to be more than just a transfer of knowledge; 21st century skills such as creativity, communication, critical thinking, and collaboration are frequently cited as necessary to any modern engineering curriculum (Berland, 2013; Conwell, Catalano, & Beard, 1993; Petroski, 1992; Rugarcia, Felder, Woods, & Stice, 2000). With this in mind, it is imperative that professional development draw teachers' attention to the ways in which engineering design might reinforce these modern skills and practices in their students.

Standard D: Professional Development for Teachers of Engineering should Empower Teachers to Identify Appropriate Curriculum, Instructional Materials, and Assessment Methods

Effective teachers must be able to identify and evaluate appropriate curriculum, instructional materials, and assessment methods if they intend to incorporate ever-changing educational tools successfully into their practice. The need for this skill is ubiquitous in K-12 teaching, and applies to engineering as much as it does to other subjects. As such, its development should be an essential element of effective professional development for all teachers. In support of this, Timperley, Wilson, Barrar, and Fung (2008) claim that "to establish a firm foundation for improved student outcomes, teachers must integrate their knowledge about the curriculum, and about how to teach it effectively and how to assess whether students have learned it" (p. 11). Furthermore, research points to the need for teachers to teach in ways that are cognitively and developmentally appropriate for their students, and for instruction to be situated within a conceptual framework for students' learning patterns and processes (Wilson & Berne, 1999). Teacher participation in professional development programs that emphasize this knowledge has yielded increased teacher focus on problem solving and improved student performance (Carpenter, Fennema, Peterson, Chiang, & Loef, 1989; Fennema, Franke, Carpenter, & Carey, 1993). Additionally, many authors regard it as essential that professional development help teachers to select and design curricula that will adequately address various sets of learning standards; in fact, evidence indicates a positive correlation between the reported effectiveness of in-service professional development programs and their alignment with academic standards (Elmore & Burney, 1997; Fullan, 1993; Garet et al., 2001; Penuel et al., 2007; Rosenholtz, 1989).

While much of what is known about curriculum and assessment as a whole can be applied to the case of engineering in particular, the nature of engineering practices as distinct from scientific practices will require that teachers be able to distill and assess student thinking from outcomes of the engineering design process. In particular, Brophy et al. (2008) point out that teachers unfamiliar with engineering "must learn a level of engineering analysis to determine the quality of a student's solution" (p. 381), suggesting that it would be beneficial for engineering professional development to engage teachers in practicing the interpretation of unique, design-based student solutions in order to equip them for full utilization of the assessments embedded in an engineering design-based curriculum. Furthermore, Hjalmarson and Diefes-Dux (2008) and Diefes-Dux, Zawojewski, Hjalmarson, and Cardella (2012) propose frameworks for classifying and analyzing the tools K-12 teachers create for assessing student learning based on open-ended products in engineering design-based curricula. Teachers who are unfamiliar with this form of assessment should gain from practice using these frameworks for the design and use of evaluative assessment tools.

Standard E: Professional Development for Teachers of Engineering should be Aligned to Current Educational Research and Student Learning Standards

Current educational research presents a strong consensus surrounding teaching and learning, especially in adults, which may be applied to the design of professional development programs. In particular, Bransford, Brown, and Cocking's book How People Learn (2000) indicates four interdependent factors that characterize effective learning communities. The authors describe effective instruction as being knowledge-centered in that it is grounded in domain knowledge of the subject, learner-centered in that it is informed by the learners' context and current state of knowledge, assessment-centered in that it is shaped by continual and thoughtful assessment of student learning, and community-centered in that it facilitates the formation of a community committed to pursuing a particular body of knowledge. These factors provide a useful framework for thinking about professional development in general and certainly apply to programs for teachers of engineering. Such a framework has significant implications for both the design and the implementation of professional development programs.

Before professional development efforts are undertaken, their design should be informed by a How People Learn-inspired framework through collaboration with educational researchers and learning experts. Multiple studies cite the crucial role that collaboration plays in the planning and organization of an effective development program (Burden & Wallace, 1983; Borko, 2004; Desimone, Garet, Birman, Porter, & Yoon, 2003; Johnson, 2006; Little, 1993; Rosenholtz, 1989). This evidence points to the efficacy of including stakeholders, content experts and pedagogy experts in the planning and design of the professional development, and supports the conclusion that effective professional development is informed by a variety of relevant voices.

With regard to the design of professional development, the research suggests that several considerations should be taken into account. First, Darling-Hammond et al. (2009) write that it is "often useful for teachers to be put in the position of studying the very material that they intend to teach to their own students" (p. 44). Evidence indicates that this is important in STEM, and in engineering in particular (Caton et al., 2000; Jeanpierre, Oberhauser, & Freeman, 2005; Kennedy, 1999; Klein-Gardner et al., 2012; Odom, 2001). To this end, Donna (2012) suggests engaging participants in a cooperative engineering design activity "designed for adult learners…to provide an experience that can add to their content and pedagogical knowledge related to engineering design" (p. 2).

A knowledge-centered approach to teaching good engineering pedagogy should, naturally, exhibit good engineering pedagogy. The learner-centered aspect of effective instruction would require that the professional development "allow for differing kinds of background training and for variations in [participants'] readiness to learn" (Bransford et al., 2000, p. 204). Special care ought to be taken so as not to discomfort some teachers, who may be used to feeling like experts in control of their classrooms, by confronting them with the demanding reality that all teachers have much to learn, especially in light of the newness of engineering in state standards and the unfamiliarity of many teachers with its practice. On the other side of this, though, there is an advantage in the fact that "engineering design-based instruction can level the playing field for students with learning differences if teachers are prepared for the challenge" (Schnittka, 2012, p. 35). With this in mind, engineering professional development ought to—and has great potential to—offer differentiated instruction to account for its variegated participants (Custer & Daughterty, 2009).

In line with the assessment-centered nature of sound instruction, professional development should also be informed largely by formative assessments that would provide learners with opportunities to revise and improve upon their own understandings and provide facilitators with insight into otherwise invisible misconceptions and false beliefs. Such formative assessment, however, depends largely upon participants' willingness to take risks, make mistakes, and learn from failures. As is the case with all subjects, learning in engineering is built upon the ability—and willingness—to make and learn from mistakes. In light of this, and in adherence to the community-centered aspect of good instruction, effective engineering professional development should endeavor to create a culture of curiosity and vulnerability among its participants and should offer many opportunities for risk-taking.

Additional research characterizes effective professional development as prolonged and ongoing, allowing for continuous follow-up with and feedback from participants. This includes not only span of time (e.g., two days), but also time spent in the activity. Often, attempts at staff development in schools are conducted as single-serving workshops or one-shot teacher enrichment seminars; the research strongly indicts such half-hearted measures in favor of more longitudinal approaches (Stein, Smith, & Silver, 1999). In fact, in-service activities are most often viewed as effective by teachers when they are sustained over time (Cohen & Hill, 2001; Garet et al., 2001; Fullan, 1993). Effective professional development should provide ample time for practice, discussion, and reflection, and should ideally be spread out over a long period of time in order to accommodate trial and error in the classroom as well as feedback and follow-up from the participants (Guskey, 1986; 1994; Penuel et al., 2007; Supovitz & Turner, 2000). The impact of lengthening and intensifying a professional development program is not insubstantial: Yoon, Duncan, Lee, Scarloss and Shapley (2007) found that a set of programs, each taking place over a course of six to twelve months and offering at least thirty contact hours, showed "a positive and significant effect on student achievement" (p. 3). Some authors also encourage the establishment of a continual process of evaluation and revision in the planning process, based upon multiple avenues of feedback such as participant assessments and interviews and corresponding student achievement scores (Custer & Daugherty, 2009; Guskey, 2003).

Conclusion

The five standards presented above are drawn from current research in the areas of K-12, postsecondary, and adult and teacher education, and from research into effective teaching practices in the areas of science, mathematics, and engineering. This research indicates that effective professional development for teachers of engineering is conscious of, and promotes deepening of, both subject content knowledge and pedagogical content knowledge; that it instills in its participants an understanding of engineering as a natural context for the reinforcement of standards of learning in other, non-engineering subjects; that it empowers teachers to identify appropriate curriculum, instructional tools, and assessment methods; and that it models effective teaching methodology as described by current education research. These standards and their supporting matrix are intended to inform the design of future professional development efforts and, while not evaluative, may be used informally as a tool for describing and providing formative assessment of the content and characteristics of current professional development programs. It is the authors' hope that these standards will serve to inform the efforts of those who design and deliver professional development in support of teachers seeking to integrate engineering into K-12 classrooms across the nation. Future work may include analyses of the application and use of the standards and matrix to specific professional development offerings.

References

Berland, L. K. (2013). Designing for STEM integration. *Journal of Pre-College Engineering Education Research*, *3*(1), 3.

Blank, R. K., de las Alas, N., & Smith, C. (2007). Analysis of the quality of professional development programs for mathematics and science teachers: Findings from a cross-state study. Washington, DC: Council of Chief State School Officers. Retrieved February, 29, 2008.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher*, *33*(8), 3–15.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn*. Washington, DC: National Academy Press.

Brophy, S. B., Klein, S. S., Portsmore, M., & Rogers, S. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education*, *97*(3), 369–387.

Burden, P. R., & Wallace, D. (1983). Tailoring staff development to meet teachers' needs. Proceedings of Association of Teacher Educators Mid-America Mini-Clinic. Wichita, KS.

Cantrell, P., Pekcan, G., Itani, A., & Velasquez-Bryant, N. (2006). The effects of engineering modules on student learning in middle school science classrooms. *Journal of Engineering Education*, *95*(4), 301–309.

Carpenter, T. P., Fennema, E., Peterson, P. L., Chiang, C., & Loef, M. (1989). Using knowledge of children's mathematical thinking in classroom teaching: An experimental study. *American Educational Research Journal*, *26*, 499–532.

Carson, E., & Chiu, J. (2011). 'E' is for innovation—how does solving authentic engineering problems impact students' comprehension skills and application skills in mathematics and science? In, Koehler, M., & Mishra. P. (Eds.), Proceedings of Society for Information Technology & Teacher Education International Conference. Chesapeake, VA.

Caton, E., Brewer, C., & Brown, F. (2000). Building teacher-scientist partnerships: Teaching about energy through inquiry. *School Science and Mathematics*, *100*(1), 7–15.

Clement, M., & Vandenberghe, R. (2000). Teachers' professional development: A solitary or collegial (ad)venture? *Teaching and Teacher Education*, *16*(1), 81–101.

Cohen, D. K. (1990). A revolution in one classroom: The case of Mrs. Oublier. *Educational Evaluation and Policy Analysis*, *12*(3), 311–329.

Cohen, D. K., & Hill, H. C. (2001). *Learning policy: When state education reform works*. New Haven, CT: Yale University Press.

Conwell, J. C., Catalano, G. D., & Beard, J. E. (1993), A case study in creative problem solving in engineering design. *Journal of Engineering Education*, *82*, 227–231.

Corday, D. S., Harris, T. R., & Klein, S. S. (2009). A research synthesis of the effectiveness, replicability, and generality of the VaNTH Challenge-based instructional modules in bioengineering. *Journal of Engineering Education*, *98*(4), 335–348.

Costantino, T., Kellam, N., Cramond, B., & Crowder, I. (2010). An interdisciplinary design studio: How can art and engineering collaborate to increase students' creativity? *Art Education*, *63*(2), 49–53.

Custer, R. L., & Daugherty, J. L. (2009). Professional development for teachers of engineering: Research and related activities. *The Bridge*, *39*(3), 18–24.

Darling-Hammond, L., Wei, R. C., Andree, A., Richardson, N., & Orphanos, S. (2009). State of the profession: Study measures status of professional development. *Journal of Staff Development*, *30*(2), 42–44.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, *38*(3), 181–199.

Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational Evaluation and Policy Analysis*, *24*(2), 81–112.

Desimone, L. M., Garet, M. S., Birman, B. F., Porter, A. C., & Yoon, K. S. (2003). Improving teachers' in-service professional development in mathematics and science: The role of postsecondary institutions. *Educational Policy*, *17*(5), 613–649.

Diefes-Dux, H. A., Zawojewski, J. S., Hjalmarson, M. A., & Cardella, M. E. (2012). A framework for analyzing feedback in a formative assessment system for mathematical modeling problems. *Journal of Engineering Education*, *101*(2), 375–406.

Donna, J. D. (2012). A model for professional development to promote engineering design as an integrative pedagogy within STEM education. *Journal of Pre-College Engineering Education Research*, *2*(2), 2.

Dresner, M., & Worley, E. (2006). Teacher research experiences, partnerships with scientists, and teacher networks sustaining factors from professional development. *Journal of Science Teacher Education*, *17*(1), 1–14.

Elmore, R. F., & Burney, D. (1997). Investing in teacher learning: Staff development and instructional improvement in Community School District #2, New York City. National Commission on Teaching & America's Future, Box 117, Teachers College, Columbia University, New York, NY10027.

English, L. D., Hudson, P., & Dawes, L. (2013). Engineering-based problem solving in the middle school: Design and construction with simple machines. *Journal of Pre-College Engineering Education Research*, *3*(2), 5.

Fennema, E., Franke, M. L., Carpenter, T. P., & Carey, D. (1993). Using children's mathematical knowledge in instruction. *American Educational Research Journal*, *30*, 555–583.

Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching*, *41*(10), 1081–1110.

Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., & Mamlok-Naaman, R. (2005). Design-based science (DBS) and real-world problem-solving. *International Journal of Science Education*, *27*(7), 855–879.

Fullan, M. G. (1993). Why teachers must become change agents. *Educational Leadership*, *50*, 12–12.

Garet, M. S., Porter, A. C., & Desimone, L. M. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915–945.

Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Researcher*, *15*, 5–12.

Guskey, T. R. (1994). Results-oriented professional development: In search of an optimal mix of effective practices. *Journal of Staff Development*, *15*, 42–50.

Guskey, T. R. (2003). What makes professional development effective? *Phi Delta Kappan*, *84*(10), 748–750.

Hjalmarson, M. A., & Diefes-Dux, H. (2008). Teacher as designer: A framework for teacher analysis of mathematical model-eliciting activities. *Interdisciplinary Journal of Problem-based Learning*, *2*(1), 5.

Hsu, M.-C., Purzer, S., & Cardella, M. E. (2011). Elementary teachers' views about teaching design, engineering, and technology. *Journal of Pre-College Engineering Education Research*, *1*(2), 5.

Jeanpierre, B., Oberhauser, K., & Freeman, C. (2005). Characteristics of professional development that effect change in secondary science teachers' classroom practices. *Journal of Research in Science Teaching*, *42*(6), 668–690.

Johnson, C. C. (2006). Effective professional development and change in practice: Barriers science teachers encounter and implications for reform. *School Science and Mathematics*, *106*(3), 150–161.

Johnson, C. C., & Saylor, L. L. (2014). The role of reflection in elementary mathematics and science teachers' training and development: A meta-synthesis. *School Science and Mathematics*, *114*(1), 30–39.

Katehi, L., & Ross, M. (2007). Technology and culture: Exploring the creative instinct through cultural interpretations. *Journal of Engineering Education*, *96*(2), 89–90.

Kennedy, M. M. (1999). Form and substance in mathematics and science professional development. *NISE Brief*, *3*(2), n2.

Klein, S. S. (2009). Effective STEM professional development: A biomedical engineering RET site project. *International Journal of Engineering Education*, *25*(3), 523–533.

Klein, S. S., & Harris, A. H. (2007). A user's guide for the Legacy Cycle. *Journal of Education and Human Development*, *1*(1), 1–16.

Klein, S. S., & Sherwood, R. D. Biomedical engineering and your high school science classroom: Challenge-based curriculum that meets the NSES standards. In Yager, R. E., ed., *Exemplary Science in Grades 9–12*. Standards-based Success Stories. Arlington, VA: NSTA Press, 2005.

Klein-Gardner, S. S., Johnston, M. E., & Benson, L. (2012). Impact of RET teacher-developed curriculum units on classroom experiences for teachers and students. *Journal of Pre-College Engineering Education Research*, *2*(2), 21–35.

Knapp, M. S. (2003). Professional development as policy pathway. *Review of Research in Education*, *27*(1), 109–157.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design (tm) into practice. *Journal of the Learning Sciences*, *12*(4), 495–547.

Little, J. W. (1993). Teachers' professional development in a climate of educational reform. *Educational Evaluation and Policy Analysis*, *15*(2), 129–151.

McGill-Franzen, A., Allington, R. L., &Yokoi, L. (1999). Putting books in the classroom seems necessary but not sufficient. *Journal of Educational Research*, *93*(2), 67–74.

Moore, T. J., Glancy, A. W., Tank, K. M., Kersten, J. A., Smith, K. A., & Stohlmann, M. S. (2014). A framework for quality K-12 engineering education: Research and development. *Journal of Pre-College Engineering Education Research*, *4*(1), 2.

Narode, R. B. (2011). "Math in a can": Teaching mathematics and engineering design. *Journal of Pre-College Engineering Education Research*, *1*(2), 3.

Nugent, G., Kunz, G., Rilett, L., & Jones, E. (2010). Extending engineering education to K-12. *Technology Teacher*, *69*(7), 14–19.

Odom, A. L. (2001). Inquiry-based field studies involving teacher-scientist collaboration. *Science Educator*, *10*(1), 29–37.

Penuel, W. R., Fishman, B. J., Yamaguchi, R., & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, *44*(4), 921–958.

Petroski, H. (1992) *To engineer is human: The role of failure in successful design*. New York, NY: Vintage Books.

Rogers, M. P., Abell, S., & Lannin, J. (2007). Effective professional development in science and mathematics education: Teachers' and facilitators' views. *International Journal of Science & Mathematics Education*, *5*(3), 507–532.

Rosenholtz, S. J. (1989). Workplace conditions that affect teacher quality and commitment: Implications for teacher induction programs. *Elementary School Journal*, *89*(4), 420–439.

Rugarcia, A., Felder, R. M., Woods, D. R., & Stice, J. E. (2000). The future of engineering education I. A vision for a new century. *Chemical Engineering Education*, *34*(1), 16–25.

Schnittka, C. G. (2012). Engineering education in the science classroom: A case study of one teacher's disparate approach with ability-tracked classrooms. *Journal of Pre-College Engineering Education Research*, *2*(1), 5.

Schwartz, D. L., Brophy, S., Lin, X., & Bransford, J. D. (1999). Software for managing complex learning: Examples from an educational psychology course. *Educational Technology Research and Development*, *47*(2), 39–59.

Sheehy, G. (1976). *Passages: Predictable crises of adult life*. New York, NY: Dutton.

Stein, M. K., Smith, M. S., & Silver, E. A. (1999). The development of professional developers: Learning to assist teachers in new settings in new ways. *Harvard Educational Review*, *69*(3), 237–269.

Stiles, K. E., Loucks-Horsley, S., Mundry, S., & Hewson, P. W. (Eds.). (2009). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin Press.

Supovitz, J. A., & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching*, *37*(9), 963–980.

Supovitz, J. A., Mayer, D. P., & Kahle, J. B. (2000). Promoting inquiry-based instructional practice: The longitudinal impact of professional development in the context of systemic reform. *Educational Policy*, *14*(3), 331–356.

Thompson, C. L., & Zeuli, J. S. (1999). The frame and the tapestry: Standards-based reform and professional development. In Darling-Hammond, L. & Sykes, G. (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp. 341–375). San Francisco, CA: Jossey-Bass.

Timperley, H., Wilson, A., Barrar, H., & Fung, I. (2008). Teacher professional learning and development. International Academy of Education Working Paper, International Academy of Education, London. Educational Practices Series 18.

Weiss, I. R., & Pasley, J. D. (2006). Scaling up instructional improvement through teacher professional development: Insights from the Local Systemic Change Initiative. CPRE Policy Briefs. RB-44. Consortium for Policy Research in Education.

Wilson, S. M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. *Review of Research in Education*, *24*(1), 173–209.

Yoon, K. S., Duncan, T., Lee, S. W. Y., Scarloss, B., & Shapley, K. L. (2007). *Reviewing the evidence on how teacher professional development affects student achievement*. National Center for Educational Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education.

Appendix A: Standards for Preparation and Professional Development for Teachers of Engineering

This document is intended to provide a comprehensive description of the professional preparation and development required to fully prepare teachers of engineering[1]. A preservice teacher preparation program should address all aspects of all standards over a student's four-year course of study. By contrast, a one-day professional development opportunity for in-service teachers should focus deliberately on a subset of the standards (while aligning with complementary opportunities so that teachers receive, over time, professional development that addresses all aspects of all standards).

Nature, Content, and Practices of Engineering

Engineering is based on extensive bodies of knowledge. It is a unique disciplinary field, yet shares some features with science, technology, and mathematics. Engineering literacy requires understanding the fundamental nature, content, and practices of engineering, which may be organized into three categories.

Literacy in the category of **engineering design (ED)** requires an understanding that engineering:

1. Is inherently innovative and creative;
2. Requires critical thinking and problem solving;
3. Is collaborative and team-oriented;
4. Involves solving problems via an engineering design process (e.g., involving design under constraints, iterative design, optimization, improvement);
5. Requires the combination of engineering subject matter knowledge with engineering practices;
6. Involves systems thinking (e.g., considering solutions as they are a part of larger systems);
7. Uses failure as a learning experience (e.g., when designed solutions fail, engineers learn from this failure and improve based on this new knowledge);
8. Addresses problems that have multiple possible solutions; and
9. Involves multiple means of communicating outcomes (e.g., technical reports, graphs, data, models, recommendations).

Literacy in the category of **engineering careers (EC)** requires an understanding that:

10. Engineering includes multiple areas of specialization (e.g., mechanical, electrical, petroleum, civil, biomedical, aerospace, environmental, industrial); and
11. Engineering career pathways are accessible via a variety of educational routes.

Literacy in the category of **engineering and society (ES)** requires an understanding that engineering:

12. Has a long and rich history;
13. Is relevant to current events;
14. Generates technological solutions that add value to society, yet may also have negative (and largely unintended) consequences for society; and
15. Is influenced by cultures and societies.

Standards for Professional Development for Teachers of Engineering

The following standards are intended to ensure that teachers develop engineering literacy (as defined above) sufficient to teach engineering to their students at the appropriate level.

Standard A: Engineering Content and Practices

Professional development for teachers of engineering should address the fundamental nature, content, and practices of engineering as defined above. To promote literacy in the category of **engineering design**, it should:

1. Engage teams of participants in authentic engineering practices and processes (i.e., participating in the engineering design process as initiated by a design challenge statement, through at least one improvement cycle, and involving communication of results);
2. Introduce participants to tools that enable success in engineering; such tools include engineering notebooks, simple tools (e.g., rulers) and more sophisticated technologies (e.g., computer probeware and software, digital multimeters);
3. Introduce participants to strategies that enable success in engineering; key strategies include engaging in teams, asking questions, communication about design, and carefully documenting work;
4. Encourage participants to reflect on multiple experiences with the engineering design process, whether these have occurred within or outside the context of the current professional development opportunity, to reinforce learning about engineering content and practices; and
5. Enable participants to compare design in engineering to design in other fields (e.g., fashion, architecture, art).

To promote literacy in the category of **engineering careers**, such professional development should:

6. Provide opportunities for participants to learn about engineering fields and professions;

[1] Teachers of engineering are all teachers who (1) are required to teach engineering learning standards (note that under the Next Generation Science Standards this includes all elementary school teachers and secondary teachers of science) or (2) employ engineering as a context for learning in other subjects.

http://dx.doi.org/10.7771/2157-9288.1107

7. Engage participants in comparing engineering with non-engineering content areas (e.g., mathematics, science, social studies, English language arts, the arts, technology education);
8. Engage participants in comparing classroom-based engineering experiences with professional engineering practice; and
9. Provide opportunities for educators to learn about the pre-collegiate and collegiate academic preparation required for engineering careers.

To promote literacy in the category of **engineering and society**, such professional development should:

10. Provide opportunities for participants to explore the work of engineers and their contributions to society, as well as ways in which some engineered solutions have caused societal challenges.

Standard B: Pedagogical Content Knowledge for Teaching Engineering

Professional development for teachers of engineering should emphasize engineering pedagogical content knowledge. It should:

1. Engage participants in exploring teaching and learning in engineering and how it is similar to, and different from, teaching and learning in science and/or mathematics;
2. Introduce participants to effective classroom management strategies for enabling learning in engineering;
3. Foster participants' ability to develop design challenges that are appropriate for their student population, teaching environments, and/or local community;
4. Facilitate participants' reflection upon their own teaching practice and encourage participants to seek feedback from others to refine and optimize their engineering teaching practice; and
5. Promote and support participants' engagement with engineering mentors who can, in turn, support participants' teaching of engineering through a variety of approaches (e.g., field experiences, field trips, internships, collaborations, classroom visits).

Standard C: Engineering as a Context for Teaching and Learning

Professional development for teachers of engineering should make clear how engineering design and problem solving offer a context for teaching standards of learning in science, mathematics, language arts, reading, and other subjects. It should:

1. Enable participants to explore research that demonstrates how using engineering design and problem solving as a context for learning improves students' critical thinking skills and academic achievement;
2. Engage participants in engineering design challenges that require horizontal integration with non-engineering content (e.g., mathematics, science, social studies, English language arts, the arts, technology education);
3. Draw attention to the way in which engineering design and problem solving reinforce skills (e.g., 21st century skills such as creativity, communication, critical thinking, and collaboration) and practices (e.g., modeling, data analysis, and presentation) that are relevant to many fields; and
4. Encourage participants to integrate engineering into the existing curriculum.

Standard D: Curriculum and Assessment

Professional development for teachers of engineering should empower teachers to identify appropriate curricula, instructional materials, and assessment methods. It should:

1. Enable participants to identify engineering curriculum that is developmentally, instructionally, and cognitively appropriate for their students;
2. Engage participants in evaluating the potential of engineering curriculum to address one or more sets of student learning standards (e.g., ITEEA learning standards, Next Generation Science Standards, state standards);
3. Engage participants in evaluating the potential of engineering curriculum to support a particular set of engineering learning objectives;
4. Engage participants in evaluating the adaptability of engineering curriculum to local conditions (e.g., scheduling/timing, emphasis on content/methods, cultural context, similarity to other activities in an existing curriculum);
5. Engage participants in evaluating the available teacher support for a particular engineering curriculum;
6. Engage participants in examining the authenticity and appropriateness of formative and summative assessments embedded in a curriculum; and
7. Demonstrate connections and alignment between engineering curriculum, instruction, learning, and assessment.

Standard E: Alignment to Research, Standards, and Educational Practices

Professional development for teachers of engineering should be aligned to current educational research and student learning standards. It should:

1. Be developed and refined in collaboration with experts in the fields of engineering, engineering pedagogy, and teacher professional development;
2. Be developed and refined in collaboration with stakeholders (e.g., state education agency personnel, school administrators, teachers);
3. Enable participants to experience the curriculum that they will teach;
4. Model effective engineering teaching practices;
5. Employ differentiated instruction techniques;
6. Be guided by formative assessment;
7. Encourage risk-taking by participants;
8. Be longitudinal; and
9. Evolve through a process of continuous improvement that employs ongoing evaluation, assessment, and revision.

Appendix B: Professional Development Matrix

Standard A: Engineering Content and Practices: Professional development for teachers of engineering should address the fundamental nature, content and practices of engineering as defined in *Standards for Preparation and Professional Development for Teachers of Engineering.*

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
To promote literacy in the category of **engineering design**, such professional development should:					
Engage teams of participants in authentic engineering practices and processes (i.e., participating in the engineering design process as initiated by a design challenge statement, through at least one improvement cycle, and involving communication of results);	Participants have the opportunity to complete multiple design challenges as initiated by design challenge statements.	Participants have one opportunity to complete a design process as initiated by a design challenge statement.	Participants have the opportunity to perform multiple steps of a design process as initiated by a design challenge statement; the remaining steps are considered but not performed by the participants.	Participants do not have the opportunity to perform multiple steps of a design process as initiated by a design challenge statement.	A1-1
	Participants engage in a facilitated process to develop a clear and concise problem statement for a given design challenge.	Participants engage in design challenges that are guided by explicit, clear and concise problem statements.	Participants engage in design challenges that are guided by implicit problem statements, but no explicit, clear and concise problem statements are provided.	Design challenges are not guided by clear implicit or explicit problem statements.	A1-2
	Participants engage in one or more design challenges that reflect authentic local or global engineering needs, and analyze the usefulness of the engineering design process to address such challenges.	Participants consider the usefulness of the engineering design process in addressing authentic local or global engineering challenges.	Participants are presented with information about the usefulness of the engineering design process in addressing authentic local or global engineering challenges.	No attention is paid to the usefulness of the engineering design process in addressing authentic local or global engineering challenges.	A1-3
	Participants engage in, and reflect on the importance of, iteration in engineering design. Participants prototype a solution, test the solution, analyze the results, generate redesign ideas, and create a new prototype. Participants may complete further cycles of improvement, or simply consider the role of such cycles in engineering.	Participants prototype a solution and consider the process that they would undertake to iterate the solution, but do not complete the iterative cycle.	Participants are informed of the role of iteration in engineering design. Prototyping, testing and redesign are described for participants.	No explicit attention is paid to the role of iteration in engineering design.	A1-4
	Participants engage in documenting, reflecting on, and discussing the key steps of the engineering design process each time the process is undertaken.	Participants engage in documenting, reflecting, and discussing the key steps of the engineering design process at least once.	Participants engage in one of the following at least once: documenting, reflecting, or discussing the key steps of the engineering design process.	Participants do not engage in an explicit discussion of or reflection on the engineering design process.	A1-5
	Participants document and communicate engineering design solutions to peers or facilitators of the professional development and identify how they would modify this communication for presentation to a client.	Participants document and communicate engineering design solutions to peers or facilitators of the professional development.	Participants document engineering design solutions but do not communicate solutions to peers or facilitators of the professional development.	Participants do not document engineering design solutions.	A1-6

Standard A
(Continued)

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
Introduce participants to tools that enable success in engineering; such tools include engineering notebooks, simple tools (e.g., rulers) and more sophisticated technologies (e.g., computer probeware and software, digital multimeters);	Participants use tools that enable success in engineering and reflect on why these tools are important to engineers.	Participants use tools that enable success in engineering and are told why these tools are important to engineers.	Participants use tools that enable success in engineering and are told that these tools are important to engineers.	While they may use some tools, participants are not engaged in evaluating whether and why such tools might enable success in engineering.	A2-1
Introduce participants to strategies that enable success in engineering; key strategies include engaging in teams, asking questions, communication about design, and carefully documenting work;	Participants use appropriate strategies to support the engineering design process and reflect on why these strategies are important to engineers.	Participants use strategies that enable success in engineering and are told why these strategies are important to engineers.	Participants use strategies that enable success in engineering and are told that these strategies are important to engineers.	While they may use some strategies, participants are not engaged in evaluating whether and why such strategies might enable success in engineering.	A3-1
Encourage participants to reflect on multiple experiences with the engineering design process, whether these have occurred within or outside the context of the current professional development opportunity, to reinforce learning about engineering content and practices; and	Participants articulate multiple experiences with the engineering design process, whether these have occurred within or outside the context of the current professional development opportunity, and analyze how the engineering design process enabled an understanding of the Nature, Content and Practices of Engineering.	Participants articulate a single experience with the engineering design process, whether this has occurred within or outside the context of the current professional development opportunity, and analyze how the engineering design process enabled an understanding of the Nature, Content and Practices of Engineering.	Participants are given an example of how a particular experience with the engineering design process might enable an understanding of the Nature, Content and Practices of Engineering.	No attention is paid to how the engineering design process might enable understanding of the Nature, Content and Practices of Engineering.	A4-1
Enable participants to compare design in engineering to design in other fields (e.g., fashion, architecture, art).	Participants are given opportunities to reflect on their prior knowledge of the meanings of the word “design”; to attend explicitly to the different meanings of the word “design” as used in everyday language and by different fields; and to compare the engineering design process to other conceptions of “design”.	Participants reflect on how the engineering design process is an example of a broader conception of design, without comparing engineering design to other ways that “design” may be conceived.	Participants are presented with information about how the engineering design process is an example of a broader conception of design, without comparing engineering design to other ways that “design” may be conceived.	No explicit attention is paid to the engineering design process as an example of a broader conception of design.	A5-1

Standard A
(Continued)

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
To promote literacy in the category of **engineering careers**, such professional development should:					
Provide opportunities for participants to learn about engineering fields and professions;	Participants research and reflect on multiple engineering fields and professions.	Participants receive information about multiple engineering fields and professions.	Participants receive information about one engineering field and profession.	Participants receive no information about engineering fields and professions. Rather, engineering is described a single general professional field.	A6-1
	Participants identify the types of engineers who would work on a team addressing a particular design challenge in a professional setting. Participants research the represented fields (i.e., professions, projects research areas) on which such engineers currently work.	Participants identify the types of engineers who would work on a team addressing a particular design challenge in a professional setting.	Participants are informed of the types of engineers who would work on a team addressing a particular design challenge in a professional setting.	No attention is paid to the types of engineers who would work on a team addressing a particular design challenge in a professional setting.	A6-2
	Participants identify the roles and responsibilities of different engineers who would work on a team addressing a particular design challenge in a professional setting. For at least one role/responsibility, participants research other engineering professions in which such roles are available.	Participants identify the roles and responsibilities of different engineers who would work on a team addressing a particular design challenge in a professional setting.	Participants receive information about the roles and responsibilities of different engineers who would work on a team addressing a particular design challenge in a professional setting.	No attention is paid to the roles and responsibilities of different engineers who would work on a team addressing a particular design challenge in a professional setting.	A6-3
Engage participants in comparing engineering with non-engineering content areas (e.g., mathematics, science, social studies, English language arts, the arts, technology education);	For a particular engineering design challenge or activity, participants analyze connections between the engineering and non-engineering content. This analysis highlights both the unique nature of engineering and how the engineering content overlaps with, utilizes, or supports the non-engineering content.	For a particular engineering design challenge or activity, participants receive information about the connections between the engineering and non-engineering content. This information highlights both the unique nature of engineering and how the engineering content overlaps with, utilizes, or supports the non-engineering content.	Participants reflect on and/or receive general information about connections between engineering and non-engineering content.	No attention is paid to the connections between engineering and non-engineering content.	A7-1

Standard A
(Continued)

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
Engage participants in comparing classroom-based engineering experiences with professional engineering practice; and	In reference to a particular engineering design challenge or activity, participants analyze how the activity has been simplified for classroom use and compare this simplification with the complexity of similar activities that might be undertaken by professional engineers. This necessitates interaction with practicing engineers if the participants do not have engineering experience of their own.	In reference to a particular engineering design challenge or activity, participants receive information about how the activity has been simplified for classroom use. This information includes comparison of this simplification with the complexity of similar activities that might be undertaken by professional engineers.	Participants engage in a general discussion and/or receive general information about the simplified nature of engineering activities as adapted for classroom use.	No explicit attention is paid to the ways in which engineering design challenges or activities designed for classroom use represent simplified versions of similar activities that might be undertaken by professional engineers.	A8-1
Provide opportunities for educators to learn about the pre-collegiate and collegiate academic preparation required for engineering careers.	Participants consider pathways for multiple careers/jobs in engineering, including high school internships, technical certifications, two-year degrees, and four-year degrees.	Participants consider the pre-collegiate and collegiate academic preparation required for limited pathways to engineering careers (e.g., only formal two- or four-year engineering programs).	Participants consider the pre-collegiate and collegiate academic preparation required for only one pathway to engineering careers (e.g., a four-year engineering program).	Participants do not consider the pre-collegiate and collegiate academic preparation required for engineering careers.	A9-1
	Participants research and reflect on engineering career pathways and the connections between these pathways. The importance of multiple pathways is considered in the context of the labor market and student engagement.	Participants research and reflect on engineering career pathways.	Participants receive information about engineering career pathways.	Participants do not consider engineering career pathways.	A9-2
To promote literacy in the category of **engineering and society**, such professional development should:					
Provide opportunities for participants to explore the work of engineers and their contributions to society, as well as ways in which some engineered solutions have caused societal challenges.	Participants research and reflect on how engineers have contributed to society.	Participants reflect on how engineers have contributed to society.	Participants receive information about how engineers have contributed to society.	Participants do not consider how engineers have contributed to society.	A10-1
	Participants research and reflect on how engineered solutions have been, or might be, problematic. This reflection could include an examination of the nature of the problem, how the engineers behind the solution might have anticipated and avoided the problem, and how engineers working today might mitigate the problem.	Participants reflect on how engineered solutions have been, or might be, problematic. This reflection could include an examination of the nature of the problem, how the engineers behind the solution might have anticipated and avoided the problem, and how engineers working today might mitigate the problem.	Participants receive examples of engineered solutions that have been, or might be, problematic.	Participants do not consider how engineered solutions have been, or might be, problematic.	A10-2

Standard B: Pedagogical Content Knowledge for Teaching Engineering: Professional development for teachers of engineering should emphasize engineering pedagogical content knowledge. It should:

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
Engage participants in exploring teaching and learning in engineering and how it is similar to, and different from, teaching and learning in science and/or mathematics;	Participants engage in (or recall past engagement in) activities involving the teaching and learning of engineering and science and/or mathematics, drawing on these experiences to reflect on the similarities and differences between teaching and learning in these fields.	Participants receive information about the similarities and differences between science and/or mathematics teaching and learning and engineering teaching and learning. Participants receive examples to illustrate these similarities and differences. Participants reflect on the provided information and illustrations.	Participants receive information about the similarities and differences between science and/or mathematics teaching and learning and engineering teaching and learning. Participants receive examples to illustrate these similarities and differences.	Participants do not consider explicitly the similarities and differences between science and/or mathematics teaching and learning and engineering teaching and learning.	B1-1
Introduce participants to effective classroom management strategies for enabling learning in engineering;	Participants research effective classroom management strategies for enabling learning in engineering, identify multiple strategies to address common challenges in engineering education (e.g., teaming strategies, materials management, project storage), and analyze these strategies to determine which will be most effective in their own classrooms.	Participants consider information about classroom management strategies that address common challenges in engineering education. Participants analyze this information in light of their own experiences to determine which will be most effective in their own classrooms.	Participants consider information about classroom management strategies that address common challenges in engineering education.	Participants do not consider classroom management strategies that address common challenges in engineering education.	B2-1
Foster participants' ability to develop design challenges that are appropriate for their student population, teaching environments, and/or local community;	Participants develop, pilot and refine a new design challenge—or adapt an existing design challenge—so that the result is appropriate for their student population, teaching environments and/or local community.	Participants develop a new design challenge—or adapt an existing design challenge—so that the result is appropriate for their student population, teaching environments and/or local community.	Participants consider how they would develop a new design challenge—or adapt an existing design challenge—so that the result is appropriate for their student population, teaching environments and/or local community.	Participants do not consider how they would develop or adapt design challenges to make them appropriate for their student population, teaching environments, and/or local community.	B3-1
	Participants consider and reflect on the demands and benefits of developing and employing a design challenge that is appropriate for their student population, teaching environment and/or local community. Participants develop and implement a plan for addressing and overcoming the identified demands.	Participants consider and reflect on the demands and benefits of developing and employing a design challenge that is appropriate for their student population, teaching environment and/or local community. Participants develop a plan for addressing and overcoming the identified demands.	Participants consider the demands and benefits of developing and employing a design challenge that is appropriate for their student population, teaching environment and/or local community.	Participants do not consider the demands and benefits of developing and employing a design challenge that is appropriate for their student population, teaching environments and/or local community.	B3-2

Standard B
(Continued)

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
Facilitate participants' reflection upon their own teaching practice and encourage participants to seek feedback from others to refine and optimize their engineering teaching practice; and	Participants engage in multiple opportunities to reflect on their engineering teaching practice. This reflection draws on all of the following: experiences (e.g., instructional interactions, prior learning), evidence (e.g., formative assessments), and artifacts (e.g., lesson plans, worksheets, assessments, student work) collected in their classrooms.	Participants engage in multiple opportunities to reflect on their engineering teaching practice, This reflection draws on some of the following: experiences (e.g., instructional interactions, prior learning), evidence (e.g., formative assessments), and artifacts (e.g., lesson plans, worksheets, assessments, student work) collected in their classrooms.	Participants engage in a single reflection on their engineering teaching practice that draws on some or all of the following: experiences (e.g., instructional interactions, prior learning), evidence (e.g., formative assessments), and artifacts (e.g., lesson plans, worksheets, assessments, student work) collected in their classrooms.	Participants do not engage in reflection on their engineering teaching practice that draws on experiences (e.g., instructional interactions, prior learning), evidence (e.g., formative assessments), or artifacts (e.g., lesson plans, worksheets, assessments, student work) collected in their classrooms.	B4-1
	Participants form or join a learning community, or recruit a mentor or coach, to obtain feedback about their teaching practice.	Participants identify opportunities to form or join a learning community, or to recruit a mentor or coach, to obtain feedback about their teaching practice.	Participants receive information about the benefits of forming or joining a learning community, or recruiting a mentor or coach, to obtain feedback about their teaching practice.	Participants do not receive information about the benefits of forming or joining a learning community, or recruiting a mentor or coach, to obtain feedback about their teaching practice.	B4-2
	Participants consider and reflect on the elements of their practice that are essential to effective teaching of engineering, set goals for improving their practice, and develop and implement a plan for achieving those goals.	Participants consider and reflect on the elements of their practice that are essential to effective teaching of engineering, set goals for improving their practice, and develop a plan for achieving those goals.	Participants consider the elements of their practice that are essential to effective teaching of engineering. Participants identify opportunities for improvement.	Participants do not consider the elements of their practice that are essential to effective teaching of engineering.	B4-3
	Participants research approaches to mentoring (e.g., in-school mentoring, informal collaborations, professional learning communities, online programs, partnerships with industry, internships, research experiences). Participants analyze these approaches to identify which would be of greatest benefit to their implementation efforts and why.	Participants receive information about approaches to mentoring (e.g., in-school mentoring, informal collaborations, professional learning communities, online programs, partnerships with industry, internships, research experiences) and how these might support implementation. Participants analyze the provided information to identify the approaches that would best support their implementation efforts.	Participants receive information about approaches to mentoring (e.g., in-school mentoring, informal collaborations, professional learning communities, online programs, partnerships with industry, internships, research experiences) and how these might support implementation.	Participants do not receive information about approaches to mentoring (e.g., in-school mentoring, informal collaborations, professional learning communities, online programs, partnerships with industry, internships, research experiences) and how these might support implementation.	B4-4
Promote and support participants' engagement with engineering mentors who can, in turn, support participants' teaching of engineering through a variety of approaches (e.g., field experiences, field trips, internships, collaborations, classroom visits).	Participants develop and implement a plan to engage mentors with expertise in engineering for support during classroom implementation.	Participants develop a plan to engage mentors with expertise in engineering for support during classroom implementation.	Participants consider sources from which they might elicit mentors with expertise in engineering to support them during classroom implementation.	Participants do not consider sources from which they might elicit mentors with expertise in engineering to support them during classroom implementation.	B5-1

Standard C: Engineering as a Context for Teaching and Learning: Professional development for teachers of engineering should make clear how engineering design and problem solving offer a context for teaching standards of learning in science, mathematics, language arts, reading, and other subjects. It should:

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
Enable participants to explore research that demonstrates how using engineering design and problem solving as a context for learning improves students' critical thinking skills and academic achievement;	Participants research and synthesize multiple studies linking engineering design and problem solving with improved student academic achievement and critical thinking skills.	Participants receive evidence linking engineering design and problem solving with improved student academic achievement and critical thinking skills. Participants reflect on this evidence.	Participants receive evidence linking engineering design and problem solving with improved student academic achievement and critical thinking skills.	Participants do not receive evidence linking engineering design and problem solving with improved student academic achievement and critical thinking skills.	C1-1
Engage participants in engineering design challenges that require horizontal integration with non-engineering content (e.g., mathematics, science, social studies, English language arts, the arts, technology education);	For one or more engineering design challenges, participants analyze and map connections to non-engineering content involved in the challenge. Participants identify which non-engineering content is required for successful completion of the challenge, and which is useful as extensions to the challenge.	For one or more engineering design challenges, participants analyze and map connections to non-engineering content involved in the challenge.	For one or more engineering design challenges, participants receive information about the connections to non-engineering content involved in the challenge.	Participants do not experience explicit opportunities for horizontal integration of engineering and non-engineering content.	C2-1
Draw attention to the way in which engineering design and problem solving reinforce skills (e.g., 21st century skills such as creativity, communication, critical thinking, and collaboration) and practices (e.g., modeling, data analysis, and presentation) that are relevant to many fields; and	For one or more engineering design challenges, participants analyze and map connections to skills (e.g., 21st century skills such as creativity, communication, critical thinking, and collaboration) and practices (e.g., modeling, data analysis, and presentation) that are relevant to many fields.	For one or more engineering design challenges, participants are presented with evidence of connections to skills (e.g., 21st century skills such as creativity, communication, critical thinking, and collaboration) and practices (e.g., modeling, data analysis, and presentation) that are relevant to many fields. Participants reflect on this evidence.	For one or more engineering design challenges, participants are presented with evidence of connections to skills (e.g., 21st century skills such as creativity, communication, critical thinking, and collaboration) and practices (e.g., modeling, data analysis, and presentation) that are relevant to many fields.	Participants do not experience explicit opportunities to connect engineering design to skills (e.g., 21st century skills such as creativity, communication, critical thinking, and collaboration) and practices (e.g., modeling, data analysis, and presentation) that are relevant to many fields.	C3-1
Encourage participants to integrate engineering into the existing curriculum.	Participants revise at least one unit of their existing curriculum to include engineering. Participants then reflect on how the curriculum is enhanced through the addition of engineering.	Participants are given examples of how other teachers have incorporated engineering into their existing curriculum. Participants analyze these examples and identify specific opportunities integrate engineering into their curricula.	Participants are given examples of how other teachers have incorporated engineering into their existing curriculum. Participants consider how they might similarly integrate engineering into their curricula.	Participants do not address the incorporation of engineering into their existing curriculum.	C4-1

Standard D: Curriculum and Assessment: Professional development for teachers of engineering should empower teachers to identify appropriate curriculum, instructional materials, and assessment methods. It should:

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
Enable participants to identify engineering curriculum that is developmentally, instructionally, and cognitively appropriate for their students;	Participants analyze and provide evidence of the developmental, instructional, and cognitive appropriateness of a curriculum for a particular student population.	Participants receive evidence of the developmental, instructional, and cognitive appropriateness of a curriculum for a particular student population. Participants reflect on the provided evidence.	Participants receive evidence of the developmental, instructional and cognitive appropriateness of a curriculum for a particular student population.	Participants do not consider the developmental, instructional and cognitive appropriateness of a curriculum for a particular student population.	D1-1
	Participants fully develop modifications to improve the developmental, instructional, and cognitive appropriateness of curricular materials.	Participants identify modifications that would improve the developmental, instructional, and cognitive appropriateness of curricular materials.	Participants consider whether modifications might improve the developmental, instructional and cognitive appropriateness of curricular materials.	Participants do not consider whether modifications might improve the developmental, instructional and cognitive appropriateness of curricular materials.	D1-2
Engage participants in evaluating the potential of engineering curriculum to address one or more sets of student learning standards (e.g., ITEEA learning standards, Next Generation Science Standards, state standards);	Participants analyze and provide evidence of how curriculum aligns with one or more sets of student learning standards.	Participants receive evidence of how a given curriculum aligns with one or more sets of student learning standards. Participants reflect on the provided evidence.	Participants receive evidence of how a given curriculum aligns with one or more sets of student learning standards.	Participants do not consider the alignment of curriculum with any particular set of student learning standards.	D2-1
	If the curriculum requires curricular extensions to increase alignment with student learning standards, participants develop such extensions.	If the curriculum requires curricular extensions to increase alignment with student learning standards, participants identify opportunities to develop such extensions.	Participants consider whether curricular extensions might increase alignment with student learning standards.	Participants do not consider whether curricular extensions might increase alignment with student learning standards.	D2-2
Engage participants in evaluating the potential of engineering curriculum to support a particular set of engineering learning objectives;	Participants receive information about the engineering learning objectives for each activity. Participants analyze the curricular materials to determine the extent to which these materials are necessary and sufficient to support the stated learning objectives.	Participants receive information about the engineering learning objectives for each activity, as well as evidence of the extent to which the curricular materials are necessary and sufficient to support these objectives. Participants reflect on the provided evidence.	Participants receive information about the engineering learning objectives for each activity, as well as evidence of the extent to which the curricular materials are necessary and sufficient to support these objectives.	Participants do not consider the engineering learning objectives for each activity.	D3-1
	If the curriculum requires curricular extensions to better support the stated engineering learning objectives, participants develop such extensions.	If the curriculum requires curricular extensions to better support the stated engineering learning objectives, participants identify opportunities to develop such extensions.	Participants consider whether curricular extensions might be developed to better support the stated engineering learning objective.	Participants do not consider whether curricular extensions might better support the stated engineering learning objectives.	D3-2
Engage participants in evaluating the adaptability of engineering curriculum to local conditions (e.g., scheduling/timing, emphasis on content/methods, cultural context, similarity to other activities in an existing curriculum);	Participants analyze a particular curriculum to identify opportunities for adaptation to address local conditions. Participants adapt one or more components of the curriculum to address these conditions.	Participants are given examples of how other teachers have adapted a particular curriculum to address local conditions. Participants analyze these examples and identify ways in which they might similarly adapt a particular curriculum to address local conditions.	Participants consider the importance of adapting materials to address local conditions and are given examples of how other teachers have adapted a particular curriculum to address local conditions.	Participants do not consider the importance of adapting materials to address local conditions.	D4-1

Standard D
(Continued)

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
Engage participants in evaluating the available teacher support for a particular engineering curriculum;	Participants receive research-based information about what constitutes good teacher support. Participants analyze the teacher support provided with a curriculum to determine the extent to which it is necessary and sufficient for its successful implementation.	Participants receive research-based information about what constitutes good teacher support, as well as evidence of the extent to which the teacher support provided with a curriculum is necessary and sufficient for its successful implementation. Participants reflect on the provided evidence.	Participants receive research-based information about what constitutes good teacher support, as well as evidence of the extent to which the teacher support provided with a curriculum is necessary and sufficient for its successful implementation.	Participants do not consider research-based information about what constitutes good teacher support.	D5-1
	If successful implementation requires additional teacher supports, beyond those provided with the curriculum, participants develop and implement a plan for engaging such supports before and during implementation.	If successful implementation requires additional teacher supports, beyond those provided with the curriculum, participants develop a plan for engaging such supports.	Participants consider whether additional teacher supports, beyond those provided with the curriculum, might be necessary for successful implementation.	Participants do not consider whether additional teacher supports, beyond those provided with the curriculum, might be necessary for successful implementation.	D5-2
Engage participants in examining the authenticity and appropriateness of formative and summative assessments embedded in a curriculum; and	Participants are provided with a curriculum's embedded assessments and the learning objectives to which they are tied. Participants analyze and provide evidence of the authenticity and appropriateness of the embedded assessments.	Participants are provided with a curriculum's embedded assessments and evidence of their authenticity and appropriateness for evaluating associated learning objectives. Participants reflect on the provided evidence.	Participants are provided with a curriculum's embedded assessments and evidence of their authenticity and appropriateness for evaluating associated learning objectives.	Participants do not consider the authenticity or appropriateness of embedded assessments.	D6-1
	If the curriculum requires additional and/or modified assessments, participants develop such assessments.	If the curriculum requires additional and/or modified assessments, participants consider how they would develop such assessments.	Participants consider whether additional and/or modified assessments are required.	Participants do not consider whether additional and/or modified assessments are required.	D6-2
Demonstrate connections and alignment between engineering curriculum, instruction, learning, and assessment.	For a given curriculum, participants analyze and provide evidence of the connections among all of the elements: curriculum, pedagogy/instruction, student and teacher learning, and assessment.	For a given curriculum, participants receive evidence of connections among all of the elements: curriculum, pedagogy/instruction, student and teacher learning, and assessment. Participants reflect on the provided evidence.	For a given curriculum, participants receive evidence of connections among all of the elements: curriculum, pedagogy/instruction, student and teacher learning, and assessment.	Participants do not consider the connections between curriculum, pedagogy/instruction, student and teacher learning, and assessment.	D7-1

Standard E: Alignment to Research, Standards, and Educational Practices: Professional development for teachers of engineering should be aligned to current educational research and student learning standards. It should:

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
Be developed and refined in collaboration with experts in the fields of engineering, engineering pedagogy, and teacher professional development;	The professional development is designed and refined with input from relevant experts in all three of these fields: engineering, engineering pedagogy, and teacher professional development.	The professional development is designed and refined with input from relevant experts in two of these fields: engineering, engineering pedagogy, and teacher professional development.	The professional development is designed and refined with input from relevant experts in one of these fields: engineering, engineering pedagogy, and teacher professional development.	The professional development is designed and refined without input from relevant experts in any of these fields: engineering, engineering pedagogy, and teacher professional development.	E1-1
Be developed and refined in collaboration with stakeholders (e.g., state education agency personnel, school administrators, teachers);	The professional development is designed and refined with input from all stakeholder groups.	The professional development is designed and refined with input from multiple stakeholder groups.	The professional development is designed and refined with input from one stakeholder group.	The professional development is designed and refined without input from stakeholder groups.	E2-1
Enable participants to experience the curriculum that they will teach;	The professional development engages participants actively in all steps of all learning modules of the curriculum that they will teach.	The professional development engages participants actively in all steps of some of the learning modules of the curriculum that they will teach. Participants engage in the key components of the remaining modules.	The professional development engages participants actively in some of the learning modules of the curriculum that they will teach. Participants receive information about the remaining modules.	The professional development does not engage participants actively in the learning modules of the curriculum that they will teach.	E3-1
Model effective engineering teaching practices;	Professional development providers always employ effective engineering teaching practices while facilitating engineering activities.	Professional development providers regularly employ effective engineering teaching practices while facilitating engineering activities, but sometimes explicitly step outside of such practices.	Professional development providers occasionally employ effective engineering teaching practices while facilitating engineering activities.	Professional development providers do not employ effective engineering teaching practices while facilitating engineering activities.	E4-1
Employ differentiated instruction techniques;	The professional development provider gathers information about the participants' background or experience in content and pedagogical content knowledge. The professional development implements fully differentiated instruction to meet each participant's individual needs.	The professional development provider gathers information about the participants' background or experience in content and pedagogical content knowledge. The professional development targets the average participant and provides general suggestions for others.	The professional development provider gathers information about the participants' background or experience in content and pedagogical content knowledge. The professional development targets the average participant.	The professional development provider makes no attempt to assess or account for the participants' background or experience in content and pedagogical content knowledge.	E5-1
Be guided by formative assessment;	The professional development includes formative assessment or checks for participants' understanding, and the professional development is modified for each participant based on these individual results.	The professional development includes formative assessment or checks for participants' understanding, and the professional development is modified based on these aggregated results.	The professional development includes formative assessment or checks for participants' understanding, but the results do not shape or modify the professional development.	The professional development does not include formative assessments or checks for participants' understanding.	E6-1

Standard E
(Continued)

	HIGH EMPHASIS	MODERATE EMPHASIS	LOW EMPHASIS	NO EMPHASIS	ROW REFERENCE
Encourage risk-taking by participants;	The professional development provides a safe place that encourages ongoing intellectual risk taking by the participants.	The professional development provides a safe place that encourages occasional intellectual risk taking by the participants.	The professional development does not overtly encourage intellectual risk taking.	The professional development discourages intellectual risk taking.	E7-1
Be longitudinal; and	The professional development requires continued engagement with participants over time.	The professional development offers multiple opportunities for continued engagement.	The professional development offers limited opportunities for continued engagement.	The professional development does not offer opportunities for continued engagement.	E8-1
Evolve through a process of continuous improvement that employs ongoing evaluation, assessment, and revision.	Professional development provider collects sufficient and relevant data before, during, and after the professional development; analyzes these data; and employs the results of this analysis to inform improvements.	Professional development provider collects sufficient and relevant data before, during, and after the professional development.	Professional development provider collects data before, during and/or after the professional development, but it is insufficient to inform improvements.	Professional development provider does not collect data to inform improvements.	E9-1