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

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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 et al., 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.

While the nature and impact of effective 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 effective professional development for teachers of engineering both as a unique discipline and as a context for teaching and learning in other subjects. By extrapolating the results of research on effective professional development both in general and in science and mathematics, it is possible to identify five standards for effective professional development for teachers of engineering.

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” 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 et al., 2007; Cohen, 1990; Garet et al., 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. Research indicates a need for K-12 teachers to "become comfortable and proficient with the engineering process" (Brophy et al., 2008), especially through participation in an engineering design process (Hsu et al., 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 et al., 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 et al., 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." 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 et al., 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 et al., 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 et al., 2002; Garet et al., 2001; Stiles et al., 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 et al., 1999; Supovitz et al., 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 et al., 2006; Custer & Daugherty, 2009; Klein, 2009; Nugent et al., 2010). These relationships have been reported to deepen teachers' understanding of scientific inquiry and to improve their delivery of inquiry-based lessons (Caton et al., 2000; Klein-Gardner, 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 et al., 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 curriculum 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 and colleagues (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 et al., 1993; Petroski, 1992; Rugarcia et al., 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 and colleagues (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." 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 et al., 1989; Fennema et al., 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 an in-service professional development program's effectiveness and its alignment with state standards (Elmore & Burney, 1997; Fullan, 1993; Garet et al., 2001; Penuel et al., 2007; Rosenholtz, 1991).

While much of what is known about curriculum and assessment as a whole can be applied to the case of engineering in particular, some caveats do exist. For one, Brophy and colleagues (2008) point out that teachers unfamiliar with engineering "must learn a level of engineering analysis to determine the quality of a student's solution," 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.

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 which 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, 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 (2009) writes that it is "useful to put teachers in the position of studying the very material which they are to teach to their students". Evidence indicates that this is important in STEM, and in engineering in particular (Caton et al., 2000; Jeanpierre et al., 2005; Kennedy, 1998; Klein-Gardner, 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."

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). 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). 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 et al., 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; Guskey, 1994; Penuel et al., 2007; Supovitz & Turner, 2000). The impact of lengthening and intensifying a professional development program is not insubstantial: Yoon and colleagues (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 gains." 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 is 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 are intended to inform the design of future professional development efforts and, while not evaluative, may be used informally as a tool for describing 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.

References

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

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.

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 M. Koehler & P. Mishra (Eds.). (2011). 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*. Yale University Press.

Conwell, J. C., Catalano, G. D. and 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), 181-99.

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.

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).

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, NY 10027.

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).

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.

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).

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 & 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).

Klein, S. S., & Sherwood, R. D. (2005). Biomedical engineering and your high school science classroom: Challenge-based curriculum that meets the NSES standards. *Exemplary Science in Grades 9-12.*

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. *The 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).

Narode, R. B. (2011). ‘‘Math in a Can’’: Teaching Mathematics and Engineering Design. *Journal of Pre-College Engineering Education Research,* **1**(2).

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: 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*, 421-439.

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).

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: Dutton, 1976.

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), 237-69.

Stiles, K. E., Loucks-Horsley, S., Mundry, S., & Hewson, P. W. (Eds.). (2009). *Designing professional development for teachers of science and mathematics*. 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), 963-80.

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), 331-56.

Thompson, C. L., & Zeuli, J. S. (1999). The frame and the tapestry: Standards-based reform and professional development. *Teaching as the learning profession: Handbook of policy and practice*, 341-375.

Timperley, H., Wilson, A., Barrar, H., & Fung, I. (2008). Teacher professional learning and development.

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 Consulting Editors: Deborah Ball and Pamela L. Grossman. *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, US Department of Education.