INTEGRATING ENGINEERING INTO DELAWARE'S K-5 CLASSROOMS:

A STUDY OF PEDAGOGICAL AND CURRICULAR RESOURCES

by

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An Executive Position Paper submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Education.

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TWO STUDIES OF PEDAGOGICAL AND CURRICULAR CHANGE

by

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ABSTRACT

This study examines the personal and curricular resources available to Delaware's elementary teachers during a time of innovative curriculum change, i.e., their knowledge, goals and beliefs regarding elementary engineering curriculum and the pedagogical support to teach two Science and Engineering Practices provided by science teaching materials. Delaware was at the forefront of K-12 STEM movement, first to adopt statewide elementary curriculum materials to complement existing science units, and one of the first to adopt the new science standards—Next Generation Science Standards. What supports were available to teachers as they adapted and adopted this new curriculum? To investigate this question, I examined (1) teachers' beliefs about engineering and the engineering curriculum, and (2) the pedagogical supports available to teachers in selected science and engineering curriculum

Teachers' knowledge, goals, and beliefs regarding Delaware's adoption of new elementary engineering curriculum were surveyed using an adapted version of the Design, Engineering, and Technology Survey (Hong, Purser, & Gardella, 2011; Yaser, Baker, Carpius, Krauss, & Roberts, 2006). Also, three open ended questions sought to reveal deeper understanding of teacher knowledge and understanding of engineering; their concerns about personal and systemic resources related to the new curriculum, its logistics, and feasibility; and their beliefs about the potential positive impact presented by the engineering education initiative. Teacher concerns were analyzed using the Concerns-Based Adoption Model (Hall & Hord, 2010). Lay understandings of engineering were analyzed by contrasting naïve representations of engineering with three key characteristics of engineering adapted from an earlier study (Capobianco Diefes-Dux, Mena, & Weller, 2011).

Survey findings for teachers who had attended training and those who have not yet attended professional development in the new curriculum were compared with few notable differences. Almost all elementary teacher respondents were familiar with engineering and able to define it using one or more key characteristics. They valued the inclusion of engineering in the elementary curriculum; however trained and untrained teachers reported they were not confident about teaching it and were unaware of the new standards related to engineering. Teachers saw potential advantages or benefits of the new curriculum as helping improve science and math understanding, an opportunity to increase vocational awareness, and engaging students and motivating them to learn. Most teachers saw similar barriers to implementation--lack of teacher knowledge, lack of time to learn about engineering and how to teach engineering, and lack of administrative support. Almost all were open to additional in-service training to learn more about this new curriculum.

Three fifth grade science units were examined for evidence of teacher pedagogical support in teaching two Science and Engineering Practices (SEP) advocated by the Next Generation Science Standards. An analytic framework was developed based upon two NGSS SEPs: Asking questions, defining problems and Engaging in argument from evidence. Findings revealed that the kits varied greatly in their pedagogical approaches to the two SEPs and differences might be explained by each kit’s underlying orientations to the teaching-learning process.

Findings from these investigations have implications for the design of professional development and for engineering curricula. They highlight the importance of considering teacher beliefs about curriculum implementation and subject matter, as well as the importance of creating curriculum materials that focus teacher attention toward student thinking and the language rich science and engineering practices. Recommendations also include ongoing professional development to allow teachers time to try out and revise pedagogical routines that support the SEPs studied here.

Chapter 1

INTRODUCTION TO THE ELEMENTARY ENGINEERING INITIATIVE

National and Local Contexts

This study is set in a specific time and place, yet in many ways, it connects with the experiences of other classrooms at the outset of the same educational change. Because of increased attention and high profile proponents, elementary engineering curricula have been adopted in K-5th grade science classrooms across America. Delaware was among the first to join the movement, but what exactly does membership entail? Although there are indications that integrated science and engineering can provide positive student benefits, there are gaps in understanding as well. What might appropriate and effective programs look like? What outcomes are reasonable to expect? How will the implementations and outcomes be identified and measured (Honey, Pearson, & Schweingruber, 2014; Martin & Ritz, 2012)? For years, education policy makers have pushed for integration of technology and engineering in order to attain economic and workforce goals.

In January 2011, Delaware Governor Jack Markell established the Delaware STEM Council to advise state educators in the development, implementation, promotion and evaluation of programs and curricula designed to realize the state Department of Education's specific goals and objectives for K-12 Science, Technology, Engineering, and Mathematics (STEM) education. Markell predicted that investing in STEM would lead to a well-prepared workforce, attract new business and deliver high quality workers for existing science and technology industries (Nagengast, 2011).

Delaware was not alone. Both Congress and the Whitehouse had their own advisors and STEM agendas. One year earlier, in 2010, President Obama's Council of Advisors on Science and Technology (PCAST) published recommendations to guide the formation of clear national goals and a plan of action to ensure the country remains a leader in K-12 STEM education. While the report's authors argued for strengthening American students' proficiency and interest in STEM education and STEM careers, they noted that STEM education had already become an important national movement. The Council reported that science and technology accounted for more than half of the seven-fold growth in per-capita income for 20th century America. Further, it found that much of the nation's scientific progress as a driver of innovation was directly supported by US education (PCAST, 2010).

According to the Government Accounting Office (GAO), in fiscal 2010 over $3 billion had been invested by 13 federal agencies in 209 programs "designed to increase knowledge of STEM fields and attainment of STEM degrees (GAO, 2012, p. x)." Additionally, the field was growing: one third of those STEM programs were less than five years old. The report found that rapid development contributed to inefficiencies and overlap in programs' scope and target and that transformative efforts and/or positive results were occasionally realized but not widely disseminated (GAO, 2012). During that period, the term STEM had been used variously to describe education programs that include any of the subjects within any of the four disciplines and/or as any program that combines the disciplines, ranging on a continuum from little to partial to full integration. For example, Delaware's 2010 application for federal Race to the Top funding laid out a broad, inclusive form of STEM: as engineering embedded in science classes (K-5); as a separate vocational-technical course of study (middle and high schools); as traditional but more rigorous science and math disciplinary subjects (high schools), and as a new subject— whole and complete— to be integrated across the entire curriculum (all grades) (State of DE, January 19, 2010).

In later publications, however, the Delaware STEM Council put forth a more integrated vision of STEM education, one that was student-focused and problem-based (Delaware STEM Council, 2012). This was similar to and anticipated the 2013 Next Generation Science Standards (NGSS) which wove together engineering content and practices with more traditional science content and practices. The NGSS "fully [integrates] engineering and technology into the structure of science education by raising engineering design to the same level as scientific inquiry in classroom instruction when teaching science disciplines at all levels, and [accords] core ideas of engineering and technology the same status as core ideas in the other major science disciplines (NGSS Lead States, 2013a, Appendix A, p. 3)."

With the adoption of NGSS, Delaware formalized the integration of engineering standards in K-12 science education. Its previous K-5 science materials (Table 1) had been described as engaging, but national technology standards were elective and engineering was not explicit within the state's core required subjects (Grusenmeyer, 2007). In contrast, Massachusetts was one of the first to fully integrate science, technology, and engineering standards for grades PK-12, citing the principle of interconnection: "Connecting the domains of natural science with mathematical study and with one another, and to practical applications through technology and engineering, should be one goal of science education (MADOE, 2006, p. 13)."

Table 1 DE Science curriculum kits by grade level and topic, prior to 2010

Grade level	Curriculum unit (Series/ Publisher)			
K	Trees (FOSS)[1]	Senses (Insights)[3]	Organisms (STC)	
1	Weather and me (STC)[2]	Solids and Liquids (STC)	Organisms (STC)	
2	Soils (STC)	Balancing and Weighing (STC)	Insects (FOSS) or Life Cycle of Butterflies (STC)	
3	Human Body (FOSS)	Earth materials (FOSS)	Water (FOSS)	
4	Structures of Life (FOSS)	Magnetism & Electricity (FOSS)	Land Water (STC)	Sky Watchers (STC)
5	Eco systems (STC)	Mixtures and Solutions (FOSS)	Motion and Design (STC)	

Note. [1]Full Option Science System; Regents of the State of California
[2]Science and Technology Concepts; Carolina Curriculum for Science and Math
[3]Insights; Kendall Hunt Publishers

When Delaware was awarded RTTT funds, state Department of Education staff, seeking examples of substantive, teacher-friendly K-5 engineering curricula, chose an existing program developed in Massachusetts— Engineering is Elementary (EiE). Designed to complement the same elementary science kits used in Delaware's K-5 classrooms, EiE introduced students to the engineering design process, to engineering as field of study and employment, and to the understanding that engineers systematically study and design solutions to important problems (Cunningham & Lachapelle, 2012). Early evaluation of materials in use looked promising. When EiE was used along with the related science kits, students showed greater understanding of both science and engineering content and process than students who used the science materials alone (Lachapelle, 2007; Lachapelle, Phadnis, Jocz, & Cunningham, 2012). Elementary students reported improved interest in engineering after participating in EiE lessons, compared to non-participating students (Cunningham & Lachapelle, 2010) even when demographic variables such as gender, race, or ethnicity were considered (Lachapelle, Phadnis, Jocz, & Cunningham, 2012). Because EiE seemed to fit with the goals and the purposes of Delaware Science education leaders, in 2011 Delaware Science Coalition voted to effect the first statewide adoption of EiE (NCTL, July 2011). For grades one to five they adopted EiE units— in some grades adding to the existing schedule of units, in others replacing one science unit with another from EiE (Table 2). In kindergarten, the committee recommended similar format from a different publisher (Table 2). A three-year teacher training schedule was devised following the existing *train the trainer* model of one-day, 6-hour workshops (T. Mead, personal communication, January 28, 2013).

Table 2 Elementary engineering units adopted by DE Science Coalition 2011-13

Grade level	Engineering Curriculum unit (Publisher)	Accompanying Science Unit
K	Push, Pull, Go (BBS)[1]	* N/A
1	Catching the Wind (EiE)	Weather and me (STC)
2	Bridges (EiE)	*N/A
3	Water, Water, Everywhere (EiE)	Water (FOSS)
4	Alarms (EiE)	Magnetism and Electricity (FOSS)
S	Slick solutions (EiE)	Ecosystems (STC)

Note. * Science unit was replaced by EiE unit; DE offers no corresponding science kit.
[1] Building Blocks of Science, Carolina Biological Supply Company

Curriculum of the Future

Much of the drive toward elementary engineering education is grounded in logic. Like scientific literacy, STEM literacy is an ideal formulated to address fundamental curriculum questions (Ellis, 2004): What do we believe about students and society? What values and skills will students need in the future? What knowledge is of most worth? STEM specific considerations have also been raised: Will students need strong disciplinary knowledge or cross-disciplinary integrated knowledge for future success? Should they study local issues or focus on global problems? (Rennie, Venville & Wallace, 2012) Part of the push for STEM education is anticipatory. Problems of the future will be ever changing, multi-disciplinary, and trans-national—e.g. searching for alternative energy, sustainable food sources, and clean water; addressing climate change; safeguarding cybersecurity and national defense (Hossain & Robinson, 2012; PCAST, 2010; Roehrig, Moore, Wang, & Park, 2012).

Bybee envisions that STEM literacy will include "…the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social and global issues (Bybee, 2010, p. 31)." He sees four activities leading to STEM literacy: acquiring content knowledge of each of the four disciplines and using that knowledge; understanding the practices of the STEM disciplines; recognizing the role STEM plays in shaping our world; and engaging in STEM-related issues as knowledgeable citizens (2010). Assunda, with a similar view based in Career and Technical Education (CTE), suggests that if science, engineering, and mathematics standards were addressed in CTE, students might better understand the concepts and context of technology; increase their STEM literacy; and aspire to STEM careers (Assunda, 2012). Similarly technological literacy is "knowledge about what technology is, how it works, what purposes it can serve, and how it can be used efficiently and effectively to achieve specific goals (Pinelli & Haynie, 2010, p. 62).” Universal technological literacy means that leaders and citizens and not just technical elites will be able to make better informed democratic choices and personal decisions (PCAST, 2011; Roehrig, et al, 2012; Williams, 2011). Others follow the same line of reasoning. STEM literate citizens will be able to address complex problems of the future when solutions will necessitate the integration of STEM disciplinary knowledge and practices within organizations, as well as within individual experts (Hossain & Robinson, 2012; PCAST, 2010; Roehrig, et al, 2012; Sanders, 2012).

This ideal vision is not without critics. Skeptical of the rhetoric, Williams denounced the “wish list of goals some would like to see achieved (2011, p. 6).” He thinks current science, technology, math and engineering lessons have been pieced together into enhanced curriculum projects that look very similar to the existing state of affairs (Williams, 2011, p.2). Sanders (2008, 2012) labeled the shallow enthusiasm, “STEM-mania” and advocates against labeling any instructional programs as best-practice until evidence can be offered to substantiate the claim. Studying the impact of year-long engineering projects on middle schoolers, Budgen (2012) came to see that “the notion that integration could, by its very nature, motivate students, improve learning outcomes, and facilitate connections between learning areas was an inadequate and simplistic notion (p. 21).”

STEM Education in Elementary Grades

Advocates for STEM education have built a strong case. Rationales for PK-5 engineering education relate to providing a sturdy educational foundation for math and science concepts/skills, for technological literacy, and for engineering practices and habits of mind (Bagiati, Yoon, Evangelou, & Ngambeki, 2010; Bers, 2008; O’Brien, 2010; Pearson & Young, 2002). Many of the activities typically found in elementary science education classes are equally appropriate for illustrating and guiding young students' understanding of engineering content and practices (Bybee, 2011; Purzer, Duncan-Wiles, & Strobel, 2013).

Others argue for PK-5 engineering curriculum from a developmental perspective. In early engineering education, children learn to see themselves and others in social relationships that are explored and developed within a technologically rich environment. As in the past, educators provide a setting for young students' sense of self and their roles in society to develop as young scientists or mathematicians, but also as positive caring members of a community. Teachers need to be aware that new technologies have become a fundamental part of the child's life experience (Bers, 2008).

In addition, there is empirical evidence that interest in science and technology careers is rooted in early grades (Maltese & Tai, 2010; Tai, Liu, Maltese, & Fan, 2006). Features of STEM and engineering education, such as open-ended/design-based lessons and relevant contexts expand opportunities to underrepresented students, making careers in science, engineering, and technology more viable. (Chubin, May, & Babco, 2005; Moore & Richards, 2012; Pinelli & Haynie, 2010). Similar to the lay client and/or public users who evaluate the usefulness and appropriate trade-offs for objects or solutions devised through engineering, STEM students from all backgrounds are able to assess and justify their design decisions, even in early grades (Cunningham & Carlsen, 2014).

Outcomes of STEM Education

Findings from previous evaluation and smaller pre-post research studies in K-12 engineering education provide evidence to support implementation of new elementary engineering programs. Elementary age students have shown improved understanding of physical concepts as well as ability to solve problems beyond their predictive ability (Levy, 2013). Other early projects report that students in STEM education programs were energized, with increased general levels of achievement, increased scientific and mathematical knowledge (PCAST, 2011; Roehrig et al, 2012; Bethke-Wendell & Rogers,2013), decreased high school and college drop-out rates (Chubin, et al, 2005; Moore & Richards, 2012), improved engagement and motivation to learn (Lottero-Perdue, Lovelidge, & Bowling, 2010; NAE, 2009; Pinelli & Haynie, 2010), and more meaningful learning (Bybee, 2011; Berlin & White, 2012). A number of these authors hope to dispel the myth that only gifted and talented students need to study science and engineering (Hossain & Robinson, 2012; Lottero-Perdue, et al, 2010).

Engineering is Elementary is not the only elementary curriculum in use, but its developers and champions have evaluated and researched it extensively. EiE students learned STEM content, engineering thinking, and improved communication skills (Moore, Hynes, Purzer, Glancy, Siverling, Tank, Mathis, & Guzey, 2014). Their conceptions of engineering and the work of engineers became more complex and nuanced (Lachapelle, et al, 2012). They improved their broad understanding of technology (Lachapelle & Cunningham, 2007; Jocz & Lachapelle, 2012). Students learned to utilize specialized skills of design optimization and trade-off (Purzer, Duncan-Wiles, & Strobel, January 2013). They reported increased interest in engineering as future careers (Lachapelle, et al, 2012).

After participation in EiE training programs, teachers have shown clearer, more accurate conceptions of engineering (Lachapelle & Cunningham, 2007). They felt more knowledgeable and confident in analyzing their students' engineering solutions (Faux, 2007). They employed new pedagogies in non-engineering science lessons and other (non-science) subject areas (Carson & Campbell, 2007). They reported improved attitudes toward problem solving strategies and inductive teaching methods (Faux, 2006; 2008).

Vision for Teachers in K-5 Engineering

Researchers that have designed and implemented elementary engineering programs agree on the teachers' critical role. Unless teachers are deeply knowledgeable about content and pedagogy, students will loose on both the disciplinary and multidisciplinary levels (Berlin & White, 2012; O'Brien, 2010; Pitt, 2009; Williams, 2011). Because engineering and science share much of the same conceptual landscape but have distinct cognitive and epistemic characteristics, there are important instructional implications to how both are portrayed in the classroom (Cunningham & Carlsen, 2014.) Successful initiatives will require teachers' understanding, ability, and desire to update their practices to incorporate interdisciplinary materials and open-ended, problem-based pedagogy (e.g., Brophy, Klein, Portsmore, & Rogers, 2008; Custer & Daugherty, 2009; Cunningham, 2009; Hossain & Robinson, 2012; Roehrig, et al, 2012; PCAST, 2010.) Yet little is understood about how teachers acquire necessary professional skills and content knowledge (Honey, et al, 2014; Krajcik, 2014; Yu, Luo, Sun, & Stroebel, 2012).

Manage ideas and develop concepts

Professional development should work to change teachers' understandings, beliefs, and pedagogies in large and small ways. As they do with science, elementary teachers report that they lack confidence regarding engineering; they misunderstand what technology is or what technological fluency and technological literacy can be (Cunningham, 2009; Pearson & Young, 2002). Teachers will need to see that technology is about ideas, not objects (Bers, 2008; Brophy, et al, 2008). A powerful tactic called for when integrating disciplines on open-ended problem oriented themes of engineering and science— teaching in order to connect to prior learning— is not typical in today's unit- and kit-based science classes (Krajcik, 2014).

Another non-trivial change involves classroom management practices. Teachers will need to allow for more open-ended, unresolved interactions between individual students and between students and their projects (Berlin & White, 2012; Brophy, et al, 2008; Custer & Daugherty, 2009; Cunningham, 2009; Rogers, 2008). To realize goals of improved student achievement, teachers must develop and use techniques that enable and support thoughtful student responses, e.g., wait-time (Harris, Phillips, & Penuel, 2012; Michaels, Shouse, & Schweingruber, 2007), clarification and focus of design goals and constraints (Harris, et al, 2012; Purzer, Duncan-Wiles, & Strobel, 2013; Michaels, et al, 2007), argument from evidence for principled design (Guzey, Tank, Wang, Roerhig, & Moore, 2014; Purzer, et al, 2013) and purposeful revision (Krajcik & Merritt, 2012; Stohlmann, Roehrig, & Moore, 2014), recognition that ethical and safety standards are not only about engineering practices but they are integral constraints to proposed design solutions (Moore, Glancy, Tank, Kersten, Smith, & Stohlman, 2014).

Need for training and development

One important requisite is high quality teacher professional development. Authors agree that one-time introduction to the engineering and the engineering design process will not suffice (Honey, et al, 2014; Cunningham & Carlsen, 2014; Krajcik, 2014). In previous efforts using well-thought-out and well-intentioned professional development programs to train teachers to develop inquiry practices, few newly trained and in-service teachers effectively adopted inquiry pedagogies. New thinking will be needed for this initiative to succeed (Lederman & Lederman, July 2014). Professional development in science education offers a theoretical and practical foundation for teacher development in the new curriculum.

Effective Elementary Science Practices

Recent exploration into what works has taken the form of meta-analysis. One synthesis of research in elementary science education focused neither on content nor objectives but on the instructional approaches (Slavin, Lake, Hanley, & Thurston, 2014). Rigorous inclusion criteria were designed to avoid inflated effect sizes reported by earlier studies. Twenty-three (23) studies published since 1990 were identified that fit the requirements. They all

- Used control groups (both groups equally focused on achieving particular objectives)
- Demonstrated group equivalence on pre-tests (if pretest data not provided, then random assignment of more than 30 units)
- Used intervention for longer than four weeks (to show that instructional practices and resources could be maintained over time)
- Employed measures not inherent to the intervention (fair to both intervention and control groups)

Studies using related approaches were grouped and effect sizes were determined for each group. Outcomes were found to be consistent within the three related approaches:

- No study examining inquiry teaching supported by kits indicated positive student outcomes.
- All studies of inquiry practices unsupported by kits yielded positive student outcomes.
- All of the studies using technology to support science learning showed some impact; four of the six studies used technological resources to complement (not supplant) classroom instruction e.g. illustrating, activating, and integrating concepts. The other two used computers to deliver content and instruction.

Because each study used sound methodology yet obtained results similar to others using the same approach, it leaves a question: What might account for the different student-level impacts when comparing inquiry pedagogies with kits to inquiry pedagogies without kits? Science educators have long complained that management of equipment and materials and supervision of procedures distracts teachers away from facilitating emergent student concepts (Duschl, 2008; Windschitl, Thompson, Braaten, & Stroupe, 2012; Zangori, Forbes, & Biggers, 2013). Not until an extended period of three to six years will teachers develop expertise to effectively implement a new instructional practice (Cunningham & Carlsen, 2014; Wilson, 2013; Hall & Hord, 2010). However, passage of time alone will not create effective science teachers. There is evidence that teachers with five or more years' experience lose their initial beliefs about the ability for student growth and about the constructivist nature of teaching and learning (Albanese, Doudan, Fiorilli, & Garbo, 2004), beliefs which mitigate enactment of inquiry and student-centered pedagogy (Lotter, Rushton, & Singer, 2013). Reflective practice is recommended to support cohesive development of both beliefs and practices (Albanese, et al, 2004; Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Lotter, et al, 2013).

Teacher as decision maker

One way to think about effective teaching that allows us to understand these findings is through an explanatory model based on the teacher's role as decision maker where clusters of beliefs contribute to instructional action, but cannot alone account for it. Teachers must decide what is most important in the long term and in the immediate moment (goals); they decide among instructional routines available using the resources at hand to accomplish those goals. Beliefs are built upon context and history and interact with knowledge (a resource). This complex interplay has been used to model and explain why "professed beliefs [are] only partially enacted in the classroom" (Schoenfeld, 2011, p.458). This frame of 'Teacher as decision maker' provides a focus for this study. What do teachers know and believe about this new curriculum and the policies that support it? What resources are available to make the pedagogical changes and enact effective practices?

Purpose of Study

The push to integrate engineering standards provides an opportunity to significantly change elementary science teaching and re-energize professional development. When teachers and teacher educators simultaneously admit to a novice understanding, it has the potential to lead them to revisit information about how people learn and then retool their approaches (Krajcik, 2014; Lotter, et al., 2013). What important personal and curriculum resources were available to Delaware's elementary teachers at the outset of this initiative? To determine the personal resources available to teacher, Chapter 3 examines Delaware’s K-5 teachers’ knowledge, goals, and beliefs about this curricular shift. Chapter 4 surveys a sample of science and engineering teaching materials for examples of pedagogical support of two science and engineering practices specified in new science standards.

Finally Chapter 5 interprets both dimensions, i.e., knowledge, beliefs, goals, and teaching materials, through the vision of “Teacher as decision-maker” where content knowledge, teaching routines, goals, beliefs, and material resources interact to impact meaning making and teachers’ in-the-moment choices (Schoenfeld, 2009).

The purpose of this project to describe teachers’ personal and curricular resources at the outset of Delaware’s educational policy initiative, Elementary Engineering Education, is to inform a path forward in curriculum development, adoption, and dissemination efforts. Delaware, a leader in the adoption of these new science policies and elementary engineering curricula, may have much to offer others who follow their example.

Chapter 2

CURRENT RESEARCH IN ELEMENTARY ENGINEERING PEDAGOGY

Tasked by National Academies of Science and Engineering to develop a research agenda for the new K-12 engineering education paradigm, Honey, Pearson, and Schweingruber came up with a number of recommendations. This paper was inspired by two of them, “How might integrated STEM experiences be designed to account for educators’ and students’ varying levels of experience with integrated learning and STEM content? …Given the variability of teachers’ own knowledge of STEM content and pedagogy, what kinds of instructional supports might be most effective and most useful to them? (2014, p.151)” Very recently, a number of strong research studies that examine instructional materials and practices supportive of elementary engineering education have come forward. They provide a foundation for this study.

Why Focus on Pedagogy?

Integrated STEM offers opportunity for teachers to enact best practices, however, these pedagogies are difficult to carry out and sustain. Early implementation studies identified major threats to student learning in the absence of high-quality engineering instruction. In the absence of practices central to engineering education, students and teachers learn little or reinforce misconceptions. Problems have been observed in poorly implemented engineering lessons, for example, when students are engaged in a design activity that has no ties to science or math content and no external authority in nature or in the constraints of the client, i.e., building or making for the sake of the activity but not ‘engineering’ (Moore, et al, 2014; Schunn, 2009). Also, in teaching design and problem solving, teachers do not know when or how to question student thinking or support its development. They design without justification or evidence to support proposal; optimization is missing (Purzer, et al, 2013). Similarly, it has been noted that teachers omit or trade-off the redesign portion of an engineering design cycle to save time and/or because they think that student efforts should be graded without benefit of redesign. They misunderstand the importance that students consider feedback from the community and justify his/her revisions. They may not value iteration’s role in problem solving and in learning (Schunn, 2009; Stohlmann, Roehrig & Moore, 2014).

Indicators of High-quality Curriculum Materials

The STEM Integration Curriculum Assessment

In order to document successful elementary engineering instruction and to assess materials, lessons, and instructional procedures that reflect new standards, researchers identified features of high quality integrated STEM curricula (such as a motivating and engaging context; students actively work to solve an engineering design challenge using relevant technologies, and math/ science content). Other important features of high-quality curriculum materials were specifically designed for the teacher-user (such as, organizational clarity; content, guidance and instructional strategies for teachers’ background) (EngrTEAMS, 2013; Stohlmann, Moore & Roehrig, 2012). The resulting checklist was called the *STEM Integration Curriculum Assessment.*

The same research team also worked to define the “core ideas, concepts, skills, and dispositions” of a quality K-12 engineering education, creating *The Framework for Quality K-12 Engineering Education*. Using established criteria for undergraduate engineering programs and a thorough review of literature, this framework establishes the engineering design process as central to STEM integration. Experts from engineering and engineering education guided revisions to ensure indicators were appropriate for younger K-12 students. This was field tested to determine whether the indicators could be clearly identified during classroom observations. Data gathered in classrooms evincing high-quality STEM instruction revealed five of the framing indicators were critical components of high-quality STEM instruction and four were optional or intermittently seen (Moore, et at, 2014).

Three items were found to be present in all high quality lessons (Moore, et al, 2014):

- A process of design e.g. identifies the problem and background, plans, implements, tests, and evaluates; this can extend across several lessons.
- Applies science, engineering, and mathematics; avoids unrelated, isolated activity for its own sake.
- Engineering thinking; uses system thinking, creativity and innovation; learns from failure.

Items that necessary parts of a full K-12 Engineering program but not required for any one lesson to be of adequate or high quality were also identified:

- Conceptions of engineers and engineering; what is an engineer and what do they do?
- Engineering tools techniques and processes; for measurement and modeling, drawing and data collection.

- Address issues, solutions, and impacts; context alone will not address this. What are the real-world consequences?
- Ethics; explicit consideration regarding proposed design and trade-offs.

The framework was later used to investigate the quality of teacher-made lesson plans— whether the essential components of K-12 STEM were addressed and how the planning documents might be improved (Glancy, Moore, Guzey, Mathis, Tank, & Siverling, 2014).

Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric

Alternatively, the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric evaluates the quality of existing curricular materials by comparing integrated science and engineering lessons with the Next Generation Science Standards (NGSS). EQuIP helps teachers envision whether their lessons work together to reach a bundle of NGSS-defined Performance Expectations (PE). PE's are embodied by the Crosscutting Concepts, Disciplinary Core Ideas and Science and Engineering Practices. EQuIP highlights student ideas and thinking as they design solutions to problems and it identifies areas for revision in order to improve existing lessons (Ewing, 2015; Next Generation Science Standards, October, 2014).

Users of EQuIP found that unlike the NGSS' vision of three-dimensional learning, then-current curriculum units were typically focused on one or two content points and/or skills all within a single discipline and topic (Ewing, 2015). The rubric positions students' explanations of phenomenon and their justifications of design solutions at the center of the curricular experience, practices that were seldom fully developed in earlier curriculum materials.

Like the NGSS PE's (performance expectations) which do not prescribe teaching approaches, the EQuIP rubric does not offer specific strategies, however it does suggest that a teacher will need a deft hand to facilitate student concept development and authentic meaning making. Teachers will also need to ensure that these practices, skills and concepts mature in age-appropriate ways (Ewing, 2015). The authors hope to identify and/or develop curriculum materials that support these pedagogical changes.

Indicators of Teacher Competence in Elementary Engineering

As stated earlier, research shows that elementary teachers face obstacles in teaching science and engineering. Typically, they are not confident. They are skeptical of the process of integrating engineering into the classroom. They do not feel prepared to teach science or design, engineering, and technology. They hold misconceptions about engineering and technology and perceive it to be a difficult unapproachable discipline. These factors impact their attitudes toward and instructional decisions about engineering education.

Content knowledge and Pedagogical content knowledge

In 2007, Hines found the following were critical components of a teacher’s engineering content knowledge (CK): engineering design, the technology development process, basic concepts of engineering technologies, materials, the profession and what engineers do, the requisite fundamental math physics and science concepts. Regarding their pedagogical content knowledge (PCK) he identified the following: PCK of students, PCK of real-world examples, PCK of appropriate examples such as analogies, PCK of managing the lesson and design activities, PCK of strategies for student understanding which includes probing questions to elicit thought (Hines, 2007).

Going further, in 2012, Yu and colleagues worked to deconstruct large sets of skills identified as components of competency models for general and engineering education and develop a list of teacher competencies specifically for K-6 engineering teachers. The list they developed was extensive and divided into seven dimensions: engineering concept knowledge; engineering skills; knowledge about engineering disciplines; engineering pedagogical content knowledge; attitudes toward engineering; attitudes toward teaching engineering; and integration of engineering with other subjects. They hope to validate the list through a future Delphi project and eventually establish whether these competencies might be mutually reinforcing (Yu, Luo, Sun, & Strobel, 2012).

Addressing similar issues in Career and Technology education, Sanders (2012) proposes that STEM best practices should be identified empirically, but founded on principles derived from educational psychology and cognitive science. His recommendations regarding integrated STEM education echo those of experts in science and engineering education. He advocates that STEM education is appropriate for all K-12 students; that it should not replace instruction in the individual disciplines; and that it should be purposefully articulated across the grades. His proposals for STEM pedagogy are similar as well and include the significance of context in STEM, of a purposeful engineering design process and of interdisciplinary thinking.

Teacher knowledge of engineering content and practices

Taking issue with NGSS’ representation of engineering and its practices, Cunningham and Carlsen (2014) argue that items labeled *Disciplinary Core Ideas* (DCI) of engineering would be more appropriately labeled as its practices and that focused efforts to teach engineering practices alone will benefit K-12 students’ understanding. Additionally they spell out distinctions between science and engineering uses of each of the NGSS-identified science and engineering practices. The resulting comparison clarifies differences and highlights distinctive features with implications for effective (and ineffective) teacher practice. See Table 3.

Table 3 Ways that NGSS science and engineering practices differ (from Cunningham & Carlsen, 2014)

NGSS Practice	Science	Engineering
Asking questions and defining problems	Goal is theoretical/conceptual progress	Goal is a useful, novel technology
Developing and using models	Explanation and prediction	Analysis and evaluation
Planning and carrying out investigations	Hypothesis-testing, may be sequential	Evaluation, usually iterative
Analyzing and interpreting data	Attention to measurable aspects of the found, natural world	Attention to diverse criteria: scientific (e.g., material properties) and other (e.g., cost, risk of failure)
Using mathematics and computational thinking	Testing conceptual models with real data	Designing concrete things, using both real and simulated data
Constructing explanations and designing solutions	Objective is a single ‘‘best explanation’’	Objective is a preferred design, selected from among alternatives, with explicit consideration of tradeoffs
Engaging in argument from evidence	Goal is to persuade scientific peers	Goal is to identify and satisfy needs of a client
Obtaining, evaluating, and communicating information	Free exchange of information is an important norm	Products often proprietary and information guarded

Pedagogy and Components of High-quality Instruction

The Elementary Education Adoption and Expertise Frameworks

Recall in Schoenfeld's "teacher as decision maker," a teacher's understanding, goals, and beliefs lead her to choose between instructional routines that in turn, frees her to focus on subsequent decisions to be made. Similarly, these researchers distinguish between *adoption* and *expertise* regarding elementary engineering education and spell out stages within each dimension (see Tables 4 and 5). The authors found that adoption is more than development of expertise. Teachers can vary across both in a number of ways. By using an iterative methodology beginning with constant comparison analysis of relevant publications and transcripts of elementary teachers discussing their engineering pedagogy and practices, authors found there were four major classifications in the Elementary Engineering Education Adoption Framework:

- perception of practicality and sustainability of engineering education
- comfort level with engineering teaching
- perception of EE benefits to the elementary learner
- degree of engineering integration

The second framework, the Elementary Engineering Education Expertise Framework, describes ways that teachers differ in their knowledge and skills of teaching engineering. Here there were three categories: contextualization of engineering learning, development of engineering teaching pedagogy, and making interdisciplinary connections.

Building on two diagnostic and analytic tools commonly used in a Concerns-Based Adoption Model (CBAM) (Hall & Hord, 2010), Stages of Concern and Levels of Use, the frames offer specific, descriptive depictions of how beliefs, concerns, and decisions at each level of engineering adoption and the instructional behaviors and choices at each level of expertise might look in actual teacher practice (Sun & Strobel, 2013).

Table 4 Elementary Engineering Adoption Framework (from Sun & Strobel, 2013)

	Perception of practicality and sustainability of EEE		Comfort level with engineering teaching		Perceptions of EEE benefits to students		Degree of engineering integration	
Stage 1: Attempter	Overwhelmed by the perceived barriers to EEE and regarding EEE as impractical and unsustainable because of the perceived barriers	Student centered------------------teacher- centered	Uncomfortable teaching EEE indicated by unwillingness to teach engineering and by rushing over engineering content when teaching	Confident, comfortable -------------Unconfident, uncomfortable	Holds an "engineering as anti-illiteracy" view of EEE benefits (i.e., learning engineering helps understand some related concepts)	Comprehensive, broad ---------------- Simple, limited	Teaching engineering discontinuously and sporadically and treating engineering teaching as isolated and as an add-on	Active, connected, regular ------------ Passive, isolated, sporadic
Stage 2: Adopter	Fully aware of the perceived barriers but viewing engineering as practical in elementary classrooms		More comfortable teaching EEE as indicated by covering expected amount of engineering content and allowing more time for engineering content and student questions		Hold an "engineering as an extension" view of EEE benefits (i.e., learning engineering helps review knowledge and skills learned in other disciplines)		Devoting more time for engineering teaching and starting to make occasional attempts to integrate engineering into the teaching and learning of other non-engineering disciplines	
Stage 3: Ameliorator	Proving practicality through engineering teaching practice and becoming conscious of the need to make EEE sustainable		Quite comfortable teaching EEE as indicated by regular engineering teaching practice and expanding engineering learning with additional engineering teaching materials		Holds an "engineering as application and enrichment" view about EEE benefits (i.e., learning engineering helps broaden students' horizon and enrich skills)		Practicing engineering teaching on regular basis and being more frequent in integrating engineering into the teaching and learning of some of other non-engineering disciplines	
Stage 4: Advocator	Convinced of EEE practicality based on successful personal engineering teaching experiences and starting to make efforts to make EEE sustainable		Fully comfortable teaching engineering as indicated by confidence gained through successful engineering teaching experiences and willingness to share successful EEE stories		Views benefits as "engineering as empowerment" (i.e., EEE promotes student development as real-life problem solvers and awareness of career potential in engineering)		Making engineering teaching an integral part of teaching practice as a result of being able to integrate engineering into all other non-engineering disciplines all the time	

Table 5 Elementary Engineering Expertise framework (from Sun & Strobel, 2013)

Stage	Contextualization of engineering learning		Development of engineering teaching pedagogy		Making interdisciplinary connections	
Stage 1: Mechanical imitator	Focusing solely on deliver of engineering content unaware of students' engineering learning needs and making no efforts to relate engineering learning to real life	Contextualized-------------- Decontextualized	Sticking to teaching procedures and steps learned in EEE PD without particular strategies or methods to address engineering learning problems and issues	Well-developed--------------→ Absent	Having no idea how engineering can be integrated into the teaching and learning of other disciplines	Well -connected--------------→ Non-connected
Stage 2: Skillful imitator	Contextualizing engineering teaching by adding some daily life engineering examples into engineering teaching but still unaware of students' learning		Relying mostly on the EEE teaching procedures and steps learned in PD but being able to apply some generic teaching strategies and methods to engineering learning problems and issues		Becoming aware of some potential opportunities to integrate engineering into teaching-learning other disciplines but no attempts to make actual connections	
Stage 3: Adaptor	Contextualizing engineering by giving students opportunity to find by themselves engineering all around them and by accommodating some generic learning needs of the students		Being able to develop some teaching strategies and methods specific to engineering content to deal with engineering learning problems and issues		Being able to find some opportunities to connect existing EEE activities with the teaching-learning of other disciplines but engineering is still largely appended in such connections	

Stage 4: Improver	Contextualizing engineering learning by making changes to engineering teaching procedures and materials based on situated engineering learning needs and by enabling students to see that engineering is for solving real-life problems		Improving EEE learning experiences by making appropriate changes to engineering teaching materials , procedures, and/or steps learned in PD, and by providing hands-on, concrete, and real-life examples		Able to combine EEE with the teaching and learning of all other disciplines and combine them to allow students to see via engineering the real-world application of knowledge and skills learned in non-engineering disciplines	
Stage 5: Creator	Contextualizing engineering learning by creating engineering learning opportunities meeting students' learning needs and promoting engineering through real-world problem solving and real-world applications		Creating opportunities for students to become active agents in the engineering teaching and learning process and to construct knowledge through active participation and exploration		Being creative in making interdisciplinary connections to make EEE possible within time constraints and enable elementary students to learn other non-engineering disciplines through a new lens and practice	

Summary

In order to summarize and compare these studies, Table 6 outlines each regarding several recommended curriculum features. These studies have pointed toward the importance of teaching practices that utilize concept development and active engagement. They point to the singularly 'engineering' processes, such as design, constraint, trade-off, and iteration, as adding value alongside other more typical science processes such as the use of math to communicate findings, argumentation from evidence, and probing questions.

Table 6 Research summary: Components of high quality elementary engineering pedagogy

Author(s) **THEME**	Context	Engineering Design process	Engineering thinking	Disciplines	Attitudes, practices, other
Sanders (2012) **STEM pedagogy**	Robust context for thinking at all cognitive and affective levels	Purposefully engage student s in designing, making, assessing solutions to real-world problems	Purposefully engages students in interdisciplinary thinking	Inter-, trans-, or multi-disciplinary formats	Consistent with accepted learning principles
Moore, et al. (2014) EngTEAMS (2013) **STEM curriculum**	Motivating and engaging context	Student actively working on design challenge with relevant technologies for compelling purpose Provides opportunity to learn from failure and to redesign	Engineering thinking	Applies science, engineering, and math concepts Student centered instruction of science and math content	Utilizes Teamwork and Communication
Hines (2007) **EE Teachers' types of knowledge** **PCK and CK**	Real-world examples Appropriate examples (e.g. analogies)	Engineering design process Technology development process	Concept of engineering technology, materials, profession, and job/ work tasks	Fundamental math and physics knowledge	Knowledge of typical students Management of lessons and design activities Strategies for student understanding, inc. probing questions
Yu, Luo, Sun & Strobel (2012) **STEM Teacher Competency**	Engineering PCK	Engineering skills	Engineering concept knowledge	Knowledge about STEM disciplines Integrating engineering into other subjects	Attitudes toward engineering Attitude toward engineering education Engineering PCK
Sun & Strobel (2013) **Expertise and adoption requirement**	Contextualization of EE learning	Develop EE pedagogy		Making interdisciplinary connections Degree of EE integration	Perception of EE benefits to elementary learners Perception of EE practicality and sustainability Comfort teaching EE

Author(s)	Context	Engineering Design process	Engineering thinking	Disciplines	Attitudes, practices, other
Cunningham & Carlson (2014) **Features of high-quality EE pedagogy**	Present open ended problems with potential to lead to multiple solutions, multiple paths to solution, unknown to the teacher	Challenge students to present designs/solutions within specified constraints (Failure is an option/ essential feature)	Facilitate ideas and reflections; Manage activity, discussion, and variety of solutions so that students analyze and reflect on results; students present and argue from evidence using data	Help participants attend to large, overarching science and engineering principles	Recognizes subtle distinctions between science and engineering practices

Discussion

Pedagogical change and curriculum materials change to support science and engineering education

The widespread adoption of elementary engineering education has exposed gaps in understanding. However, a consensus is building among educational researchers regarding what comprises high quality elementary engineering education: It requires a compelling context; employs an engineering design process; uses engineering thinking; and connects learning to disciplinary content (math, science, or engineering concepts). Engineering teachers need to be skilled in learner-centered pedagogies as well as management of activities and classroom discourse. They need to know how to lead students to evaluate and argue for designs, solutions, and iterations using evidence and data collected through observation. Teachers need to be comfortable with tasks that have unknown or multiple solutions and real opportunity for project failure. Finally, if the core content/ideas of early engineering are in fact *the practices of engineering* (as Cunningham and Carlson assert), teachers will need to consciously make these practices visible and valuable. Engineering practices need to be made accessible, empowering, and relevant to their young students.

In the model of "teacher-as-decision-maker" professional developers must help teachers to develop the resources, goals, orientations and beliefs necessary to enact new practices (Schoenfeld, 2011). Because values, beliefs, and goals may widely vary, as will resources available to each teacher, the paths to change will also vary.

Thus, in order to assess the current context using Schoenfeld's framework, this study examines two resources:

1. Teachers’ views of this new engineering curriculum, specifically their knowledge, goals, and beliefs
2. Teacher materials’ explicit support to teach two science and engineering practices

The next two chapters present the methods of data collection (teacher survey and curriculum analysis), findings, and discussion regarding these important pedagogical resources.

Chapter 3

TEACHER UNDERSTANDINGS AND BELIEFS ABOUT ELEMENTARY ENGINEERING

In Chapter One, research showed that inadequate teacher knowledge and disconnected or undeveloped beliefs regarding science and STEM can present challenges to a program's successful implementation. In Chapter Two, research in elementary engineering curriculum and instructional practices has suggested potential indicators of high-quality pedagogy. How might Delaware's initiative build on this prior research?

This chapter examines teacher understandings, beliefs and concerns about new engineering standards as enacted in Delaware's K-5 kit-based curriculum. For most teachers, a move to integrate engineering into science education will require major changes in instructional routines. If teaching is decision making, how might teacher beliefs and understandings influence and inform pedagogical routines in this newly adopted integrated curriculum model? This chapter addresses this in sections-- guiding questions, methods of data collection and analysis, participants, findings, and discussion. A summary of data collection and analysis can be seen in Table 7.

Guiding Questions

To address the question, "How do teachers currently view this new engineering curriculum, specifically what knowledge, goals, and beliefs do they hold?" the following focus questions were investigated:

- What do Delaware elementary teachers understand and believe about engineering and engineers?
- How do they understand and what do they believe about elementary engineering?
- Do teachers' understandings, beliefs and concerns differ between those who have attended Delaware's elementary engineering training and those who have not?

Table 7 Data collection and analysis by focus question

Question	Data Collection Tools	Data Analysis
How do Delaware's elementary teachers understand and what do they believe about engineering as a profession? How do they understand and what do they believe about elementary engineering education?	Online administration of Design, Engineering, and Technology Survey (DET) Open-ended survey items: Concerns; Description of engineering; Benefits	Quantitative- descriptive statistics DET Qualitative- inductive and deductive content analysis to identify teachers understandings, beliefs, and concerns
Do these values, understandings, and beliefs differ between teachers who have attended Delaware's elementary engineering training and those who have not? Do concerns (informational, personal, management, impact) differ between those that have attended training and those who have not?	Online administration of Design, Engineering, and Technology Survey (DET) Open-ended survey items: Concerns; Description of engineering; Advantages	Chi-sq. analysis of DET groups- with and without training a. Analytic frame (Concerns) b. Analytic frame developed for this study (engineering) c. Grounded, iterative content analysis (Advantages)

Data Collection and Analysis

In order to better understand how Delaware teachers view the new K-5 engineering curriculum, data was collected from a large sample survey administered at the outset of the initiative. A link to the online survey (which was developed and administered using *Qualtrics*) was distributed to all Delaware district science coordinators asking that they forward emails requesting K-5 public and charter teachers to participate. It is not known how many science coordinators ultimately forwarded the information and link. Between April 1 and May 30, 2013, 179 surveys were initiated, and 138 surveys were fully completed. Because no items were designated as *required*, individual items varied in their response numbers. Total N for each item is reported with survey results in Appendix B. Respondents were asked brief demographic details, but all were anonymous.

Design, Engineering, and Technology (DET) Survey

To assess teacher knowledge and beliefs about engineering and engineering education, the Design, Engineering, and Technology (DET) Survey (Yasar, Baker, Kurpius, Krause, & Roberts, 2006) was adapted. Hong, Purzer, & Cardella (2011) found DET to be a sufficiently reliable measure of elementary teachers' understanding and beliefs regarding design, engineering, and technology. It uses 39 items and 4-point Likert type scales (Strongly disagree-Disagree- Agree- Strongly agree) or (Not at all-Not much- Somewhat- Very much).

The phrase "Design, Engineering and Technology" or DET, was replaced by the word "engineering" to focus solely on the state's introduction of engineering into K-5 science classes. In addition, three open-ended questions sought to uncover additional information regarding teacher knowledge and understanding of the engineering enterprise, their beliefs about personal and systemic resources related to the new curriculum, their understandings of program logistics and feasibility, and their beliefs about potential positive impacts presented by the initiative. See Appendix A for complete survey items and Appendix B for survey results.

Responses were analyzed with descriptive statistics. To determine if there were significant differences between teachers who had and had not yet attended curriculum training events, chi square was used. Finally, partly due to low response numbers, survey results and analysis were presented to a small number (3) of exemplary teachers to gauge their opinion regarding wider applicability of the findings.

Implications of the surveys and teacher feedback were considered within the frame of “teacher as decision-maker;” that is, what the teacher knows and believes about the content and about the process of teaching and learning are resources she draws upon in the moment to reach her curriculum and pedagogical goals (Schoenfeld, 2009).

Open-ended Items

Lay understandings of engineering

To gauge teachers’ understanding of the field, an open-ended item asks how they might describe engineering to a friend. To classify responses, an analytic frame was developed from Capobianco Diefes-Dux, Mena, and Weller (2011) who contrasted naïve representations of engineers (repair technicians, builders) with a more accurate view that consists of three key characteristics of engineers: they engage in the practice of problem solving; their work has a socio-cultural aspect; and their work utilizes specialized knowledge, skills, and tools. For this study, the question was refocused from describing an *engineer* to describing *engineering*. The analytic frame was adapted from the above representations: Did respondent define engineering as a problem solving endeavor with a socio cultural aspect that uses specialized knowledge or skills? Survey responses were also examined to determine the number of characteristics the teacher definitions used. See Table 8 for coding scheme with summary of authors' descriptions.

Table 8 Coding scheme: Key characteristics of *engineering*

Characteristics	Summary description adapted from Capobianco Diefes-Dux, Mena, and Weller, 2011.
Naïve description	Includes notions of fixing, building, or making and using vehicles, engines, or tools.
Problem solving	Recognizing problems, identifying solutions, working within constraints, constructing and evaluating designs, prototypes or models
Sociocultural aspect	Working in teams and collaborating to make decisions; Communicating ideas and learnings to others
Utilizing specialized knowledge, skills, and tools	Use of scientific knowledge as well as practical and technical knowledge; use of skills in cost, risk, and benefit analysis; use of critical thinking and creativity; use of tools of science and technology in design and evaluation of solutions

Stages of concern

The second open-ended item was designed to yield insight into teachers' personal beliefs and perceived support needs regarding implementation of the new curriculum: "When I think about using this engineering curriculum in my classroom, my biggest concern is…."

Statements of concern were analyzed qualitatively, after the process developed in the Concerns Based Adoption Model (CBAM) (Hall & Hord, 2010; Hall & Hord, 1987; Newlove & Hall, 1976). CBAM researchers have documented that an individual's stage and intensity of concerns will change as the implementation of the program continues. Concerns are influenced by a number of internal factors (motivation, confidence, and depth of knowledge) as well as external factors (physical context, competing pressures). While concerns are not mutually exclusive, stages (and concerns) reflect changes in intensity as the program adoption continues. Participants do not always progress in a step-wise manner through the Stages of Concern and there is no ideal or terminal stage (Hall & Hord, 1987; Hall & Hord, 2010). CBAM's person-centered theory of change has identified seven levels of concerns, in four dimensions: awareness (Stage 0), self (Stages 1-2), task (Stages 3-4) and impact (Stages 5-6). See Table 9.

Table 9 Stages of concern defined (from Hall & Hord, 2010)

Stage of concern			Definition
0		Awareness	Little concern about or involvement with the innovation is indicated
1	Self	Informational	A general awareness of the innovation and interest in learning more about it is indicated
2		Personal	Individual is uncertain re: demands of the innovation, his/her inadequacy to meet those demands, and role with the innovation
3	Task	Management	Attention is focused on the processes and tasks of using the innovation and the best use of information and resources
4		Consequence	Attention focuses on impact of the innovation on students in the immediate sphere of influence
5	Impact	Collaboration	Focus is on co-ordination and co-operation with others re: use of the innovation
6		Refocusing	Focus is on exploration of more universal benefits from the innovation, including the possibility of major changes or replacement with more powerful alternatives

Because responses to the open-ended statements may express more than one concern within an extended response, the authors recommend that all sentences within a response are analyzed collectively. When more than one concern is expressed, they are taken together, not as a single average or as a choice among them with one superseding concern. In cases with multiple concerns, they are treated as a constellation of stages. As the program progresses and with support, the constellation will also evolve, new concerns rising to prominence (Hall & Hord, 1987).

Beliefs about advantages of elementary engineering

A final open-ended item asks teachers, “When I think about using this engineering curriculum in my science classroom, the biggest advantage I see is—” in order to identify their beliefs about potential advantages resulting from the new initiative. Analysis followed a grounded (open-coding) approach (Strauss & Corbin, 1998). Initially thirteen codes emerged. Further analysis yielded six categories or themes:

1. ***Potential to improve student affective experience***, e.g. Increased student engagement/ motivation/enjoyment;
2. ***Potential to improve, strengthen, or expand curriculum***, e.g. Opportunities for student collaboration; Hands on learning/ building/ manipulative materials; Real-world context
3. ***Potential for positive student academic impacts***, e.g. Increased creativity, higher order thinking, problem solving; Improved science and/or math learning; Learn design process/ engineering skills; Increased vocabulary/ concept development (general); Increased communication skills, including reading, writing, presentation, and ELA
4. ***Potential for increased student vocational/career awareness-*** Increased awareness- science, technology and/or engineering careers
5. ***Other,*** i.e**.,** Benefits to teacher; General or global benefits to student
6. ***No positive impact***

Triangulation

To strengthen the findings, and expose any potential biases in the data, results of the DET sections of the survey are compared with the teacher responses to open-ended questions. In addition, a small group of elementary teachers (N= 3) were interviewed to provide a check on the findings drawn from the survey results. Panel experts were sought through informal channels for current public and charter school teachers who had several (3+) years of experience teaching elementary science; were seen as expert and/or reflective science educators; held leadership positions in their schools and districts, and had trained and used the engineering curriculum materials adopted by Delaware. Each agreed to participate in two 45 minute semi-structured interviews. The first interview asked about their opinions and beliefs regarding the integrated engineering and science curriculum and for their reflections on the findings regarding the online teacher survey. The second interview asked their opinions regarding the findings of the curriculum analysis in Chapter Four. (One of the three was not available to participate in the second interview). Interviews were recorded and transcribed; participants were asked to review transcripts for accuracy.

For this survey of teacher knowledge and beliefs of the elementary engineering initiative, the three teachers were asked to reflect and comment on the survey results. They also talked about their experiences with the curriculum, relative benefits they may have observed, and whether and why the program works. Their observations are reported in this chapter’s discussion section. Institutional Review Board determined this study’s data collection as exempt from review. See Appendix D for interview protocols, Appendix E for the IRB certification letter and Appendix F for interview consent form.

Survey Participants

Survey respondents varied regarding years of teaching experience and represented different locations. They represented schools in all three counties, with slightly more than half (54.8%) from New Castle County (see Figure 1). A few (3.7%) taught in Charter schools. Approximately ten percent (10.2%) reported that they taught multiple grades. The remainder was distributed across the grades K-5 with a slightly larger percent of respondents (28.5%) at second grade (see Figure 2). Almost half (47.4%) have taught more than eleven years while 5.2% have taught fewer than two years (see Figure 3).

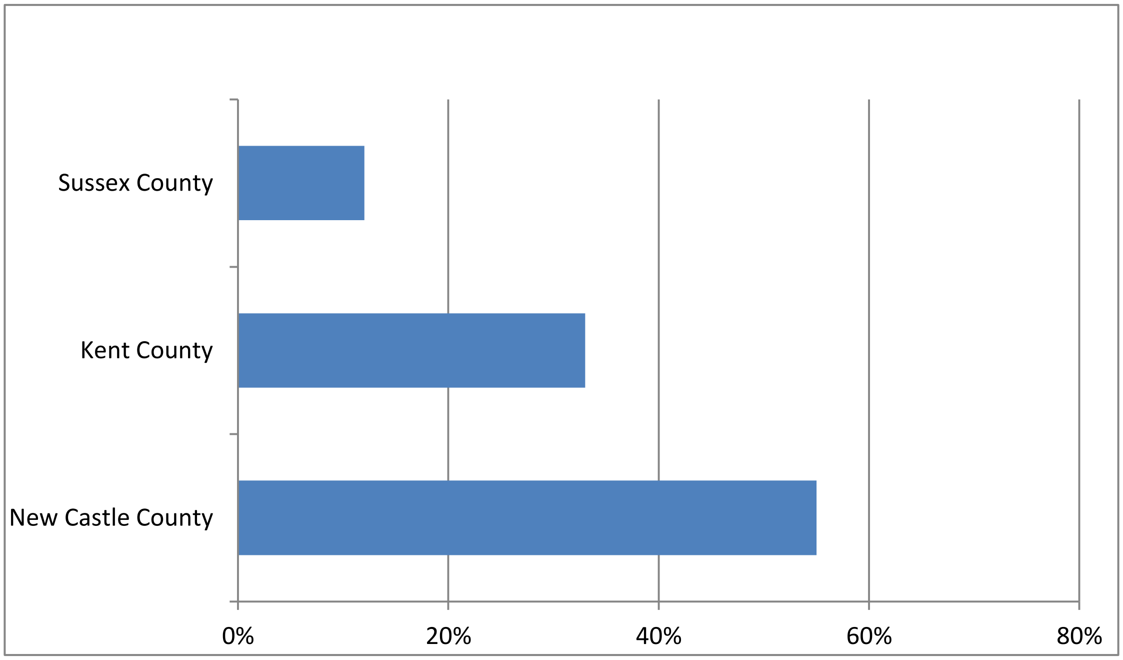

Figure 1 Locations of teachers' current schools by county (%)

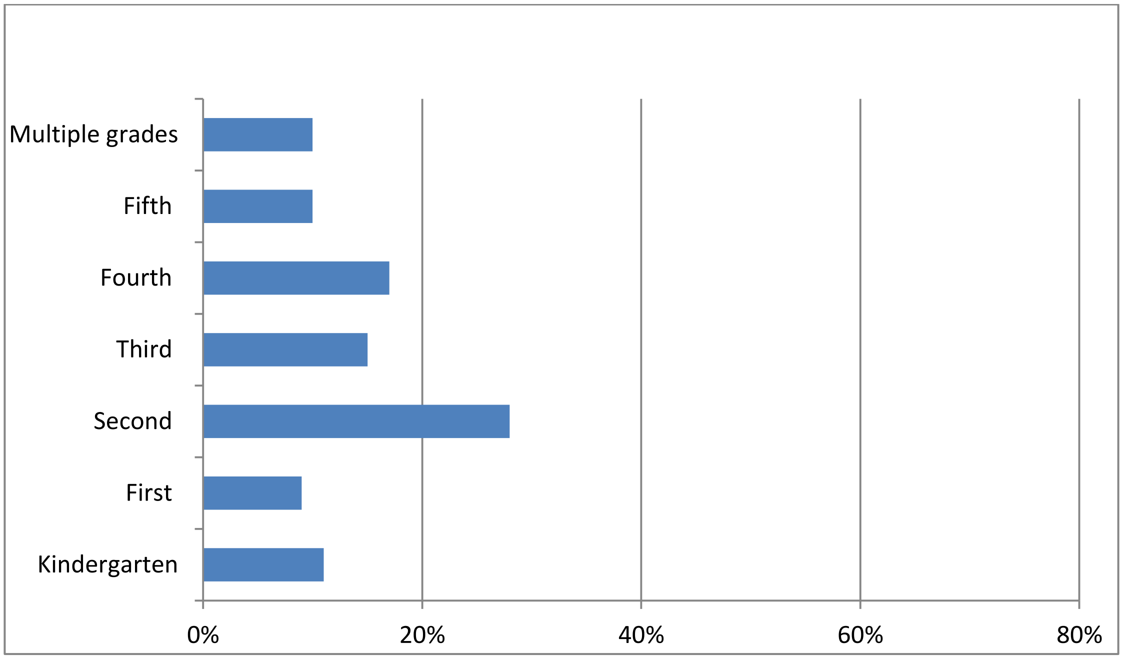

Figure 2 Teachers’ current grade level assignments (%)

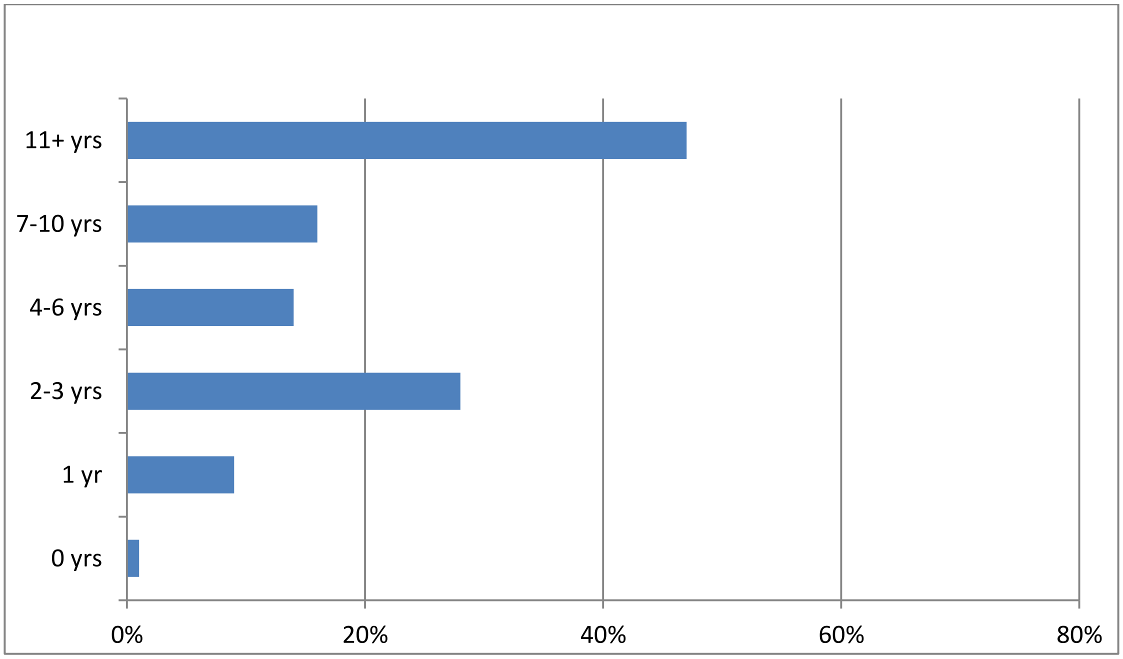

Figure 3 Teachers’ years of teaching experience, including this year (%)

Approximately ten percent (9.6%) reported they had specialized degree or training in a STEM field. Examples included degrees in biology, architecture and design, environmental studies, or mathematics. Another teacher who indicated special training specified attending professional development events in four of the Engineering is Elementary kits through the curriculum publisher, Boston’s Museum of Science.   More than one-fourth (29.0%) responded *somewhat* or *very much* when asked if their pre-service training included “any aspects of engineering.”

More than one-fifth (22.6%) have trained other teachers in science kit use. Almost one in six (16.9%) have led a science or engineering extra-curricular activity, summer group or club. A small number (7.4%) currently do not have teaching responsibilities that include science. Teachers in this category reported duties such as remedial reading and ESL (English as Second Language).

Finally, more than half (60.1%) reported they had attended at least one training event in the engineering curriculum through the Delaware Department of Education/Delaware Science Coalition. More than one-fourth (27.5%) reported they had not attended any training. The small percent (12.3%) that did not respond to this item was removed from comparison of teachers with and without training that are reported in findings below. See Figure 4 for teacher experiences.

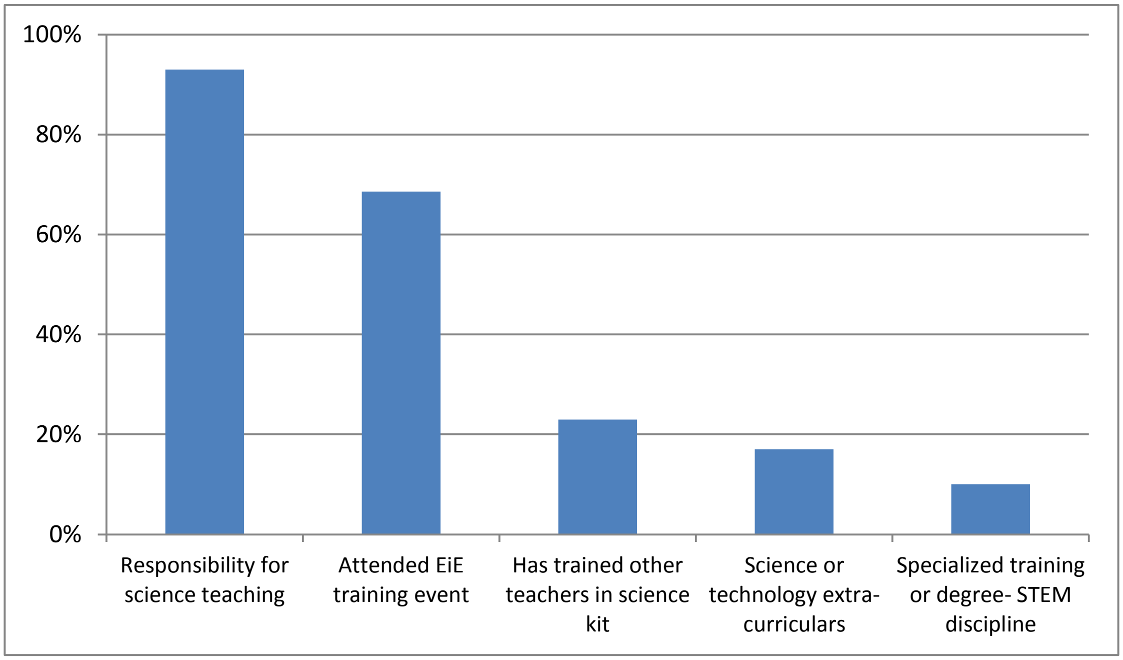

Figure 4 Teacher experiences related to elementary engineering and science (%)

Findings

Findings for this study are reported below in relation to the focus questions—first the overall survey results, then responses compared by teacher training status. Complete survey results are in Appendix B. Comparison between teachers who had and had not yet attended training was tested for significance using chi-square; results of these analyses can also be found in Appendix C.

Finding 1. Almost all of the teachers see engineering as beneficial to society. Almost all believe that engineers are skilled in math, science, and communication. All agree that engineers make "good money."

While almost all (98.5%) agreed *very much* or *somewhat* that "Engineering has positive consequences for society," and 84.5% believe "engineering should be integrated into the K-12 curriculum, more than half (54.8%) indicated they were *not much* or *not at all familiar* with engineering (see Table 10). All agree engineers do well in science and math and almost all (98.9%) agree that engineers "earn good money" (see Figure 5).

Table 10 Teacher knowledge and beliefs about engineering, beliefs about engineering education (%)

	Very much	Somewhat	Not much	Not at all	Total N
Engineering has positive consequences for society.	62.7	35.8	0.7	0.7	134
I believe engineering should be integrated into the K-12 curriculum.	41.9	42.6	14.7	0.7	136
How familiar are you with engineering?	5.8	39.4	40.9	13.9	137

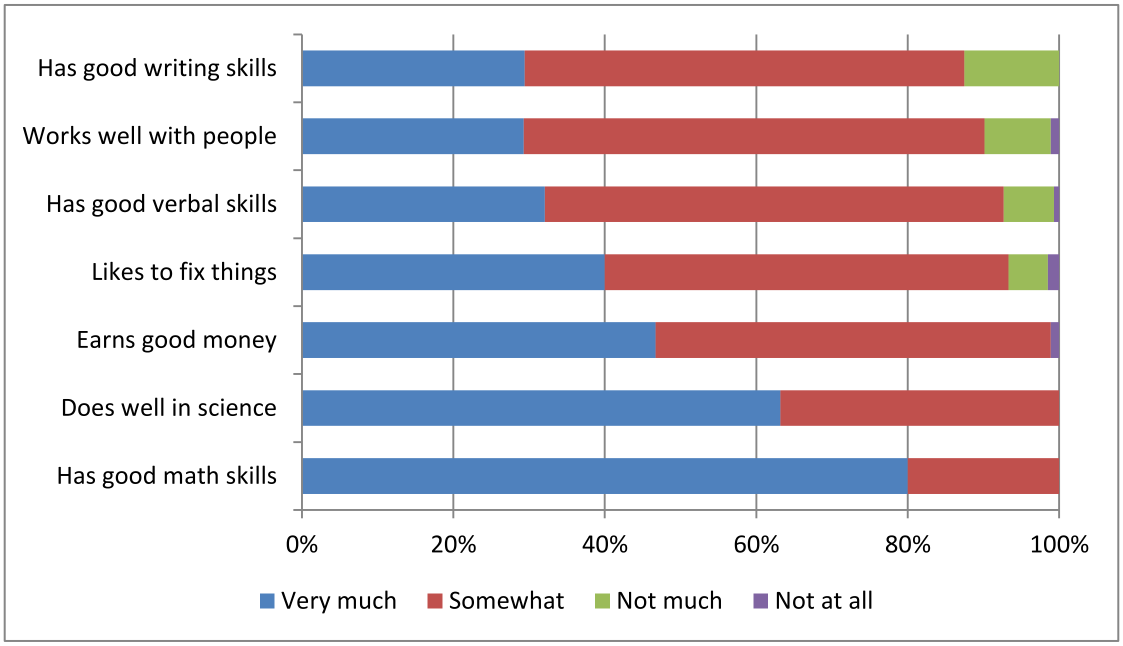

Figure 5 Teacher beliefs about a typical engineer (%)

Finding 2. More than half have a friend, family member or acquaintance that is an engineer or works in an engineering career.

Teachers were asked to recall all the formal and informal sources of their information about engineering: from friends, family, and acquaintances (56%), various media— books and magazines (33%), TV (26%), and movies (13%)—, academic courses (18%) and/or high school or college advisors/counselors (17%). Almost one fifth (19%) indicted they had learned from other sources, specifying prior work experience in an engineering or technical setting; visiting a robotics lab; attendance at district or state professional development; reading kit materials; and/or speakers at national science education conferences. Because teachers could indicate more than one informative source, percent total is greater than 100 (see Figure 6).

Chi-square tests compared responses from those who reported a personal relationship with an engineer to those without one, but no significant differences were noted. Personal knowledge did not significantly increase self-reported familiarity with engineering or with the confidence to teach the new engineering curriculum. Ideas about typical engineers or the value of teaching engineering in grades K-12 were also similar regardless of a personal relationship. See Appendix C for results of chi-square tests of these two groups’ responses.

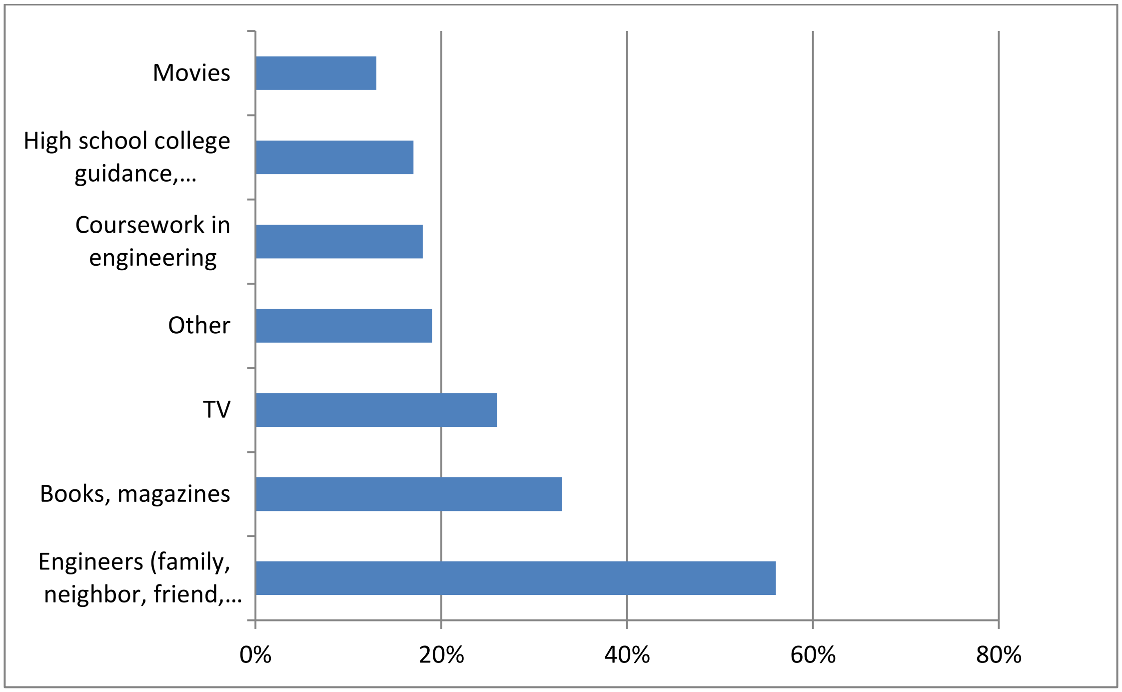

Figure 6 Sources of teachers’ information about engineering (%)

Finding 3. When teachers describe engineering, it is most often characterized as designing solutions and problem solving.

An analytic frame was developed to classify teacher descriptions of *engineering* as either naïve or accurate. Accurate descriptions included one or more of three key characteristics: Practice of problem solving; Socio-cultural aspect; and Utilizes specialized knowledge, skills, and tools. For examples of key characteristics described in teacher responses, see Table 11. While a few responded “I don’t know” and a few responses were coded *other* (e.g., “A hard major to get into in college”), most (77.0 %) associated engineering with the practice of problem solving and design. Because teachers could describe engineering using multiple traits, column total is greater than 100%. Less than one-fourth (22.0%) described engineering using two characteristics while very few (4.0 %) described it by using all three key characteristics. It was noted that a few teachers described an engineer rather than engineering. Their responses were coded by applying an adaptation of the same three characteristics, as in the example in Table 11, "They are very verbal and communicate well with others." (For examples of statements with multiple codes, see Table 12).

Table 11 Teacher responses exemplifying coding scheme: How would you describe engineering to a friend? (Multiple responses; total> 100%)

Characteristic	Examples of teachers response	% (N)
Naïve description	Building things	7.0 (7)
	Maintenance of technical systems	
Practice of problem solving (PS)	The process of developing a plan to build or make things work efficiently	77.0 (77)
	Being able to construct a strategy/ technology to solve a problem.	
Utilizes specialized knowledge, skills, and tools (SKT)	Analytic application of mathematics and science principles to work on projects in various applications	39.0 (39)
	Having the knowledge to design, build, and repair machines. Knowing how to measure precisely and/or understanding chemicals.	
Sociocultural aspect (SA)	They are very verbal and communicate well with others.	5.0 (5)
Don't know or unrelated comment	Not sure	5.0 (5)
	A nerd or a dork	

Table 12 Teacher responses exemplifying multiple codes: How would you describe engineering to a friend? (N=26; 26% of total)

Multiple characteristics	Teacher response	N
Two characteristics	(PS, SKT) Engineering is a field of study where a person uses math and science knowledge to solve a real-world problem in a unique way;	22
	(SA, SKT) Engineering is a process of a lot of different things—Making, creating, integrating, and writing are all wrapped up into one.	
All three characteristics	(PS, SA, KT) I believe engineering is an area where individuals problem solve, collaborate, and integrate math, science, and technical skills all together to create solutions	4
Total		26

Finding 4. Teachers identified many reasons to teach engineering. However, the largest percent see this initiative as an opportunity for students to enjoy learning.

Most agreed they are motivated to teach engineering for a variety of reasons, e.g. to help students understand technology (89.6%) and to prepare them for careers in science, engineering and technical fields (77.9 %). The highest area of agreement was "To promote an enjoyment of learning" (95.1%) while the area of least agreement was "To promote understanding of how engineering affects society" (70.4%). See Figure 7 for teachers' responses.

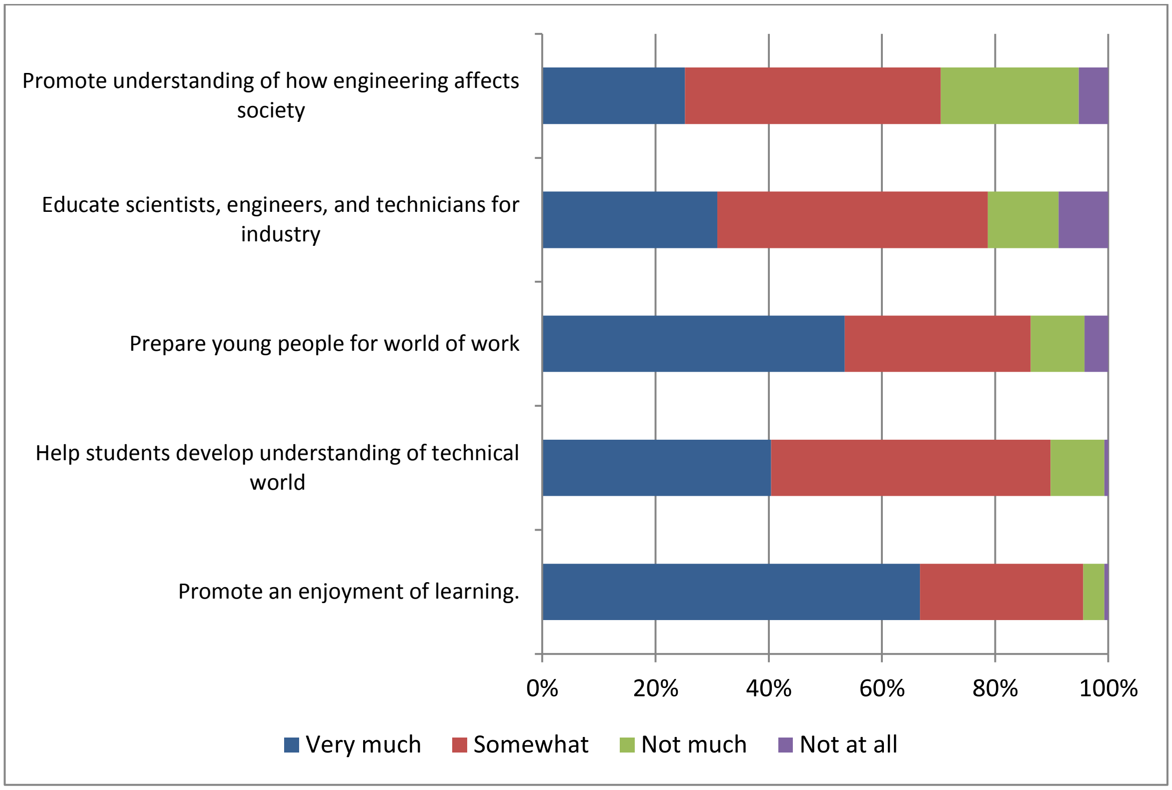

Figure 7 Teachers' motivation for teaching engineering (%)

In addition, teachers were asked, "When I think about using this engineering curriculum in my science classroom, the biggest advantage I see is—." Analysis of open-ended responses supported findings seen in Likert-type survey items (above). Fewer (27%) anticipated vocational benefits, while more anticipated benefits to student academic learning (48%). Table 13 lists the themes and examples of survey responses that illustrate each. Because some teachers named more than one advantage, column does not total 100%.

Table 13 Teacher responses exemplifying themes re: advantages of elementary engineering adoption (N= 100)

Themes	Examples teacher responses	% (N)
Improved student learning: academics	Deeper knowledge of math and science; Inspire and excite children to understand applications of science/math.	48.0 (48)
Improved or expanded course curriculum	Will help to keep us up to date with technology and how it affects all the things around us in the world. It would take learning outside the classroom to real-life things.	44.0 (44)
Increased student engagement/ motivation/enjoyment	The kids will enjoy it; The kids are excited and interested in it.	30.0 (30)
Improved student career awareness	Develop a sense of whether they want to work in this field.	27.0 (27)
No advantages anticipated	Students need to know the basic reading skills first.	4.0 (4)

Finding 5. Most, but not all, believe engineering should be included in K-12 curriculum, but almost two-thirds do not feel confident about teaching it.

When asked about their goals for teaching engineering, more teachers agreed that they would like to teach their students “to understand the problems to which engineering can be applied” (88.8%), “the science and or math of engineering” (88.3%), and “to understand the design process” (86.8%). See Figure 8.

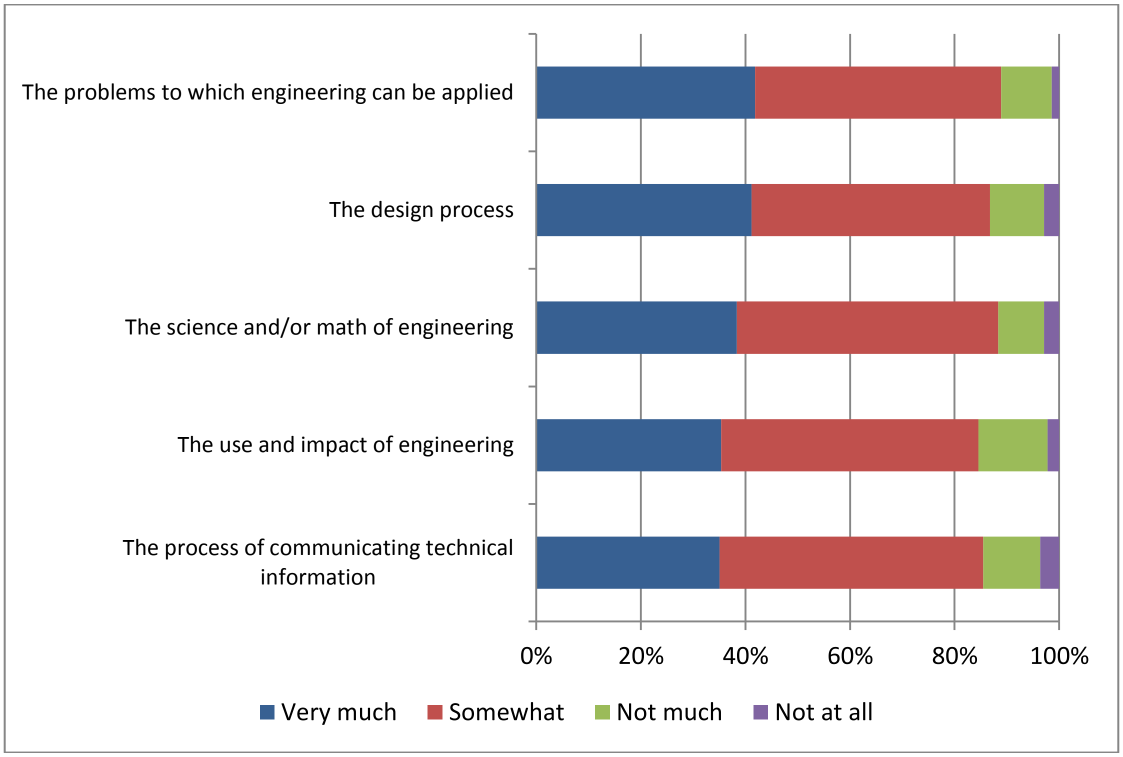

Figure 8 Teacher goals for teaching engineering (%)

Finding 6. Almost all believe that the lack of teacher knowledge and lack of time to learn about engineering are major obstacles to the program's implementation. Almost all are willing to attend some form of professional development.

Delaware's teachers' opinions about barriers to implementation repeat those reported in the research literature. Few feel confident about teaching the new curriculum (38.6%), and many indicated that lack of teacher knowledge (89.6%) and lack of time to become prepared (94.1%) were two barriers to implementation. (See Figure 9.) When asked which forms of professional development they might be interested in attending to learn more about engineering, more indicated "in service training" (78.1%) and "workshops" (73.6%). See Figure 10.

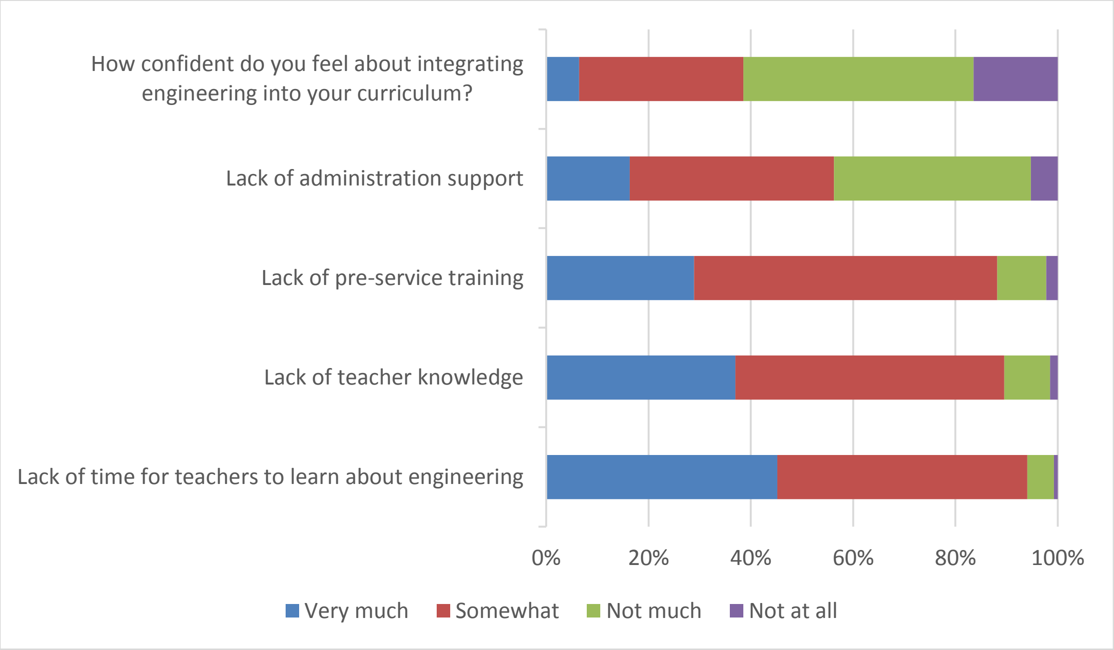

Figure 9 Barriers to integrating engineering (%)

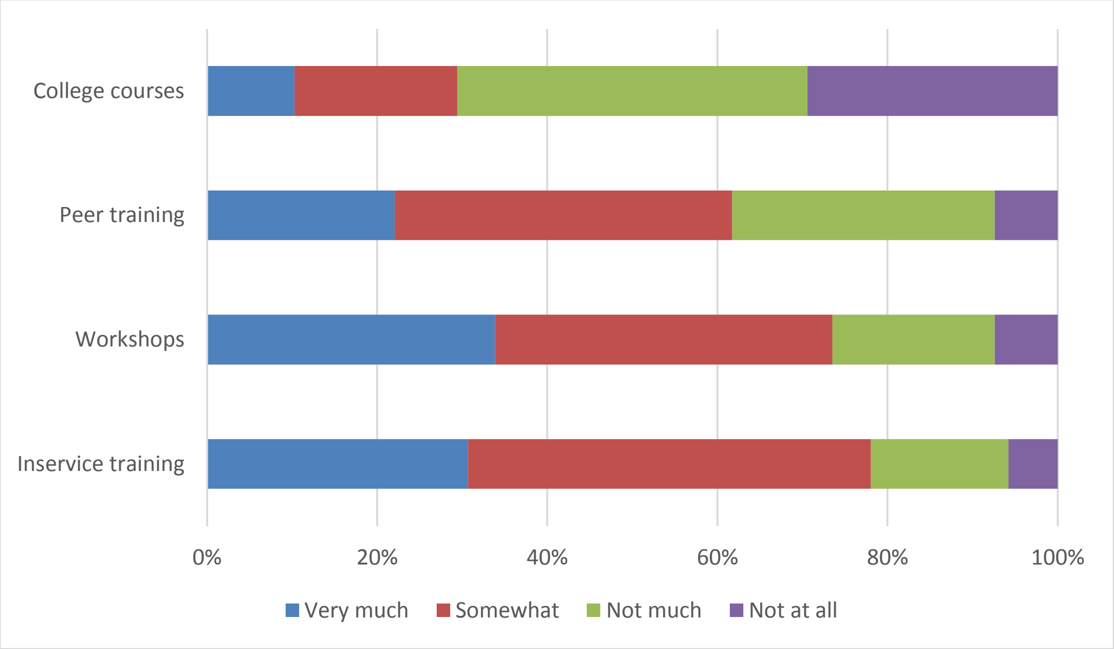

Figure 10	Teachers' interest in learning more about engineering through… (%)

Finding 7. Almost all acknowledge some personal concerns regarding the new curriculum.

Their open-ended statements of concern affirm this lack of confidence and desire for more information. The analytic frame, Stages of Concern, was applied following the protocol of the authors (Hall & Hord, 2010). An example of coded teacher responses is shown in Table 14. Approximately half (51.9 %) reported informational and personal concerns, either in combination with other concerns (e.g., management, student impact) or as a single most pressing concern. Both informational and personal concerns are typically seen in early phases of adopting an educational initiative.

Concerns are not mutually exclusive. Nearly half (45.3%) offered multiple concerns and these tend toward meaningful patterns. For example, 87.0% of those combinations included some concerns for self, i.e., needing information (Stage 1) or lacking confidence that they are able to meet program demands, including necessary qualifications, level of effort and/or instructional abilities (Stage 2). Examples of responses showing constellations of concerns are in Table 15.

Table 14 Teacher responses exemplifying Stages of Concern (N=106[1])

Stage of concern	Example teacher response	% (N)
Awareness	I would think [it] would best be taught by an experienced engineer or an education professional with engineering coursework.	2.8 (3)
Informational	How would it relate to the Common Core for my grade level?	39.6 (42)
Personal	…not having enough time to teach it properly [and] having to invest significant time in order to feel comfortable teaching it.	22.6 (24)
Management	Making sure I have the necessary materials to teach the information in the curriculum. [And] the amount of time given to be able to teach the information.	56.6 (60)
Consequence	Students do not understand the process or see how it applies to them.	20.8 (22)
Collaboration	EiE has some units but they are not at the level of our gifted and talented students, so [our team of teachers worked to] “upscale” two units to our students’ levels.	1.0 (1)
Refocusing		2.8 (3)

[1] Teachers may have offered multiple concerns. Total N> 106.

Table 15 Teacher responses exemplifying combined Stages of Concern

Stage of concern-level	Example teacher response
Awareness and informational	Lack of knowledge on my part and not being able to clearly teach the needed skills or concepts
Awareness and consequence	I do not have much information. I think that elementary schools should make sure students have a firm grasp of the basics and be motivated to be lifelong learners before adults get all worked up about them learning everything in the universe.
Personal and management	Our current curriculum require all our allotted time for teaching with no time left….I'm not sure how we can adequately implement the engineering program.
Management and consequence	Having the time for students to fully engage in investigating and solving problems….there should be a lot of time for discovery, mistakes, and extension on a project….time is a valuable and finite commodity that does not allow for the luxury of thorough investigations.
Collaboration and refocusing	EiE has some units but they are not at the level of our gifted and talented students, so [our team of teachers worked to] "upscale" two units to our students' levels.
Personal, consequence, informational, and refocusing	I don't know about the technical words. The students don't understand the technical words. Some of the experiments were very time consuming and frustrating for the teacher and students to set up. I don't understand why they only learn about bridges in the engineering curriculum. It would be nice if they could learn about some aspects closer to them-houses, roads, etc.

Knowledge, Goals, and Beliefs Before and After Professional Development

In order to expose typical and pre-existing patterns regarding teachers' thinking and beliefs about the new curriculum, all survey responses were compared between those who had attended elementary engineering professional development training and those who had not yet done so. Chi-square values were tested to determine statistically significant relationships between beliefs and understanding and training condition for responses to Likert-type items. Descriptive comparisons were made for open-ended items regarding teacher definitions of engineering and their concerns about implementation. What follows are findings related solely to significant differences. Results of chi-square tests for items where significance was not found or where chi-square test may be inaccurate due to small sample size are not shown here, however results of all chi-square analysis can be found in Appendix C.

Demographic comparisons

Chi square was used to compare demographics of those who had attended training on the new curriculum to those who had not yet attended. No significant differences were noted regarding grade-level assignments, number of years teaching, county locations, specialized degrees, experiences as kit trainers, or extracurricular experience with STEM activities. While their preservice training differed (more trained teachers' pre service training included *some aspect* of engineering), numbers were too small for chi-square test to be accurate.

F**inding 8. With training, significantly more teachers reported they were more favorable toward and more confident about the curriculum, more knowledgeable of standards, and more likely to use the materials.**

When a chi-square test was performed, no relationship was found between training and the frequency of teachers who indicated they were familiar with engineering. No difference was noted when comparing beliefs statements about *typical* engineers and similar proportions of each group responded they *strongly agree*/ *agree* that "most people feel female students can do well in engineering," and that "most people feel minority students can do well in engineering." Both groups overwhelmingly agreed that engineering "has positive consequences for society. Both similarly agreed that lack of teacher knowledge, lack of administrative support, and lack of time for teachers to learn about engineering are barriers to implementation.

Differences were noted though on items clearly associated with the explicit and intended goals of the professional development program. Teachers with training were more likely to indicate that they use the curriculum, χ^2 (1, N=121) = 14.18, p=0.00; that they know the national standards associated with engineering, χ^2 (1, N=121) = 9.23, p=0.00; and that they feel confident about integrating more engineering into the curriculum, χ^2 (1, N=120) = 9.01, p=0.00. Also, a significantly larger number of those with training reported they believed engineering should be a part of K-12 curriculum, χ^2 (1, N=120) = 5.16, p=0.02.

It is worth noting however, that and nearly two thirds of trained teachers also reported they were *not knowledgeable* about science standards related to engineering and fully half of those who had attended training reported they were *not confident* about integrating engineering into the curriculum (see Table 16).

Table 16 Teachers' beliefs and practices about elementary engineering: With and without training (N)

	Somewhat/ Very much		Not at all/ Not much	
	With training	Without training	With training	Without training
I believe engineering should be integrated into the curriculum. (N=120)	75	29	7	9
I use engineering activities in my classroom. (N=121)	48	8	35	30
I know the national science standards related to engineering. (N=121)	34	5	49	33
How confident do you feel about integrating engineering into your curriculum? (N=120)	41	8	41	30

Just as teachers who had attended development were significantly more likely to value the integration of engineering, they also were significantly more likely to identify these three factors as one of their motivations to teach the new curriculum:

- To prepare young people for the world of work, χ^2 (1, N = 110) = 6.50, p =0.01
- To educate scientists, engineers, and technologists for industry, χ^2 (1, N = 120) = 3.89, p =0.05
- To promote understanding of engineering's effects on society, χ^2 (1, N = 120) = 7.37, p =0.01

Finding 9. More untrained teachers voiced concerns indicating little awareness of the program, while more trained teachers voiced management concerns such as the need for time, materials, and space.

Stages of Concern were identified and compared for both groups. While most teachers in untrained group voiced informational (*Stage 1*) concerns, most concerns of trained teachers focused on *Management* (*Stage 3*). Both groups described *Personal* concerns *(Stage 2*) and both identified concerns with adverse *student impacts (Stage 4)*. Few teacher concerns were noted at Stages 5 and 6—stages associated with curriculum adaptation. Because teachers shared more than one concern, row totals are greater than 100%. The patterns are typical in newly introduced initiatives, i.e., need for information, concerns for self, and need for time to process/practice new behaviors and expectations (see Table 17).

Table 17 Teachers' Stages of Concern: With and without training % (N=106)

	Unaware	Information	Personal	Management	Student Impact	Adaptation
Stage	0	1	2	3	4	5-6
Untrained N=29	6.9 (2)	62.1 (18)	24.1 (7)	41.4 (12)	17.2 (5)	6.9 (2)
Trained N= 77	1.3 (1)	31.2 (24)	22.1 (17)	62.3 (48)	22.1 (17)	1.3 (1)

Rows total >100%.

Finding 10. While teachers in both groups described engineering using one or two key characteristics, there also were teachers in both groups who didn’t know or offered naïve definitions of engineering.

Teachers were asked to describe engineering to a friend, using their own words. Respondents’ depictions of engineering were somewhat similar when the groups were compared. Both were likely to describe engineering in ways that include at least one of three key characteristics. A small percent of respondents from both groups offered a naive view of engineering, for example, building, making, or repairing. Only teachers from the trained group responded they *don’t know* and more trained teachers define engineering as having a socio-cultural component (see Table 18).

Table 18 Teacher definitions of engineering: With and without training % (N=106)

	Don't know	Naïve	Design/ problem solving	Specialized knowledge, skills, and tools	Socio cultural aspect
Untrained N=29	0	13.8 (4)	69.0 (20)	51.7 (15)	3.4 (1)
Trained N=71	7.0 (4)	4.2 (3)	80.3 (57)	28.2 (20)	5.6 (4)

[1]Teacher responses may have indicated more than one component; Rows total >100%

Discussion

This survey elicited teachers' understandings and beliefs regarding a new policy initiative that adds a supplementary engineering program in order to incorporate engineering content into elementary science classrooms. The survey, based on an established instrument—the Design, Engineering, and Technology Survey (DET) (Yasar, et al, 2006), was administered in the early days of the programs' roll-out, offering an opportunity to compare the knowledge, concerns, and expectations of teachers with and without professional development. The questions outlined at the start of this chapter guide the discussion that follows. Both are framed within the idea, "teacher as decision maker."

How do Delaware's teachers understand engineering? What do they believe about engineering and engineers?

One of the obstacles to implementation that was recognized in early phases of the initiative was a lack of shared, coherent definition for STEM. The general public often saw “technology” as synonymous with “computers” and had little understanding of what engineering does or its ubiquity in modern society. In those years, research found that K-12 teachers often held similar vague understanding. This study takes place in Delaware, a state long identified with technology and engineering, including a large workforce supporting an established corporate presence (Delaware Department of Economic Development, in Grusenmeyer, 2007). In this survey, most teachers were found to have a fairly well-developed sense of engineering as a process of designing solutions and solving problems. They believed engineers were skilled in science and math, but also skilled in personal interactions and communication. They saw engineering as valuable to society, regardless of whether they identified a personal relationship with an engineer as a source of their information. They did not see that others thought women or minorities could not succeed as engineers. These understandings held up under comparison, that is, both trained and untrained teachers had similar understandings regarding engineering as a profession and engineers as people. In an earlier study, the DET found teachers reported less familiarity with engineering and more stereotypically negative beliefs, e.g., engineers are unskilled in writing and communication; women and minorities do not make successful engineers (Yasar, et al, 2006). It is worth noting again that a few teachers in the *trained group* provided naïve definitions of engineering.

What did Delaware teachers understand and believe about elementary engineering education?

This survey also took place at the outset of a new elementary engineering curriculum adoption, during a three-year implementation which included professional development for all K-5 teachers of science. Both trained and untrained groups believed that engineering should be included as part of the elementary curriculum. While significantly more of the untrained teachers reported they were not confident and were unaware of the new standards related to engineering, fully one half of trained teachers also stated they did not feel confident about the new curriculum integration.

Interviews with expert teachers served as a check against the small response numbers and the passage of time since the initiative began. Most of these findings were corroborated by the expert teachers when they were asked whether they thought most, some or no teachers they knew would agree with the responses. Few areas of difference were noted regarding knowledge of engineers and engineering, or teacher positive value for engineering to society and to students.

Expectations about the initiative: Advantages, concerns, training, needs

Trained and untrained groups perceived similar barriers to implementation, e.g. lack of teacher knowledge, lack of time to learn about engineering, or lack of administrative support. Many teachers saw potential advantages/benefits of the new engineering curriculum to academics such as science and math and opportunity to increase vocational awareness. This is in keeping with policymakers' statements of intent prior to the initiative's adoption. Large number of teachers in both trained and untrained groups anticipated that one of the program's greatest advantages would be student engagement, enjoyment and motivation. Almost all were open to additional in-service training in order to learn more about teaching this new and valued discipline.

One expert teacher felt that her district was ahead of others in providing support and training in the new curriculum. She felt that most teachers she knew would not be concerned with their own lack of knowledge, but speculated that a few experienced teachers might find the changes more difficult. The other expert teachers however did believe that most teachers they worked with held that concern and that they were mostly not confident about teaching the new materials.

Identification of concerns has been shown to be an important first step in implementing school change, and can serve to evaluate impact and to enhance wide diffusion or adoption. Here, teachers were often seen to hold mixed concerns, possibly due to their familiarity with the engineering profession. While teachers in both groups held constellations of concerns, almost always including concerns related to self, the concerns were qualitatively different between those stated by teachers in the untrained and those in the trained group. These differences also point to a developmental path. Some untrained teachers held similar management or impact concerns as the trained teachers, but more of the untrained teachers expressed a need for more information. Trained teachers often expressed concerns related to issues of program management (e.g. time and materials) but also they were concerned about their own abilities or need to expend effort to develop new behaviors and skills.

A vexing question arises. Why did teachers who had attended a six-hour training workshop differ so little from those who had not yet attended one? It is possible to interpret this seeming lack of PD impact within the constellation of knowledge, goals, and beliefs that inform teacher decision making in the moment. A trained teacher has new knowledge of materials that layer over her existing routines and practices. Even if she values the initiative and sets a goal for her students to learn about the engineering design process, she will continue to reach for those same pedagogical routines (Schoenfeld, 2011), relying on her personal PCK (Pedagogical Content Knowledge). This may not line up with the adaptive, responsive practices seen in Chapter 2 in the Elementary Engineering Expertise Framework (Sun & Strobel, 2013).

Gaps or needs are obvious when considering teachers' need to develop or acquire new instructional routines that encompass fuller context of real-world application and cross-disciplinary connections. Gaining expertise implies time to practice and reflect upon the new engineering pedagogies. Recall that Delaware teachers attended a one-time, six hour workshop, essentially a tour of the new engineering kit. Yet, two factors related to values and beliefs point to an opportunity for positive change. First, Delaware teachers believed the new curriculum will benefit students and society. Second, after professional development, half the teachers reported they were at least *somewhat confident* about teaching the curriculum and more likely to use the adopted materials.

Delaware's elementary engineering initiative did not take place in a vacuum. Some of these features of curriculum unification and integration would soon be imposed into the system and onto schools, teachers, and students. Delaware would be involved in development of new science standards that would ensure a place for technology and engineering in all classrooms, advocating for integration to be accomplished through new Science and Engineering Practices infused throughout traditional content areas and topics. Chapter Four describes an examination of curriculum materials available to support pedagogical change required to attain and enact two of the Science and Engineering Practices envisioned by the Next Generation Science Standards. Do the materials offer sufficient guidance and support for teachers seeking to develop expertise?

Limitations

The method of survey distribution (science coordinators were asked to forward the survey link to their teachers by email) did not allow for calculation of response rate since it was unclear whether they had all done so. Also, had the survey invitation come from a single source, a follow-up or reminder email might have resulted in a larger number of completed surveys. The relatively small number of respondents thwarted analysis of chi square correlations. One example, so few teachers disagreed with the statement that “Engineering has positive consequences to society” that chi-square tests could not be run when comparing pre- to post- professional development teacher groups or when comparing those with and without personal relationships to engineers. It is possible that 30-50 more responses might have allowed testing for correlations.

Also, the high agreement might indicate that survey items themselves may have become out dated, no longer capturing nuances in the public understanding of engineering. Much STEM-mania has erupted in the more than 10 years since the instrument was first published and it is possible that opinions and values have grown favorable, or that responses are perceived as more acceptable or correct than in the past.

However , the potential limitation due to disparity between teachers’ self-reported levels of understanding and confidence (rated on a four-point Likert scale) and their more authentic, day to day understanding of engineering or confidence with teaching the new curriculum was partially addressed in the survey’s open ended questions. Teachers were asked to define engineering as if to a friend and to elaborate on their concerns regarding the new curriculum and the benefits they anticipate it might yield and results to these questions were presented alongside the ratings, adding a check or triangulation point.

Chapter 4

SUPPORT FOR TEACHING SCIENCE AND ENGINEERING PRACTICES IN FIFTH GRADE SCIENCE CURRICULUM MATERIALS

Historical Context

During implementation and roll out years following Delaware's policy decision to supplement each elementary grade's existing science curriculum by adding one engineering unit, state science leaders were caught in the crosswinds of educational reforms. Not only were the new Common Core Curriculum Standards coming into use, but the Next Generation Science Standards (NGSS) were also issued in 2013, with Delaware as one of the early adopters. These new voluntary national science standards repositioned engineering and technology, infusing them through all areas of science content by way of Disciplinary Core Ideas (DCI), Crosscutting themes (CTs) and Science and Engineering Practices (SEPs). Already working in a three-year timeframe of incremental introduction and adoption of new engineering materials and assessments for elementary science, state leaders announced another incremental and overlapping roll-out to study curriculum alignment with NGSS, plan professional development, and develop assessments.

During these large curricular upheavals, could coherence and cohesiveness be achieved with science and engineering units continuing to be taught and professional development workshops provided? How might teachers come to gain instructional skills they identified needing and move toward those critical science and engineering practices established within NGSS performance evidence statements? "Each state adopting and implementing the NGSS will need to equip and motivate hundreds or thousands of district leaders, principals, and teachers to change their day-to-day practices (Achieve, 2013, p.5).”

Previous research has found that professional development in engineering for elementary teachers emphasized activity completion with an unstated belief that "the essential elements of engineering design were being used, therefore understood" (Custer & Daugherty, 2009, p. 21). During those training events, teachers’ primary focus was on materials, tools, procedures and technical details and not primarily on teaching methods or learning processes (Custer & Daugherty, 2009). Use of science activity kits has been shown to increase student content learning and attitudes toward science over use of textbook-only (Dickerson, Clark, Dawkins, & Horne, 2006; NRC, 2000) regardless of intensive or sustained professional development (Young & Lee, 2005). However, these reports of efficacy predate the new multi-dimensional science standards and are contradicted in rigorous meta-analysis (Slavin, Lake, Hanley, & Thurston, 2014).

While the integrated science and engineering practices (SEP) found in the new standards act as organizational structures for students to demonstrate their understanding of Disciplinary Core Ideas (DCI) and Cross-cutting Themes (CT), the NGSS do not prescribe how they are to be taught, sequenced, or contextualized, specifying only Performance Expectations, i.e., outcomes to be assessed at the end of grade level for K-5 and at the end of grade band for 6–8 and 9–12 (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014; Lederman & Lederman, 2014). If in order to be effective, the integrated science and engineering practices (SEP) require different teaching methods and intentionality in pedagogical routines (Bismack, Arias, Davis, & Palincsar, 2014; NRC, 2012), how might pedagogical practice shift with adoption of integrated science and engineering curriculum? “Well-designed reform-based materials can be a key component of efforts to support teacher change (Schneider, Krajcik & Blumenfeld, 2005, p. 287)."

Curriculum materials have long been recognized as important and dynamic resources in relationship with teachers (Davis & Krajcik, 2005; Davis, Palincsar, Arias, Bismack, Marulis, & Iwashyna, 2014). Efforts to create curriculum materials that both sustain teacher actions and further their learning have also shown positive impact on students' learning (Schneider & Krajcik, 2002; Schneider, Krajcik & Blumenfeld, 2005). Called *Educative materials,* such text-based tools, along with professional development and supportive contextual change, might assist science teachers implement reform curriculum and adopt changes in pedagogy, and is similar to the teacher-guidance feature identified in high quality STEM curriculum reported earlier (Moore, et al, 2014).

At the state level, Delaware required one six-hour training session for each science kit per grade. This was a quick, one-time overview of materials and activities with little or no follow up. This chapter examines the pedagogical message in the teacher manuals/texts in use at the time, i.e., teacher guidance in curriculum materials intended to support teaching practices specific to an integrated vision of STEM. To what extent did these physical teaching resources support teaching and learning of the Science and Engineering Practices that permeate Next Generation Science Standard's vision of disciplinary content?

Curriculum materials in use in Delaware were examined for explicit presence of two of the eight NGSS SEPs directed toward teachers in overview and guidance materials and in lesson plans, instructional materials, and student assessments to find whether and how two practices advocated by the NGSS (Asking questions and defining problems; Engaging in argument from evidence) were intended in then-current science and engineering materials. Specifically the following focus questions were addressed:

- In what ways were *teachers guided* to present/teach two SEPs (Science and Engineering Practices) in Delaware's fifth grade science and engineering curriculum materials?
- To what extent were these practices *as presented in lessons* consistent with the Performance Expectations advocated by the NGSS?

Methods

Led by these questions and building on Performance Expectations/ Condensed Practices (NGSS Lead States, January 2013b; Achieve, January 2015), a checklist was developed in order to survey three of the four modular science units then used in Delaware's fifth grade classrooms to determine whether the practices were present and the extent they were consistent with new standards documents. Through this process, gaps were identified where appropriate and valuable curricular improvements might be made.

This chapter is reported in sections. The first addresses the choice of materials, the SEPs used for analysis, and the development of the coding checklist/ framework. The second presents findings of the curriculum analysis, each in turn. Evidence of findings is illustrated using excerpts from the teachers' manuals and lesson plans, and findings are summarized in a modified conjecture map. Finally, using the information obtained through curriculum analysis, and using insights developed from interviews with expert teachers, reflections and recommendations are offered to strengthen and support teaching strategies and to bridge gaps. See Table 19 for overview.

Table 19 Methods and sources of data collection and analysis, Curriculum study

Question	Data Source	Data Analysis
In what ways were **teachers guided** to present/teach two SEPs (Science and Engineering Practices) in Delaware's fifth grade science and engineering curriculum materials in use at the time of NGSS adoption?	Teacher manuals and student materials for *Mixtures and Solutions (FOSS), Ecosystems (STC)* and *A Slick Solution (EiE)*	Document analysis guided by NGSS science and engineering standards, within and across units Asking questions, defining problems Engage in argument using evidence
In what ways are the three units' representations of the SEPs consistent with the vision of the NGSS?	Teacher manuals and student materials for *Mixtures and Solutions (FOSS), Ecosystems (STC)* and *A Slick Solution (EiE)*	Modified Conjecture maps

Topic Selection: Science and Engineering in Ecosystems

Three modular units were selected for this investigation, all adopted by Delaware Science Coalition for use in fifth grade public and charter classes: Full Options Science System (FOSS) *Mixtures and Solutions*, 2nd ed. (Regents of the State of California, n.d.), Science and Technology Concepts (STC) *Ecosystems* (Smithsonian Institution, n.d.), and Engineering is Elementary (EiE) *A Slick Solution* (Hester, Pederson, & Favazza, 2011). EiE kits, such as *A Slick Solution*, were developed to complement one of several science kits in wide use across the US, such as STC *Ecosystems*. Solely analyzing these two units, however, offers a disconnected view of elementary engineering as 'supplemental' rather than portraying it as a central to an integrated science curriculum. Casting this wider view to include a third unit not linked with EiE—*Mixtures and Solutions*—more closely resembled the curriculum context envisioned by the new standards, experienced by students, and enacted by classroom teachers at that point in time.

The three modules/kits were similar in that all include these components:

1. Teacher manual in the form of a binder with
    - Overview section spelling out program goals, student outcomes, guiding standards from professional organizations, philosophy of education and/or principals of teaching and learning to orient the programs' authors;
    - Background information directed to the teacher regarding necessary content knowledge;
    - Directions for introducing and carrying out student activities that lead to/develop the students' conceptual understanding and skill mastery;
    - Important teacher practice and management tips posted throughout the activity pages;
    - Formal and informal assessments; extension and/or remedial activities; homework suggestions; copy masters for parent communication; sources for additional resources—print, digital, and video.
2. Student reader/workbook for each student
3. Totes or bins with sufficient supply of most consumable and non-consumable materials (beakers, filters, hand lenses, thermometers, powdered solutes such as alum and citric acid, etc.) for individuals or small groups of students to perform all the activities as described

Delaware was one of the states that participated in the development and piloting of STC *Ecosystems* (Smithsonian, n.d.) and the kit was in use in the state's mandated fifth grade science curriculum prior to the EiE adoption. *Ecosystems* teaches the role of environment and its impact as students investigate ways that plants and animals connect to each other and to their physical environment. Students build physical models (aquaria and terraria) then connect them into an eco-column to study the effects of typical types of run-off on the mini ecosystem. Along the way they learn to make predictions based on evidence or prior knowledge; about the purpose of collecting data from multiple samples; and the importance of creating and observing change in an unaffected sample, i.e., the experimental control. They are guided to evaluate their own questions as tool to focus and drive the design of an experimental inquiry, and to revise both the question and the plan to provide useful and clear data. To introduce engineering into fifth grade classrooms, Delaware chose this STC unit's EiE counterpart, *A Slick Solution* (Hester, et al, 2011).

Like all EiE kits, *A Slick Solution* introduces and motivates student learning activities through a realistic but fictional narrative, i.e., students read about another boy or girl trying to solve an unstructured problem, introducing them to engineering as an enterprise and engineering as a design process. In this story, two children in the American Northwest meet an environmental engineer and help to devise a systematic method to clean an environmental spill located along a wilderness riverbank. In addition, each EiE unit links to existing science content standards. Here, the unit materials revisited the concept of environmental interdependence that was also taught in the *Ecosystems* kit. Like all of the EiE units, the primary goal of *A Slick Solution* is to teach students to understand and use the Engineering Design Process to solve a problem similar to that shown in the story (see Figure 11). In this unit, students explore materials to contain and absorb an oily substance in a shallow pan of water, then design a procedure to solve the problem of oil spills in a natural setting. They are provided material costs and a budget that act as constraints to the project and to subsequent redesigns.

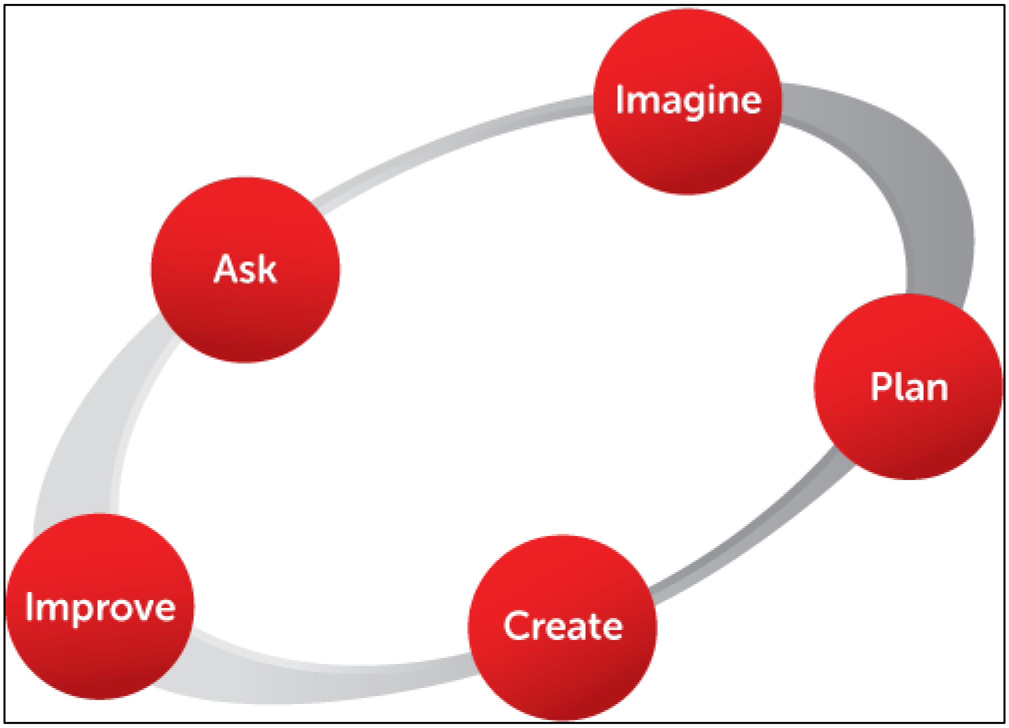

Figure 11 Engineering Design Process from Engineering is Elementary

In an attempt to more fully understand the experience of instruction of both science content and science and engineering practices, a third publisher and kit was selected for this study. *Mixtures and Solutions,* (Regents of the State of California, n.d.) was selected because its content seemed to be a natural and easy fit with the content in the first two. This kit/unit leads students to experience fundamental concepts of physical matter such as mixture, solution, concentration, and saturation, and also teaches simple forms of separation and analysis. While these seem like important concepts and skills potentially useful in an investigation of an environmental clean-up of unknown chemical spills, FOSS allows students to experience the materials freely, offering little context for student inquiry. The three units together represent differing views to science education and provide a greater opportunity to examine curriculum integration implied in the STEM movement.

In this study, a checklist was developed to identify components of the intended curriculum in teacher manuals and student textbooks. Because evidence statements capture the behaviors that substantiate student learning related to the SEPs, the checklist was adapted from the corresponding Performance Expectations (NGSS Lead States, January 2013b) and Evidence statements (Achieve, January 2015). This section will describe the Science and Engineering Practices (SEPs) and explain their position within a multi-dimensional vision of science education.

What Does the NGSS Say about SEPs?

Next Generation Science Standards (NGSS) uses the term Science and Engineering Practices (SEP) to identify those student behaviors that previously had been referred to as “skills,” “applications,” “activities,” “hands-on,” “inquiries,” and “processes” (Gross, Buttrey, Goodenough, Koertge, Lerner, Schwartz, & Schwartz, 2013, pp.20-21).The new term “practices” emphasizes students’ need for both skill and knowledge in order to participate in the related and overlapping activities of science and engineering, a vision of learning as deeper and multi-dimensional. Today’s practices are visible demonstrations of performance and understanding that build together to explain and predict natural phenomenon, thus “the framework seeks to illustrate how knowledge and practice must be intertwined in designing learning experiences in K-12 science education (NRC, 2012, p.11).” The NGSS identified and described eight essential practices in which all students should participate, with differing levels of practice for every grade level (NGSS Lead States, 2013a):

1. Asking questions and defining problems

2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Central to a vision of integrated science education

Although content and practices join naturally in the work of scientists and engineers, in traditional K-12 science education, content (lectures, concepts) was contrasted against process (labs, demonstration) in outcomes, goals, and assessment (NGSS Lead States, 2013c, p. 11). The NGSS describe a coherent idea of science education where all dimensions are combined to work together. This multidimensional vision is “perhaps the most significant way in which the NGSS differs from prior standards documents (NGSS Lead States, 2013b, p. 48).” Critics of the new standards caution that practices should not substitute for content (Disciplinary Core Ideas- DCI) and that curriculum must fill in where the new standards are vague in order to support, motivate, and guide good teaching by explicitly identifying and detailing content (Gross, et al., 2013).

By design, SEPs are neither mutually exclusive nor sequential steps in a process. They intersect and interact within authentic inquiry. For example, asking a question may lead to analogy, diagraming, and/or prototyping—all forms of modeling. Findings and observations might direct students to think mathematically and/or to present data and communicate with others using appropriate and understandable language. In turn, these findings may require an explanation to be developed or revised. Deep engagement with these practices was intended to improve student understanding of the phenomenon (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014; NGSS Lead States, 2013a).

Selection of practices to guide this study

Selection of the two SEPs that guide this study's analysis was rooted in recognition that as depicted by the NGSS, science instruction is language intensive (Bybee, 2013a; Duschl, Schweingruber, & Shouse, 2007; NRC, 2007) and that an effective, phenomenon-centered classroom is marked by lively science talk and argumentation to uncover explanation and understanding (Keeley, 2014; Schunn, 2009). The use of language allows student experience to move between the experience of concrete phenomenon and the abstract world of ideas, explanations, and predictions (Bransford, Brown, and Cocking, 1994; Osborne, 2010; Willingham, 2009).

Research has shown that collaboration and reflection as well as argumentation and presentation of evidence can be taught to students regardless of prior achievement (Llewellyn, 2007; Schunn, 2009) and learning scientists recommend asking deep explanatory questions and using concrete examples to explain abstract concepts (Duschl, et al, 2007).   Student answers are important but will only make sense in relation to the questions asked (Willingham, 2009). In a constructivist or knowledge integration orientation to teaching and learning, these two SEPs might form a sturdy pedagogical routine, providing structure to pull other practices into meaningful use (Brooks & Brooks, 1999; Dantonio, & Beisenherz, 2001; Osborne, 2010). The next section addresses the two, specifically their definition and importance to science education, how they might appear in elementary science classrooms, and how they were adapted to create a coding checklist.

Asking questions and defining problems

In earlier science education policy documents, inquiry played a prominent, defining role as steps in an investigation similar to the way scientists think and work and inquiry was a standard to be attained as any other. Questions – whether formulated by student or by teacher – were intended as central drivers to the development of science content and skills (AAAS, 1993). However, when enacted, inquiry was found to be shallow. Teacher-directed questioning or adherence to a contrived “scientific method” lacked authentic discourse issuing from well-developed questions and avoided students’ engaging in with analysis or argumentation (Llewellyn, 2007). Instead of struggling to identify a fundamental, driving question or to communicate and justify explanations, instructional inquiry was perceived as data-gathering: procedural, prescribed and ineffective at supporting true concept development (Duschl, 2008; McGonigal, 2006; McNeill & Krajcik, 2008; Zangori, Forbes, & Biggers, 2013).

Still, the practice of asking questions and defining problems remains central to science and engineering and to empirical knowledge. When existing understandings fail to account for observations, questions emerge and re-emerge. Important and well-defined questions are resolved through satisfactory negotiation between observation, evidence, and explanation. In addition, asking questions and defining problems establishes a purpose against which to seek and evaluate text-based sources of information about the phenomenon (Bybee, 2014; NRC, 2007). The NGSS propose to reinvigorate scientific inquiry by building on the expectation that all students ask questions and define problems and by ensuring that all students explicitly return to this practice when evidence warrants (NGSS Lead States, 2013b).

In application, how might this practice appear in an NGSS-informed elementary science classroom? The lesson might begin with an observation, comment, interesting question or an initial challenge. Although students may ask questions of the teacher and each other, true scientific questions surface when seeking additional knowledge to understand or explain a natural phenomenon. For example, questions and subsequent investigations might be motivated solely by curiosity, or they also might arise with the need to solve a problem, evaluate a model, or verify a prediction. Students determine what they already know about the topic or phenomenon under study and explore the science to fully answer their question or resolve their challenge. Later another question may develop in an iterative, generative manner (Keeley, 2014). The NGSS Evidence statements (Achieve, January 2015) offer examples of classroom behaviors for students Grades 3-5 that, together, constitute this practice. From this description of component behaviors, a checklist was devised in order to survey the curriculum materials (see Table 20).

Table 20 Component behaviors adapted as checklist: Asking questions, defining problems (Adapted from NGSS Evidence statements Grades 3-5)

Asking questions, defining problems: Component behaviors	Are these behaviors portrayed / enacted in lesson plans, notes to teacher, or student materials? No-Yes
Student questions consider phenomena of the natural world	Do student formulate questions?
	Do students (or teacher) critique or reflect on whether questions address the phenomenon under study (DCI)?
Identify the scientific nature of the question	Do students critique or reflect on whether answers to that question might lead to understand of how the phenomena works and/or how that phenomenon impacts the dilemma they are addressing?
	Do students critique or reflect on the testability of the question in this setting?
Identify the problem to be solved	Do students identify a simple problem?
	Do students critique or reflect on their understanding of the science related to the phenomenon and needed to solve the dilemma?
Define criteria for and constraints to the successful solution*	Do students define the indicators of success?
	Do students define the constraining factors that may be met and/or must be addressed by a successful solution?

Argumentation and evidence

In earlier policy and standards documents, argumentation was a valuable but aspirational skill. “Students of all ages should learn to ask and answer “how do you know?” and “Why do you believe this to be true?” when offered “Everybody knows it” as evidence (Rutherford, & Ahlgren, 1991, p. 182).” Teacher actions and student outcomes were clearly spelled out, “As students come up with explanations for what they observe or wonder about, teachers should insist that other students pay serious attention. Students hearing an explanation of how something works proposed by another student or by teachers and other authorities should learn that one can admire a proposal, but remain skeptical until good evidence is offered (Rutherford & Ahlgren, 1991, p. 284).” In practice though, researchers found that argumentation was sidelined as an untested skill, unaccepted as either official curriculum content or as a path to enhance student understanding and concept development (Erduran & Jiménez-Aleixandre, 2008; Osborne, 2010).

Today’s NGSS recommend that students go beyond merely seeking agreement; that they develop an ability to discuss and evaluate competing ideas and participate in the discussion and evaluation of their own ideas, interpretations, and proposals (NGSS Lead States, 2013a). The new science standards do not redefine scientific argumentation but instead place it at the center of and require its use within the cycle of scientific inquiry and engineering design. Yet, teachers report that creating an environment that *requires* defending propositions was a primary obstacle to students practicing and attaining skill in argumentation (McNeill & Krajcik, 2008).

How might this SEP look in an elementary classroom? Because engaging in argument from evidence requires a talk format where students explain and defend their reasoning to others, it also requires participation in patterns of discourse previously missing (McNeill & Krajcik, 2008). Together the class participates in explaining and defending reasons why something does or does not address the phenomenon or question at hand. Then, after students investigate their ideas, they return to the discussion, possibly to provide new evidence to support or to revise their initial claims. Throughout, a teacher or student might act as group note-taker, making their thinking visible by capturing thoughts, predictions, arguments, claims and evidence for public display on whiteboards, smart boards, chart paper, etc. or for private reflection, in individual student lab notebooks or journals. Students learn that natural phenomenon will be the authority for an idea's acceptability and that they are accountable for the clarity and accuracy of any contributions to the group discussion (Keeley, 2014), leading to deep engagement with meaning.

In engineering, special cases for argumentation include proposal as claim; trade-off and optimization as claim; and also defining constraints and indicators of successful design as claim. All require rationale and evidence to the design team and to the client or consumer. Because that evidence needs to be evaluated for applicability as well as potential for contribution to the solution, students need to identify the scientific understandings regarding the phenomenon they hope to address or to harness in order to achieve their results (McNeill & Krajcik, 2008; NRC, 2012).

Component behaviors related to this practice were summarized to develop an analytic frame and translated into *yes-no* questions to clarify and simplify coding texts (see Table 21).

Table 21 Component behaviors adapted as checklist: Engaging in argument from evidence (Adapted from NGSS Evidence statements Grades 3-5)

Engage in argument from evidence: Component behaviors	Questions to reliably guide coding curriculum materials: Are these behaviors portrayed / enacted in lesson plans or notes to teacher? In student materials? No- Yes
Makes a claim to be supported	Are students asked to make a claim about the phenomenon—e.g. propose a central relationship, or generalization, or predict an outcome if a change is made or a solution adopted? (Claim is related to the DCI and/or dilemma under study.)
Identify the evidence	Do they identify the evidence by describing the data, facts, models they have compiled through reflection, research, and/or observation?
Evaluate and critique the evidence	Do students determine the strengths and weaknesses of evidence, and in grades 3-5, whether it is relevant, appropriate, or sufficient to support the claim?
Reasoning and synthesis	(Gr. K-2) Are students asked to connect/summarize the examples they listed to justify their claim regarding the disciplinary core idea?
	(Gr. 3-5) Do students describe their use of reasoning to connect evidence, data and/or models to the claim? Ex. cause and effect reasoning (this leads to that) or correlational reasoning (if this then that and if less this then less that.)

Methods of Data Collection and Analysis

Teacher materials were examined for evidence of the SEPs as identified by the above frameworks and specifically for their teacher support.

- In what ways were *teachers guided* to present/teach two SEPs (Science and Engineering Practices) in Delaware’s fifth grade science and engineering curriculum materials?

- To what extent were these practices *as presented in lessons* consistent with the Performance Expectations advocated by the NGSS?

First, to determine the ways in which the SEPs were explicitly intended, the sections of the teacher manual that addressed program and unit goals, its instructional overview or philosophy, the standards that guide the program and other meta-directives toward the teacher were considered. Student assessments which identify program expectations, impact or outcomes were also investigated for the indications of measured outcomes, thus implying intended curriculum. Their presence or absence was noted and example wording was collected.

Then, the lesson plans in the teacher manual and accompanying student materials were surveyed for evidence of SEPs in action, as statements of guidance plainly addressed to student and teacher, to teacher only, or whether implied by action to be taken. Samples from the text that illustrate some of the coding decisions (whether *implied*, *stated clearly*, or *omitted*) as well examples of coded passages that did not align well with NGSS vision are found in Tables 22, 23, and 24 below.

For example, Table 22 has passages from two of the kits that illustrate the coding scheme for *one* component behavior out of the *eight* envisioned within the SEP "Asking questions, defining problems"—the requirement that students' questions address phenomenon in the natural world. The first passage was labeled *implied* because the text did not directly talk to the teacher about students relating their question or investigation to the concept of solution and evaporation at the heart of the lesson. It implies however that they <u>might</u> develop some curiosity regarding the phenomenon during the investigation they had just completed.

The second example from Table 22 contrasts with the first. Teachers are directly prompted to open the lesson with a discussion of the phenomenon students had read about and presented in class the day before. Then they are directed to have students develop a question to investigate the phenomenon built on their prior understanding.

The third example in Table 22 labeled *missing altogether* is in an authoritative voice from the text that tells the students to act and tells them to fill in a pre-existing data table fitted with pre-existing observations for the chemicals they will manipulate. Even though students are not invited to develop or explore a question at this point in the unit, they also avoid the heavy cognitive work of recalling what they already know about saturation (the phenomenon) and how this activity might relate, or of predicting and explaining what they anticipate finding (and why). Thus, an opportunity that could or should enact this component behavior ("questions address phenomenon of the natural world") was rated as *missing.* Similar passages that exemplify coding decisions across the three units are seen in Tables 23 and 24.

This coding process yielded a number of data tables for each unit. That is, one table for each SEP, tallying incidents by location and quality, resulted in two tables per unit, with each tally indicated Yes-No- Partial/optional and each tally annotated with comments and page number. This was the raw data that underlies the findings which follow. An example of one table can be seen in Appendix F.

Because the coded statements directed to teachers have pedagogical meaning when viewed in relationship to each other and as an instructional whole within the unit, findings are reported below at the unit level. For example, meta-cognitive behaviors modeled during a think-aloud by the teacher in one lesson might be required of students in the next and may be assessed or evaluated at another point. In another section or text, teachers might be advised to diagnose and shape the students skill at enacting these complex, language-rich behaviors. Alternatively, teachers and students may not be encouraged to enact the SEPs and their components as part of the intended pedagogy or lesson plan. Teachers may not be prompted toward formative assessment or support for students' emerging ways of thinking. Thus, to make sense of the raw data/ tally marks, the findings are presented at a meta-level, by unit.

Table 22 Examples of coded passages- Asking questions, defining problems: Questions address phenomena of the natural world.

Directly stated, implied in action, missing	Passage from student text or teacher manual
Implied within an action	"[After a guided investigation of evaporation] Students may want to add water to see if the salt crystals will dissolve again and evaporate to form characteristic square crystals a second time. Encourage them to do so **if they show an interest**. (Regents of the State of California, n.d., p.1.23)"
Directly stated	"Ask students **what they learned about the three pollutants during Lesson 9's presentations**….In Step 1 students [working in teams] must decide on a specific amount of pollutant and how often they want to add it….**Step 2 asks the students to formulate an experimental question.** This should be specific (for example, will over fertilizing an ecosystem cause an overabundance of plant growth?). (Smithsonian, n.d., pp.101-102)
No, missing altogether	"Challenge: Can you identify the missing chemical? Here is a table of properties for five chemicals. Record your observations about the mystery chemical. (Regents of the State of California, n.d., Student sheet 10)"
Directly stated that this will occur in discussion	"To introduce the goals of the unit, help students understand they will study two different types of environments….Next, display two sheets entitled, 'How living things depend on each other: What we know now' and 'How living things depend on each other: what we would like to find out'… [Student and class responses and questions] provides important information about their baseline knowledge of eco systems. (Smithsonian, n.d., pp.3-5)"

Table 23 Examples of coded passages- Asking questions, defining problems: Define criteria for and constraints to the successful solution of the problem

Directly stated, implied in action, missing	Passage from student text or teacher manual
Directly stated but insufficient for NGSS SEP	"How will you evaluate your oil spill cleaning process? (Hester, et al, 2011, Student sheet 4.3)" [Students are being asked to locate the indicators provided in the handouts. This does NOT meet 5th grade level behaviors in NGSS]
No, missing altogether	"Tell the students their goal is to separate the mixtures so that the water is in one cup and the solid material is in another….Tell the students that a filter might come in handy for separating the mixtures. One type of filter is a screen. Ask students to read and follow the procedures on the sheet. (Regents of the State of California, n.d., p. 1.13-14)"

Table 24 Engage in argument from evidence: Identify the evidence

Directly stated, implied in action, missing	Passage from student text or teacher manual
Implied within an action	[Students develop a plan and follow it to separate dry mixture using filters] "Summarize the results of your plan. Describe how you might improve your separation. (Regents of the State of California, n.d., Student sheet 7)"
Directly stated	[Scenario in assessment- Two students are making instant ice tea with equal amount water, but one student uses twice as much tea and it doesn't dissolve.] "'I think you have a saturated solution,' said Mack. 'Why don't you add more water?' Would Mack's suggestion to add more water work? Explain your answer.(Regents of the State of California, n.d., Student sheet 9)"

Findings

Findings are presented by unit and summarize the extent to which each of the two practices (Asking questions and defining problems; and Engaging in argument from evidence) were explicitly intended as goals or instructional components of this unit. Examples of statements that illustrate the findings are provided. Finally, reflections and recommendations for instructional improvements are offered. Comments and suggestions from expert teachers that both support and challenge the findings and offer ideas to help align the units with the NGSS and support teachers as they adopt new pedagogies are found throughout this section.

Finding 1**. -** ***Ecosystems*** **(Science and Technology Concepts)**

Clearly and explicitly, the focus SEPs are intended to be taught and assessed. Lesson plans follow a constructivist or knowledge integration model of instruction that fits with a complex vision of multi-dimensional science instruction put forth by the Next Generation Science Standards (NGSS).

Each component part of the two SEPs is easily tracked through the unit in its entirety. Instruction follows an intentional, cognitive-based approach: As component ideas and skills are brought to the fore in one section, they are examined and developed then put to use in subsequent sections, allowing new, more complex ideas and more mature skills to gain attention and develop. This method seems to assume a teacher's growth mindset and her skill in purposeful observation and informal assessment.

Goals and standards

Explicitly stated program goals associated with the fifth grade science kit, *Ecosystems* (Smithsonian, n.d.) include helping students to cultivate "scientific attitudes and habits of mind… [and to develop] scientific reasoning and critical thinking [based on] current knowledge about how children learn (Section 1, p.8-9). *Ecosystems* unit was aligned with National Science Education Standards (NRC, 1996) and mapped onto specific lessons—easily identified and followed through the document. Goals targeting the two SEPs were cited in front-matter of teacher manual and taken from different age-bands of NSES standards. From grades 5-8, students are to "ask a question about objects, organisms, and events in the environment; plan and conduct a simple investigation; and use data to construct a reasonable explanation (Section 2, p. 8)." From grades K-4, students are to "identify a simple problem; propose a solution; implement a proposed solution; and evaluate a product or design (Section 2, p. 9)."

Instructional foundation and guidance

When lesson plans are followed in a straightforward manner, it would be difficult to omit or sideline the SEP component skills, as they are central to the instructional philosophy and pedagogical foundation, a four-part learning cycle: Focus, Explore, Reflect, and Apply (Section 2, p.13). Both of the SEPs central to this study are integral to development of understanding as student experience progresses through the phases in lesson activities and assessments, built on authors' beliefs about cognitive development and reflecting a constructivist bent. "Students analyze their observations and data, review their original ideas related to the phenomena investigated, and provide evidence for their explanations of what they have observed (Section 1, p.9)."

In an extensive overview section entitled, "Teaching strategies," teachers are advised to lead class discussions by choosing questions intentionally in order to follow up on student responses and facilitate concept development, helping students make connections, draw comparisons, formulate explanations, or justify conclusions (Section 2, p. 13). There are recommendations for leading a brainstorming session- (to stimulate student thinking or to informally assess prior understanding) and a section on the benefits of cooperative groups (students share ideas and get feedback while learning from one another). There are two sections on using graphic organizers to represent abstract thinking and develop deeper understanding about concepts, terms, processes, and functions. Another section on assessment includes more about using questions and discussion to uncover student thinking.

Formal and informal assessment

Overview notes on “Assessing student’s progress” make a case for assessment that is ongoing and integral to instruction, where students are assessed as they are taught—that is, by *doing.* Assessments of experiments or reports “permit examination of processes as well as products (Section 2, p. 15)” and are intended to gauge scientific reasoning as well as understanding of concepts.

Background information and guidance on assessment is both sizeable and nuanced. It addresses role and types of assessment, providing strategies to support teachers’ informal and formal assessment during task completion, discussions, problem solving, and demonstrations. Additionally, it helps her to identify ways of thinking revealed in verbal expression. One example addressed prediction activities, “Unlike guesses, predictions are based on knowledge and can therefore be used to assess thinking and learning…in both formal and informal prediction activities.… (Section 5, p. 6).” Another resource to help teachers organize individual student assessment data during in situ observations is a checklist of all goals to be accomplished and includes three items which focus on student use of these SEPs: "Planning, implementing, and analyzing experiments and drawing conclusions from the results; Making and testing predictions; Applying previously learned information to analyze a problem and suggest solutions (Section 5, p. 29)."

Lesson plans: Science and engineering practices taught, practiced, assessed

How did statements about unit goals, influential standards documents, and general philosophy of teaching and learning show themselves in turn-by-turn lesson plans? This unit consists of seventeen lessons, scheduled for 45-60 minutes per day for approximately five to six weeks, designed in an instructional arc that authors label as a 'conceptual storyline' where mastery grows in steps or lesson groups. The detailed synopsis that follows endeavors to capture the seemingly understated workings of the instructional arc. The manual groups lessons into 'sub-concepts' seen below.

Lesson Synopsis

Sub-concept 1. (Lessons 1-3). Three lessons across several days examine students' prior understanding of both content (ecosystems) and scientific process and procedure (using models to make careful observation/collect standardized data). After exploring initial understandings via guided discussion and graphic models, pairs of students create model ecosystems (aquaria and terraria linked into columns) to observe, measure, record, and analyze growth and change of both plants and animals. At the same time, class members build and maintain seven communal terraria to use later.

Sub-concept 2. (Lessons 4-7). During this phase, when fish, crickets, and/or pill bugs are added to the eco-columns, students continue with measurements and observations, reporting and sharing findings. Working together and guided by teacher questioning, they discuss dependence and interdependence within and between the systems, leading to initial predictions — how one ecosystem might affect another. Concepts emerge during discussion and are represented in a shared, evolving concept map.

Sub-concept 3. (Lessons 8-13). The instructional focus broadens from modeling stable ecosystems to implications of imbalance and change in the real world. Using six of the shared class terraria (no animals), students expand upon their emerging concepts by designing studies to examine their predictions regarding what changes might occur in the terraria following the introduction of real-world pollutants. The seventh terrarium serves as an experimental control for all. They continue observation, measurement, and data reporting but add new cognitive expectations. Students begin to tentatively revise their predictions and to consider real-world implications of natural and man-made pollutants.

Sub-concept 4. (Lessons 14-17). Students begin to draw conclusions to answer their research questions. Going further, they consider a case study of run-off pollutants from the Chesapeake Bay, an ecosystem in danger. They read about points of view of ordinary citizens, land developers, recreational boaters, and watermen. Student groups each present one community's point of view to the class with the goal of talking about the contributions this group makes to the problems in the Chesapeake Bay, as well as ways this group might help to address the problems. Each team then come up with three possible actions their identified community group might take and advantages to the bay as well as costs or disadvantages born by the group for each potential solution. Students offer and discuss trade-offs by considering their constituent positions, and analyzing the potential cost and benefit of each trade-off to come to a joint proposed solution.

Explicit pedagogy in support of 'Asking questions'

In *Ecosystems*, lessons exemplify the iterative vision of the NGSS where in dialog and discussion students examine and revise their understanding of the disciplinary concepts at the center of the curriculum. Typical lessons plans begin with large-group recap, i.e., *where are we in process or in understanding at this point*? As the group examines, tests, expands, or revises a new question may bubble up to focus and drive the next phase of activity. This SEP is brought forward to be developed in an explicit, methodical way in lesson 10. First, teachers are advised to explore the sports analogy of a race in the day's opening discussion, a familiar example of a fair test with uniform conditions that determines a winner. Then, "Ask students what they learned about the three pollutants during Lesson 9's [readings and] presentations….In Step 1 students [working in teams] must decide on a specific amount of pollutant and how often they want to add it….Step 2 asks the students to formulate an experimental question. This should be specific (for example, will over fertilizing an ecosystem cause an overabundance of plant growth? pp.101-102)."

So that she might assist any student teams before they begin investigations, the text advises her on critical points for formative assessment. She is to observe each team while they focus and formulate their question. Later when reviewing their record sheets, she attends closely to the question and its features, i.e., does it target the disciplinary core ideas? Is it specific? Could it realistically lead to the answer they intend to find?

> "Review each team's plan for the pollution experiment….offer [assistance to teams] as needed before they begin experimenting. Make certain every team member understands his or her own group's decisions… in the following areas: The plan is realistic and feasible….the experimental question is narrow enough to be answered by the experiment itself. For example, 'What does salt do?' is too broad. 'How does salt affect the plants in our Eco column?' is better (Smithsonian, n.d., p. 103)."

Explicit pedagogy in support of 'Identifying problems'

This unit's activities do not neatly separate the science processes from the engineering processes as they might be stereotypically portrayed. Instead traditionally-labeled scientific processes overlap with the processes commonly attributed to engineering design. In one example, in the days spent waiting and watching for effects of pollution, the teacher assigns a new task. In order to gauge abilities to identify a problem and design a process to solve it, she is told, "Let the students design and carry out an experiment on their own…. [Have them] set up a fair test to find out if an ice cube with salt on it melts faster than one with no salt. …[Look for] a systematic approach… use of controls starting at the same time in the same location…attempt to quantify the size of the ice cubes…to measure the melting process…to keep records (p. 121).” Students have to narrow and define the problem they are to solve. She doesn’t tell them to create a fair test with multiple trials and specified measures. But, she is prompted to observe these component behaviors and coach students in their work.

An opportunity to practice identifying a problem and defining its limits occurs again later. Lesson 14 begins with this challenging message to the teacher: “The process students use to reach their conclusions today is more important than the conclusions themselves…. [As] they soon will discover, the results of an experiment are not always clear-cut. While students all will agree on some points, they will argue about others. This is appropriate because it is also what happens in professional experimental labs (p.133).” As the class compares and compiles data, they inevitably discover differences between small groups’ observations and measurements. How are discrepancies resolved? Which data are accepted and which are questioned?

Although not an engineering context, per se, this is an authentic problem and occurs in open-ended scientific inquiry. Their teacher guides a discussion, whether they agree or disagree with the findings. Students are asked to think of ways they could clear up differences or disputed points. The questioning is intended to lead to a proposed solution, such as to repeat the same experiment or to design a new investigation to answer new questions that arose. In an optional extension activity, teachers challenge students to design and conduct inquiries that could resolve the disputes.

In one last example, a more traditional ‘engineering’ problem has been identified in advance but the context and details which surround it offer multiple and competing ways to look at the problem and as many possible solutions. For the unit’s multi-day capstone project, students adopt roles of different community members in a case study of a polluted watershed. As they develop and present their group’s proposal, students rely on component behaviors that together make up the SEP defining problem, that is, they explore the underlying science, define possible constraints to action, seek indicators of success, and then propose a creative solution balancing and trading their own constituent group’s costs for potential benefits.

Explicit pedagogy in support of ‘Engaging in Argument from evidence’

In the central investigation of the *Ecosystems* unit, teachers and their students participate in a sophisticated weaving of claims that are revised or clarified via questions and observations, where students are led to value and to expect evidence for proposals, predictions and emergent understandings.

Beginning with lesson 10, when planning inquiries into the effects of pollutants on their terraria, students are asked to predict what will happen to the plants and algae in their team’s eco-column and in the class control eco-column, then prompted to explain those predictions, “we think these things will happen because… (p. 108).”

Component behaviors identified by NGSS expectations (to evaluate and critique the evidence and describe the use of reasoning) move to the forefront as well. In lesson 11 when in the early days of their observation students may not find measurable impacts, teachers are directed to "discover the usefulness of varying results,” and to understand that “A negative result provides just as much information as a positive result (p. 114).” Later when differences become more prominent in lesson 14 and students begin to recognize and discuss their discrepant findings, data quality and standard measures become important considerations.

As the investigation and observation progresses, students are asked to propose why or why not a measure has changed. Finally students are asked to predict what would happen to the crickets and isopods if pollutants were introduced into their own eco-columns. As they make the predictions, they are to refer to a graphic model from an earlier lesson, the food chain wheel. “What would happen to the crickets if the plants were destroyed? Would the isopods be in danger as well? Explain why you feel this way (p. 120).” Rather than portraying the graphic as a meaningless prop, it is a source of justification. The manual reminds teachers to reflect "how scientists use models to answer questions (p. 125)."

Finally, in lessons 15 and 16, the unit’s capstone project, students bring all the components of this SEP together to present findings about a real-world environmental challenge. Each small group researches and represents a constituency in the Chesapeake Bay region. They pose solutions from one view, and then evaluate the positions and solutions of other groups. They engage in a negotiation of trade-offs based on the group evaluation of evidence and reasoning. The teacher’s role is to note whether students used reason and justification in their presentations and final discussions.

Summary

Close study of the fifth grade science unit, *Ecosystems* using two SEPs—Asking questions and defining problems and Engaging in argument from evidence—reveals they are explicitly intended to be introduced, developed and assessed in a manner consistent with the expectations of the NGSS. In this program, the practices build on each other in order to reinforce understanding of the central content. Specifically, they are introduced and reviewed in a *lesson arc* that allows students to develop and research a feasible question, then to predict outcomes based on emerging understanding. This iterative process is buttressed by observed data as well as by content from readings in the topic of ecology. It is also grounded in solid inquiry. Students develop and refine the questions they would like to answer, are guided to maintain investigation variables that can be compared to the control, and measure change carefully and consistently.

Unlike the stereotype of kit-based inquiry, lessons do not provide for undirected discovery or exploration of materials. They do not follow a lock-step procedural model of instruction where doing leads to learning. Instead, they create opportunities for deep thinking, where students develop and then demonstrate the practices and values of science and scientists. An opportunity to think about a complex real-world problem and negotiate a creative proposal for its solution has the potential to lead students to sophisticated levels of thinking about scientific themes and processes.

Reflection- *Ecosystems*

As I began talking about tentative recommendations with the expert teachers as sounding boards, I became the learner. Thinking that this curriculum, *Ecosystems*, and its teacher guidance could become an example for improving both of the other science units, my eyes were opened to potential weaknesses, especially when typical elementary teachers implement this curriculum. It offers a lot to consider, perhaps too much for some.

One of the experts remarked at my detailed study of overview sections and background information provided in the teacher manual, exclaiming, “Nobody reads that.” She also asked, “Is it really the manual’s job to tell us how to teach?” reminding me that teachers are professionals who come with training and experiences that are not to be dismissed. Professional development, like any other learning opportunity, should always take the learner’s background and motivation into account. For some, this may include having skipped over background materials in the teacher manual.

Both expert teachers interviewed for this section believed that typical elementary teachers follow the text closely. If the manual explicitly states to say or do something, they usually will—a potential strength in this unit because it maps a route using class discussion, concept mapping, and data sharing. However, the side notes that prompt teachers to use purposeful questioning and informal assessment techniques to steer students’ thinking might be easily overlooked by a busy teacher with limited preparation time consumed with organizing and managing materials and spaces.

In discussing the unit’s initial lessons—setting up the eco-columns that form the foundation for the rest of this unit— one teacher suggested the lesson would be vastly improved if students could brainstorm their own unique designs, as they do in the Engineering is Elementary kits. Since she had not taught this unit or experienced the unit unfolding, I responded cautiously. For this lesson, only standardized terraria and aquaria would serve to teach about controlled variables and synthesis of data.

Because she made an important point, I replayed this teacher’s suggestion in my head for weeks. The purpose of controlling all but one variable is to answer a very refined question about effects of change or differential impacts. In contrast, the purpose of creative design is to solve a specific problem while meeting its requirements or parameters. Creativity in search of the solution can lead to divergent thinking and many possibilities. Eventually, I saw that she was right about the potential for student engagement. Students could propose an investigation design *and* agree to keep the eco-columns comparable and uniform. I wouldn't have thought of this on my own, though. Later, the unit's capstone allows them to identify a unique question to independently research, as she advocated.

This interaction brought me to think deeply about the purposes of science and engineering, about the cognitive processes that may or may not matter in the end. It brought to mind some of the published commentaries that opposed including engineering in elementary science curriculum because it has the potential to perpetuate misconceptions about both. I agree that is a risk, but that same risk was already in place. By bringing high quality curricular resources and pairing it with high quality teacher training to help teachers recognize and understand these distinctions, might those risks become instructional assets?

Finding 2. ***Mixtures and Solutions* (Full Options Science System)**

The central philosophy of *Mixtures and Solutions* is that students learn best from direct experience through activities defined by investigation. This effectively casts Science and Engineering Practices as secondary consequences that follow from students' first-hand experience with the materials. Lesson plans did not clearly or explicitly direct teachers to instruct or guide student skill in the two Science and Engineering Practices; however students were required to provide explanations

in written assessments, implying that having and communicating an explanation were behaviors expected in the unit.

Here, learning science content is like a treasure hunt— a fun, motivating opportunity for students to discover something, where teamwork increases the chance of success. Along the way, SEPs might be useful tools for communicating your discoveries to others. In *Mixtures and Solutions*, one of the two language-intensive SEPs, Arguing from evidence, is necessary in order for students "to explain and defend their intellectual constructs effectively (Introduction p.1.4[1])." The other, Asking questions and identifying problems, may or may not be realized through the program's goal, 'Conducting Investigations' since its lesson plans depend on students following procedures to answer questions provided by the authors of the text. Essentially, students are expected compare their experiences and observations with the world so that new questions and new inquiries will then arise, motivating new, direct experiences.

Goals and standards

The science and engineering practices were addressed tangentially. Full Option Science System's (FOSS) primary goal was to provide all students with age-appropriate scientific experiences that prepare them to understand the natural world. This first-hand experience is intended to contrast against a stereotypical lecture-reading- demonstration format of science instruction. As with the previous unit, the National Science Education Standards (NRC, 1996) informed and guided development of this unit. Specifically, it was intended that students come to "generate questions;

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[1] Pages are numbered within section for FOSS unit, ex. p.1.4 is section 1, page 4.

design and conduct scientific investigations to answer those questions; … use data to construct reasonable explanations; develop and communicate explanations using evidence; analyze alternative explanations and predictions (Regents of the State of California, n.d., p.2.2).”

Instructional foundation and guidance

If the process of understanding moves from concrete to abstract, then instruction must begin with hands-on investigation that “pushes students to explore widely at their cognitive level (Introduction p. 1.5).” Teachers were advised to start right in with hands-on activities, that any discussion would be more profitable afterward. If students explored, they would naturally develop a need to communicate their ideas. Teachers were also told to introduce terms or vocabulary only at the point of necessity. No plans were presented to surface students’ prior thinking about the central content, or any systematic, explicit guidance to teach the methods of discourse that underlie the NGSS vision of the two SEPs. Instead teachers are assured that fifth graders are developmentally capable of forming advanced concepts “based on evidence and their advancing language skills’ (Introduction p. 1.4) and they can “formulate testable questions, conduct experiments, and build explanations based on data (Introduction p. 1. 2).” This seems to imply the skills will arise or evolve without intentional or direct instruction, an inference that was later confirmed in notes regarding the assessment of the capstone project, “Projects allow students to follow their own interests and gives you some insight into how well they *have internalized* the inquiry process (italics added, p.4.26).”

One page in the overview section of the teacher manual, “Encouraging discourse,” provided a system to classify questions into two types: broad (which do not have right answers) and narrow (which do). Examples help the teacher distinguish variation within the two types, such as, “What would the beach look like if sand were soluble in water?” and “How did you feel when your reaction bag got bigger in your hands?” Nothing followed to illuminate pedagogical purpose or instructional rationale. One single line advocating wait-time leads teachers to believe that some responses are better than others, but nothing more.

Other brief tips emphasize management of student behaviors but not the skills required to limit or refine a question, identify a problem and its constraints, or use evidence to make a claim. Teachers are directed to yield the responsibility for whole class discussion to a student. Similarly, they are told to monitor group work for successful vs. unsuccessful groups, and then to ask successful students to assist their peers. "An important part of inquiry is being able to construct reasonable explanations from the results of investigations and support conclusions with evidence. One way to foster the development of discourse is to turn over the discussions as much as possible to students. When a volunteer answers a question, invite that student to take charge of discussion and ask other students if they agree or disagree with the response. All explanation should focus on the answer rather than on other volunteers and the discussion must be constructive and not personal (Overview p. 2.10).”

The program overview and teaching guidance section explain the unit’s lesson format and focuses on activities and supervision techniques. Again, there was nothing about discussion or idea management. To ensure that small groups of students work collaboratively teachers should assign each student a role within the group. The teachers’ primary energy was focused on setting conditions for guided exploration based on the provided questions. Teachers were cautioned however, that background information in the teachers' manual was provided for her benefit only.

Formal and informal assessment

Close examination of the section on assessment revealed that students were expected to show skill in the two SEPs. Unit goals explicitly evaluate three outcomes:

1. Student acquisition of content knowledge
2. Their skills required to *conduct an investigation*
3. The *quality of their explanations* that support their ideas about the experiences of the phenomenon (italics added, Introduction p. 1.8).

The text asks teachers to use both formative (diagnostic) and summative assessment in each section. An example is provided the teacher:

> "For example, guided by the teacher, *students conduct investigations* with a number of different solid materials to determine how much solid material will dissolve in 50 mL of water. Students learn the *content knowledge* that there is a limit to the amount of solid material that will dissolve and that the amount is different for different materials. Students then *build explanations* about what might be happening when a solution is saturated (italics in text, p. 2.11)."

The following section examines the lesson plans to determine whether these SEPs- Asking questions and identifying problems and Arguing from evidence—are presented as skills to be directly taught or as processes to be experienced within the inquiry model of instruction.

Lesson plans- Science and engineering practices taught, practiced, assessed

This unit, *Mixtures and Solutions* (Regents of the State of California, n.d.) consists of four extended (multi-day) investigations. The unit is estimated to take 6-8 weeks with 45 minute lessons each day. The four content investigations have several sub-investigations/activities, a student book with related readings, and a number of optional extension activities. In the matrix that maps the science content and the thinking process to each investigation, none of the SEPs were included as either outcomes to achieve or practices to be used in the four inquiries.

Lesson synopsis

1. *Separating mixtures.* Students create mixtures of soil, gravel and salt, then use filters and screens to separate them. They make a mixture of salt and water then separate the solution using evaporation.
2. *Reaching saturation*. Students make two saturated solutions- one with salt and water, one with citric acid and water. They compare the two on both mass and solubility. Finally, they identify an unknown solution using solubility.
3. *Concentration.* Students make and compare salt solutions of different concentrations, then decide relative concentration of three unidentified solutions.
4. *Fizz quiz*. Students explore chemical reactions by mixing various solid materials with water. They investigate reactions and the solid materials that are produced. A summative two-week capstone inquiry is titled, ‘Choose your own investigation.’

Explicit pedagogy in support of ‘Asking questions’

Analysis of lesson plans was conducted by noting locations in the text that required any of the component behaviors named by NGSS that form “Asking questions”: Do student formulate questions? Do they reflect on whether questions address the phenomenon or whether answers to that question might lead to understand how the phenomenon works? Do students reflect on the testability of the question in this setting?

In *Mixtures and Solutions*, a typical lesson begins like this example taken from investigation 2: “Challenge: Can you identify the missing chemical? Here is a table of properties for five chemicals. Record your observations about the mystery chemical. (Student sheet 10)" Any questions or challenges as well as the criterion to accomplish the inquiry have been provided. The students' task is to carry out procedures leading to the conclusion or solution.

Through the weeks, only one activity was offered where students might reflect on the relationship between the given question and the phenomenon, when students are parsing their ideas about saturation solution of salt water. How should they measure the amount of salt in that solution? In an extended vignette illustrating a classroom working on this same investigation, the teacher clarifies a very precise question that leads them to consider the phenomenon before they begin. With or without the vignette, this instructional move may elude a typical teacher.

In the final capstone project, teachers help students choose a topic by reminding them of ideas or questions that were side-lined during the unit or by suggesting investigation extensions from the text. Students must choose a topic and propose an investigation, beginning with a question. Teachers should "guide them to make sure that they are proposing something that is realistic and will benefit the class (p.4.28)." The proposal is not scored for its focused question but for its logical process and whether students could form that plan independently or not. Thus the SEP, Asking questions, was recommended to be assessed in a formative way, but not in a summative way.

Explicit pedagogy in support of 'Identifying problems'

While not a messy real world problem, what if planning an investigation of materials and their properties were considered an application of *this* SEP? How would this unit teach those skills? Do students identify a simple problem? Do students critique or reflect on their understanding of the science related to the phenomenon that is needed to solve the dilemma? Do students define the indicators of success? Do students define the constraining factors that may be met and/or must be addressed? The simple answer would be perhaps-yes. This sections presents analysis using that thinking. For example Investigation 1 potentially, but not explicitly, aligns with NGSS expectations for identifying problems—if the teacher guided discussion allows for students to discuss prior understandings and constraints.

> “Explain ‘When you put two or more materials together, you make a mixture…..Then ask students to describe mixture in their everyday lives, e.g. breakfast cereal, chocolate milk, egg salad, etc. Tell students that mixtures can always be taken apart. …Ask, ‘How can these three mixtures be separated?’ Discuss ideas as a class (Regents of the State of California, n.d., p.1.13).”

By asking teachers to “Discuss ideas…” the lesson plan opened a line of talk and imagination related to problem identification—an opportunity to focus on the phenomenon and make claims and predictions. It also suggests a simple remedy that might be applied in other lessons—i.e., opportunities to improve the unit by first *discussing ideas.*

There are days when the teacher is given an option, such as in Investigation 1 part 2, “If students need guidance in their inquiry, distribute a [step-by-step procedure] sheet to each…. otherwise postpone the distribution of the sheets until they have tried their ideas (Regents of the State of California, n.d., p.1.19).” The manual does not elaborate further about problem identification or design thinking, but allows for students to *explore* the problem and seek out solutions.

In a subsequent activity, teachers were directed to critique and guide groups to develop an investigation. In Investigation 1 part 3, students plan their procedures in small groups. “Don’t have a class discussion of plans—each group should formulate its own…. Visit each group to make sure they have a written plan…. [it] should replicate the saturation test that students conducted [earlier] (Regents of the State of California, n.d., p.1.23).” The criteria and constraints are not explicitly surfaced for teacher and students to discuss. Teachers are advised it should replicate previous activities that had been spelled out.

Then again later, in Investigation 2 part 3, an opportunity occurs for formal assessment of students’ ability to determine how many grams of a given material will saturate 50 ml of water. Teachers are told to evaluate the logic of the students’ plan and their independence in planning to solve the problem.

Typically, however, students have no reason to identify a problem or any of its considerations. Challenges are specified, targets are implied, and there are few opportunities to revise an earlier design. Most problem solving-design challenges are like these, where suggested materials prompt the suggested solution:

> “Tell the students their goal is to separate the mixtures so that the water is in one cup and the solid material is in another….Tell the students that a filter might come in handy for separating the mixtures. One type of filter is a screen. Ask students to read and follow the procedures on the sheet (Regents of the State of California, n.d., p. 1.13-14).”
>
> “Challenge: Design a method to separate a mixture of gravel, salt, and powder….Describe your plan for separating the mixture so that the salt is in one cup, the gravel is in the second, and the powder is in the third cup (Regents of the State of California, n.d., Student sheet 7).”

The idea that direct experience leads to more mature thinking is on display and influences the unit’s approach to problem solving by doing. Teachers are told to “allow plenty of time for students to understand the core chemistry concepts by working with the solutions…. The more autonomy students can exercise, the better they will learn the process of logical problem solving (Regents of the State of California, n.d., p.2.7).”

Explicit pedagogy in support of ‘Engaging in argument from evidence’

All through this unit, teachers are prompted to ask direct questions that require students to make claims, draw conclusions, predict outcomes, and in the final project, to design a process to investigate a related question. Even though the use of Argumentation and evidence was implied in the overview notes regarding summative assessment, teachers are seldom prompted to examine a student’s thinking behind the claim or to follow up regarding their rationale for a proposed design, e.g., *why do you choose that plan*? Or *what makes you say that*?

Passages imply that students will offer reasons for their answers, but there is no direct or planned effort to teach the skill or to systematically ask students to defend their statements. “Ask, “Did the mixtures of chemicals form solutions when they were mixed with water?’ …Some may claim it was not a solution because of the white stuff that settled out … (Regents of the State of California, n.d., p.4.13).”

A few times a direct request for justification was seen, as in this activity to reinforce the new vocabulary term, ‘reaction.’ First, the teacher states the definition then poses questions to see whether that new term matches their recent observations, “Did a chemical reaction take place in cup 1? How do you know? Did a chemical reaction take place in cup 2? How do you know? (Regents of the State of California, n.d., p.4.14).” The student was asked to indicate whether and why the given definition matched the outcome of activities they had just seen.

In activity worksheets there are occasional directives to “Explain your answer,” as in Investigation 2 when a worksheet asks the students to comment on two fictional students’ plans to reach saturation (Worksheet p.9). More typically, worksheets ask students to record observations then to respond to the original question. In corresponding assessment notes the teacher is asked to indicate yes or no with a checkmark, whether students draw conclusions from the evidence. While this implies student inference, it does not support the process and does not fully describe the vision of argumentation found in the NGSS.

In the written assessment at the end of unit there are open-ended items that ask, “How do you know” or “Why or why not?” Scoring rubrics for these and other items indicate that students are expected to support the responses with clear, specific, and numerous reasons. Because “I know it is a reaction when it makes bubbles” is correct but not necessarily a thorough list of indications, that response receives a low score.

Summary

The assumption that sustained experience leads to more mature thinking influences the unit’s approach to learning by doing. This is at odds with the language and discourse-rich SEPs examined. It denies the value and importance of students’ prior experience and emergent ideas about materials and materials transformation. Lesson plans and worksheets for FOSS’s *Mixtures and Solutions* imply that argument and analysis are spontaneous responses/processes applied during the enacted lesson plan and can be observed in outcomes. While students are, however, directed to recall and summarize their observations, there are also missed opportunities for students to stretch toward deeper understanding via dialog and shared analysis of data, supporting students to draw conclusions and/or develop appropriate but durable scientific explanations.

Reflection- *Mixtures and Solutions*

> “The big idea in this investigation, and surely one of the biggest in the whole FOSS program, is the concept of material transformation (Regents of the State of California, n.d., p.4.6).”

There is little evidence in cognitive research that proficiency in inquiry and argumentation naturally emerges (Erduran & Jiménez-Aleixandre, 2008), but studies of the long-term retention of other science practices has been shown following extended practice alone, i.e., without direct instruction (Dean & Kuhn, 2007). While the Science and Engineering Practices are not designed as teaching methods, but rather as actions students take to embody the practices attributed to science and engineering, their absence in this unit can indicate opportunities. In fairness, another SEP not included in this study, “Planning and carrying out investigations” better fits the activity-based format of this unit, however developers of NGSS state that any practice might be applied to science or engineering and that SEPs are intended to overlap in application. I feel that either of the SEPs, Asking questions and defining problems or Engaging in argument from evidence, could be made into important and central features of this program by reordering the lesson activities and repositioning the DCI, material transformation. Start there and return to it relentlessly, providing the inquiry with both purpose and context.

Redesign activities to require that students struggle with concepts and explanations regarding the phenomenon—through data collection and observation as in this kit, but add discourse, prediction, analysis, and critical questioning of their findings. Aim for the DCI. Help teachers see how a hands-on activity reflects or might reflect her students’ emerging understanding. This is where the STC teacher manual overview could act as a starting point.

Here in this kit, the disciplinary core ideas are effectively discrete but tied together in time and space like beads on a string. Because there is a need for a coherent model of material transformation and its central place in science, teacher professional development of the content would be a necessary first step to improving unit cohesion. For example, I talked with the expert teachers about the idea that saturation is one end of a spectrum of concentration. Yet, in this unit they are disconnected. Saturation is a taught as vocabulary by way of a demonstration of saturation. Concentration of solutions is taught days later, a new term with its own embodiment through exploration/demonstration. In a decontextualized vocabulary list, they do not seem to be related.

One other suggestion—an introductory dilemma or scenario could orient the unit and its activities, possibly providing a culminating activity that can more authentically require carefully posed questions, data collection, analysis and reporting. The expert teachers agreed that the FOSS kit lessons studied here reflected little of the new pedagogies. One explained that children today are no longer challenged by the directed activity formula as they were in the past, "They are so much more advanced now."

Finding 3. ***A Slick Solution*** **(Engineering is Elementary)**

Engineering is Elementary centers on and is defined by a graphic model of the engineering design process. The model drives the activities and captures the unit's message— engineering is a design process that people follow/use in order to solve problems. Society and nature provide context, but in this unit they offer few opportunities, considerations, or constraints. Inside this model of Engineering Design Process there is space to manifest the two Science and

Engineering Practices (SEPs), yet the simplified, procedural quality of the lessons— designed to ensure the transmission of the image and message of EDP— run counter to the robust dialog envisioned by the Next Generation Science Standards.

Goals and standards

Because Engineering is Elementary (EiE) was created early in the movement to integrate engineering with elementary science topics, three of its four primary goals relate unambiguously to the movement, i.e., to make engineering more available in American schools, conduct research in elementary engineering education, and change teacher behaviors. One goal, "Increase children's technological literacy (Hester, et al, 2011, p.1)" implies that the cognitive skills described as SEPs might be essential to this program because "engineering fosters problem solving skills, including problem formulation, iteration, and testing of alternative solutions (Hester, et al, 2011, p. 2)."

Authors align the lessons with a number of International Technology and Engineering Educators Association (ITEEA) standards, largely identifying knowledge-based or content standards, e.g. "4A- The use of tools and machines can be helpful or harmful; 5C- The use of technology affects the environment in good and bad ways (Hester, et al, 2011, p. 16)." However, they also identify a few standards that loosely correspond to the Science and Engineering Practices (SEPs), and imply cognitive and verbal skills. Specifically, the SEPs focused on in this study correspond to these ITEEA standards:

1. <u>Asking questions</u> is contained within ITEEA standard 10A-"Asking questions and making observations helps a person to figure out how things (technologies) work."
2. <u>Identifying problems</u> is seen within ITEEA standards 9C and 8D- "The engineering design process involves defining a problem, generating ideas,

selecting a solution, testing the solution(s), making an item, evaluating it, and presenting the results; and Requirements for a design include such factors as the desired elements and features of a product or system or the limits that are placed on the design."

3. Arguing with evidence seems an implied component of ITEEA standards 11E, 11F, and 11G- "The process of designing involves presenting some possible solutions in visual form and then selecting the best solution(s) from many; Test and evaluate the solutions for the design problem; Improve the design solution (p.16)" but it is not an explicitly named standard of the ITEEA. Determining which solutions or improvements are "best" implies some use of claim and evidence.

Instructional foundation and guidance

Little in the manual's overview section directly addresses pedagogy and nothing explicitly supports teaching the SEPs. The section entitled "How to use this curriculum" briefly cautions that EiE units were not intended to teach science content and therefore must accompany or closely follow instruction in the appropriate science content. The publisher's engineering units stand apart from each other and may be used in any sequence, that is, content in one does not depend on any other. Further, all lesson plans have been adapted for both Basic (grades 1-2) and Advanced students (grades 3-5). The unit format, delivery, activities, goals, and objectives apply to all grades, but teachers can choose which adaptations suit their class. Finally, the overview suggests that students in grades 1-2 work in pairs, and in grades 3-5 they work in groups of three. Without an instructional overview, teaching tips and background information are dispersed throughout the lesson plans. In addition lesson plans have notes on common misconceptions associated with their goals or content. It is noteworthy, however that the final lesson begins with an extended explanation, "Teaching the Engineering Design Process (Hester, et al, 2011, p. 111)" with important information about common difficulties students face when working in an engineering paradigm. Had it been placed at the outset of the entire unit, teachers may have been alert to informally check in with students or alternatively, she may have challenged them to think in more authentic ways as the unit progressed.

Formal and informal assessment

In a generic statement, the teacher manual's introduction to assessment states that accompanying activity work sheets [are] "another good source of information about student understanding" and to "use the [lesson] rubric to evaluate student performance (Hester, et al, 2011, p.18)." It also provides non-specific strategies for informal assessment, such as "Observe student contributions to class discussions (Hester, et al, 2011, p. 18)."

If a teacher were to turn to each lesson plan's appendix, she would find that rubrics provide details about expected outcomes, with four scores tied to the specific objectives of the lesson. The first example in Table 25 (below), taken from Lesson 1 rubric, typifies the objectives that focus on content only. The second, from lesson 2 rubric is one of three (or possibly four) objectives explicitly indicating that *proficient* students will "build a case," or otherwise use observed evidence to justify an argument or claim. The third example from lesson 4 implies that students performing this indicator at the *distinguished* level may identify questions or identify newly emerged problems to solve. The SEP is optional even at a proficient level. How the lessons unfold, how teachers are to guide the learning process, and how students acquire ability to demonstrate the targeted practices are examined next.

Table 25 Excerpts lesson rubrics (Hester, et al, 2011)

Student will be able to…	Novice 1	Apprentice 2	Proficient 3	Distinguished 4
Discuss the work of environmental engineers and their role in cleaning up pollution (p. 1-10)	Student does not successfully explain what environmental engineers do for work	Student explains one or more aspects of the work of environmental engineers. Response is partially correct. Student may require significant support.	Student correctly explains at least two aspects of the environmental engineers work.	Student goes beyond proficient level (e.g. by discussing how environmental engineers might work to prevent pollution.)
Compare historical soil and water data to current data to build a case for the sources of pollution in Greentown (p. 2-14)	Student is unable to build a case by comparing historical and current data	Student is able to compare historical and current data, but draws incorrect conclusions or is otherwise unable to build a case.	Student successfully compares historical and current data and is able to **build a case** for the sources of pollution.	Student goes significantly beyond proficient level (e.g. by making projections for future possibilities for Greentown.)
Utilize their prior knowledge of how well various materials and tools work to contain or remove oil to inform their designs (p. 4-13)	Student does not successfully use knowledge gained earlier in the unit to inform the design of a clean-up process	Student uses at least some prior knowledge to correctly **inform the design of a clean-up process**.	Student correctly and completely uses prior knowledge to **inform the design of a clean-up process.**	Student goes significantly beyond proficient level (e.g. by **identifying relevant questions** for further identification)

Lesson plans: Science and engineering practices taught, practiced, assessed

Four activity-based lessons follow a fictional story of a child in Alaska who discovers an environmental threat in the form of an oil spill in a nearby river. How her community faced and solved the problem provides the backdrop for the fifth grade readers to re-enact a similar materials test and then plan and demonstrate a process to contain and absorb an oil spill. When Tehya meets the environmental engineer who leads the clean-up, our students are vicariously introduced to the field of environmental engineering.

Lesson synopsis

Lesson 1- *Tehya's Pollution Solution*. Students are introduced to the story of Tehya and her dilemma. They learn about environmental engineering and the Engineering Design Process, through examining the program's graphic model and comparing it point by point with actions of the story's character.

Lesson 2- *An Enviro-mystery*. Students are presented with an imaginary case of soil contamination and attempt to locate the source of the pollution by conducting actual pH tests on teacher-prepared soil samples, then comparing their findings to historical pH data located on a map of the affected town. They see a demonstration of water moving through soil as an analogy to ground water moving to disperse chemical pollutants to and through the community water table. Finally, students present their findings and justifying their conclusions to the "town council."

Lesson 3- *A Slick Idea*. In part 1, students are cast as players in a tableau, modeling an interconnected web, analogous to the physical components and creatures in an ecosystem. Teacher then poses a question about what happens to the web when an oil spill is introduced. In part 2, the teacher proposes a test for materials, tools, and processes similar to the test Tehya conducted in the story. Implied are the evaluation criteria: efficiency and effectiveness. Student observations subsequently inform their planning in lesson four.

Lesson 4-*Cleaning an Oil Spill*. Working with partners, students use the Engineering Design Process to plan, demonstrate, evaluate, and improve a process to contain and absorb oil spilled onto a container of water.

Explicit pedagogy in support of 'Asking questions'

Are students led or required to formulate questions in this unit? The short answer is no. In all of the planned activities and lessons, students do not formulate their own questions regarding natural phenomena. In this unit, questions are provided, as are the problems to be solved. However, at the end of lesson 2, there are optional extension activities where teachers may ask students to develop and conduct additional pH tests at home or to compare plant growth in soils of three different pH levels. This might also encourage students to develop questions that engage their interest and guide their testing, but it is not required in the directions.

Interestingly, on one occasion, students were asked to reflect on the *relationship between* the (given) question and the natural phenomena, a component of the NGSS vision. Specifically, in lesson 3 when questioned about what might happen to a food web when oil is spilled in the river, students were invited to think how the components and the web as a whole might be impacted due to the inter-dependent nature of the food/energy cycle: "Do you think the living things that live in the soil on the riverbanks might be affected by the oil? How so? (Hester, et al, 2011, p.89)." This was the single example. More often, both question and connections were provided via pointed, step-wise series of questions. In lesson 2, before students begin to investigate a fictional town where plants and frogs are mysteriously dying, the teacher is advised to "Reinforce for students that non-living parts of the ecosystem (the physical environment) can provide habitats for the living organisms in an ecosystem (Hester, et al, 2011, p.62)." Shortly after that, she asks, "What do you think pollution is? What parts of an environment do you think can be polluted? …Have you heard the term pH before? (Hester, et al, 2011, p. 63)" thereby providing the dilemma, the connection to nature, and the path to solving it.

Explicit pedagogy in support of 'Identifying problems'

Regarding the science and engineering practices related to identifying problems to be solved and defining criteria and constraints to the successful solution, again there are few examples of directly teaching these skills and no expectations that students define a problem or develop indicators of success. As in lesson 3 part two, when students first test the materials and processes to observe their efficacy and efficiency at containing and absorbing an oil spill, the problem to be solved has been already identified. In the final lesson, when students demonstrate their mastery of the engineering design process they design a solution and a process to solve a problem identified in advance then test its efficacy using criteria defined by others. The sole example advises teachers how to promote thoughtful iteration after the first test of their process. “If students do not use the information that they gathered… to help identify improvements, [then] help students identify weaknesses of their first design... Each improvement should address a specific problem (Hester, et al, 2011, p. 111)."

Teachers are told that cost is an important constraint because it "forces [students] to think critically and creatively as they select which materials they will use (Hester, et al, 2011, p.110).” However, the program uses an arbitrary cost scheme that may *prevent* creative use of additional materials: i.e., if any new materials are more effective than the provided materials, then they are also assigned higher prices.

Side notes to the teacher offer an option that, if adopted, might improve student engagement and deepen their understanding. “If time allows… have students try to generate ideas how they might test and evaluate their oil spill processes, instead of just introducing the evaluation methods in Step 12 (Hester, et al, 2011, p.118).”

Explicit pedagogy in support of ‘Engaging in argument from evidence’

Of the SEPs examined here, the behaviors that make up Arguing from evidence are clearly intended to be taught. The practice was a stated part of learning objectives to be assessed by the rubrics. Lesson plans explicitly guide teachers to require that students make claims about phenomena and to provide evidence to support that claim. In addition, this instruction is supported by the planned sequence of investigations and activities, from observation to analysis to solution or resolution. For example, observations made during materials tests in lesson 3 provide information to buttress student claims for their clean-up designs and revisions in lesson 4. In a separate activity, also in lesson 3, observations from student examination of soil sample are compared to historic pH measures, differences are noted and inferences made. Then students communicate their conclusions and reasoning regarding source of contamination in fictional town.

At other times, claims may be supported by evidence gathered from reading, as in lesson 1 when students are asked to respond to the story of Tehya… whether her idea to use engineering design process was a good one and whether this story is one that could really happen... and then to justify their thinking (Hester, et al, 2011, pp. 49-50).

Examples of arguing from evidence were found in all four lessons. Two component behaviors (determining strengths and weaknesses of the evidence and describing their use of reasoning) were seen only in lesson 4. There one example of examining the quality of evidence follows the design testing phase. However, notes directed to the teachers frame this as optional or contingent, rather than necessary and inherent to making any claim. The text prompts that if students see a large amount of oil drops when they evaluate their process, teacher should ask, "What do you notice about how the technique affects the ability to clean up the oil? [and check that] …students should notice that technique is just as important as materials choice (Hester, et al, 2011, p.136)."

An opportunity to introduce a discussion of a fair test or data quality was missed when introducing procedures for materials testing in lesson 3 and/or design evaluation in lesson 4. The teacher side notes specify using standard measures for evaluation. She should "point out on the *Materials and Tools Price Sheet* that the price for using the pipette is per squeeze and the price for using the spoon is per scoop (Hester, et al, 2011, p.119)." But the directions stop there at informing and fall short of the bigger ideas of science.

Summary

This program's use of a fictional context to frame and guide the investigations and motivate students to search for engineering solutions has merit. It adds a dimension of reality helping to connect young students to the program's central goal—developing an understanding that Engineers solve problems. It motivates action regarding an otherwise abstract or unrelated dilemma. It gets them talking but the program does not direct their thinking (or discussions) much beyond the text. They do not reach high or far enough. It asks that student approximate the SEPs but stops short of asking that they grapple with the cognitive practices associated with the SEPs.

This unit, *A Slick Solution*, intends active exploration of materials along with the story context to lead students to purposefully approximate engineering design process. SEPs are positioned within the design process. That is, SEPs are helpful to identifying and planning solutions and to communicating reasons for choices. Here the SEPs do not focus student thinking on the phenomenon, but instead upon the design process itself. If the SEPs at the center of this study were enacted with integrity an vigor, would optimization, constraint, risk assessment, or redesign find a more natural and easy role here?

Reflection- *A Slick Solution*

Analysis of SEPs addressed in this unit, *A Slick Solution*, reveal opportunities that might be strengthened as well as gaps that might be filled to create a more robust learning experience presented by the new science standards.

The history of this unit's development might explain its oversimplification. It was intended to be adopted in variety of locations including informal science centers, camps, and/or after-school programs for groups with a broad range of ages and levels of background knowledge. Because it was initially designed to be used by teachers with no additional training and very little understanding of engineering as a career, a process, or an elementary school topic, the teacher's manual assumes little and provides much, to the detriment of student thinking and concept development. Opportunities to improve the program include extending expectations for student outcomes, as exemplified in the rubrics that assess performance. The *distinguished* level might be reconceived as *basic* or *proficient* in light of the fact that fifth graders will have encountered the core "Engineering is problem solving" message for many years prior. They are capable of more complex thinking and conceptual growth. They can responsibly collect data, report to the group, and analyze its implications in these proposed activities. They can also participate in a deeper, more connected dialog and develop skills we call Science and Engineering Practices (Schunn, 2009).

Using of fictional context to frame and guide the investigations creates a sturdy pedagogical foundation. Yes, there is a place for open and free exploration of materials and absorption, but there is also a time to learn how scientists and engineers are led by clear, measurable questions. Keeping the story's framing influence, students could go further yet stay within the scenario to clarify ideas and develop questions to drive their research. Some better-defined questions for story about the town with dying frogs and the story about a wilderness oil spill include these:

> What is causing so many plants and animals (frogs) in this town to die?
>
> In what ways does a common houseplant (or vegetable) grow differently in soils of three different pH levels?
>
> Of the methods we have demonstrated, which are most effective at removing all oil? Which are least expensive? Which are most effective in a time-limited study?
>
> Of the methods which are most effective at removing all oil, which are least expensive?
>
> Of the methods which are most effective at removing all oil, which are quickest acting?

Identifying problems is a clear and well-defined program component, intended to be taught as content and skill. However, it is not. The overall experience could be much richer and more authentic if students also understood that "The essence of engineering is design under constraint (Rutherford & Ahlgren, 1991)." This would require greater consideration of the science content ostensibly at the center of the dilemma. As it is now, the challenge is roughly equivalent to a test of substance removal, part process but mainly focused on material choice. By requiring students to first think about criteria of effectiveness as it appropriately relates to three previously unimportant factors: the ecosystem model of inter-relatedness, the water table demonstration, and the notion of soil pollution affecting water quality. Teachers could also refer back to the unit on mixtures and solutions. *How does what we know about separation of mixtures and solutions apply? What is a colloidal suspension*? Having students think about nature as a source of constraint and a measure of success can elevate the urgency of speed and containment (don't make it worse!) over other possible factors such as cost, completeness of removal, or creativity. It demonstrates the value associated with the term *cost*. What are we trading off or gaining as we consider changing costs? By reframing nature and science at the center of this dilemma, we can make iteration more purposeful and ignite creative and cooperative design processes.

In some ways the SEP Arguing from evidence is knit into the fabric of the lesson plans, but there are opportunities for strengthening that require a re-centering of the capstone project (designing a clean-up solution) to the environmental science content it presents to the students. As the SEPs are non-exclusive and generative, so this critique connects with that above. Elevating the position and importance of evidence and claim also occurs when students design with urgency of environmental impact in mind and are not given established criteria to address first, then asked to connect results backwards to impacts on the ecosystem.

Additionally, when the work sheet has been established as the authority, there is no need to discuss whether evidence is sufficient or appropriate to answer the questions at hand. For example, when students iterate their cleanup design (make new claims) they may appropriately test their cause-and-effect reasoning and possibly correlational reasoning, using the data from their worksheet, i.e., more of this means more of that. On the other hand, in the soil pollution activity, the correlation that results from noting increased pH levels over time, may point to possibilities, but not sufficiently answer the bigger questions. What is killing these creatures? Where is the source of the pollution? A reflective thoughtful and age-appropriate conversation about correlation could enhance the understanding of how environmental engineers work to understand complex issues.

A third point was first raised during one of the expert teacher interviews. Teachers might not understand that predictions and proposals are *claims* and as such, need to be supported by evidence. What I know about this phenomenon and what I know about its behavior when introduced to a particular agent of change (addition of liquid, reduction of temperature, effects of aging, exposure to light, etc.), combine to justify a proposal or prediction. The misunderstanding confuses the creative and analogous thinking that can help to form predictions and proposals, but because nature has requirements, we must ask for reasoning or justification, e.g., if this substance always dissolves in water, what do you know that makes you say it will be different this time? This is essential when communicating an engineering proposal. What makes you say this process will work? What do you know about the materials that lead you to choose them? Occasionally, the lesson plan asks students to justify their designs and iterations. In order to enact a fuller more complex classroom dialog, it is important for teachers to understand the cognitive processes at work. All claims are not conclusions drawn from observation.

Finally, I wonder if the takeaway message of this unit were different, that is, if instead of centering on the simple graphic of the EDP, the central message was that there are many ways to solve problems and many ways to choose between proposals using objective and/or subjective values. I wonder if that shift in emphasis might support the use of analytic and empirical processes that young people are capable of using, helping them to value both science and engineering as endeavors set apart from everyday ways of thinking, where carefully defined, agreed-upon standards add value and can help make the choices less confusing, if not less difficult.

Discussion

Do existing materials support teacher with implementation of NGSS?

> "Concreteness is not a magical property that allows teachers to pour content into the students' minds. It's familiarity that helps, because it allows teachers to prompt students to think in new ways about things they already know (Willingham, 2009, p. 18)."

Regarding the NGSS's primary goals and purpose to advance integrated engineering and science— how do these materials perform on the measure of overall coherence and cohesiveness regarding the two SEPs studied? In the discussion above, it seems that the Disciplinary Core Ideas (DCI) have been ill-served in the FOSS and EiE units. To be fair, the authors of EiE state that science content should be taught by other means prior to their unit's introduction. However, the program would be stronger if it attended more to the phenomenon at the core of the problem and solution. These SEPs are not skills in isolation; they require a context and/or a phenomenon to provide weight and meaning.

One goal of the Next Generation Science Standards is to enrich student learning and their classroom experience by elevating engineering and technology in the science classroom. When engineering and engineering design is brought into the classroom to illuminate and enhance the content of science, if the students do not need to know or understand the principles of science in order to design their solution or to better improve an existing solution, then it seems less than integrated science and engineering, and more like *tinkering* or another current trend, *making*.

There are pedagogical practices and instructional routines in use today that guide teachers and students toward the SEPs. Early in this research study, I viewed a series of science teaching videos produced in 1997 by Annenberg. Reflecting on this kit reminded me of a specific video. Richard Duschl coached a fifth grade teacher to establish a purpose when planning her lesson in order for students to take data collection and recording seriously. The larger goal was to enhance the role of data in science, but the teacher found the practice improved student engagement, independence in learning, and investment in accuracy of daily observations (Annenberg Learner, 1997).

I was later reminded of Duschl's advice to that teacher when I spoke again with Tonyea Mead about the curriculum study she is currently working on with the DSC. She speculated that a really good teacher could use any of these kits and still meet the new standards as they are envisioned (Personal communication, February 22, 2017). I agreed in theory. If Richard Duschl's recommendations were widely employed, these kits might come alive. However, that is not how teachers are prompted by the FOSS or EIE manuals. It is not how they were trained in PD workshops of the past.

If curriculum materials are to bridge and support teachers as they move away from existing teaching practices toward new pedagogies that invite students to engage deeply with ideas through science and engineering practices, the expert teachers I interviewed agreed that these particular materials fall short. Harried teachers rely on the text to guide them toward enactment. They trust that the path through the text has been designed and chosen to enable students to learn the concepts and skills necessary for future success. The expert teachers believed that, in the new paradigm, most teachers will experience discomfort and uncertainty as students struggle with difficult problems and a multitude of possible solutions; that changing teaching requires extra time and preparation and has a real potential for failure; but risk and uncertainty are what authentic inquiry requires.

Limitations

In hindsight, this curriculum analysis could never have been conducted with a quantitative design. Terms such as “explicit” and “intended” require interpretation within an imaginary, typical classroom. In reality, every classroom is unique, a concert of interdependent actors and conditions. Here is where the discussions with expert teachers provided the most value. They spoke about teachers who are hardworking professionals who generally want to succeed, who want their students to succeed. By acting as a check on this qualitative design, they helped to provide Chapter 4’s reflections and recommendations and helped to bridge the distance between ‘business as usual’ and the ambitious NGSS science and engineering practices.

Also, since this project first began, the initiative continued to evolve. New research has offered insights into effective STEM classrooms and impactful teacher development programs. Delaware has embarked on its own curriculum review and remediation process. Specifically, teams of teachers have been trained to lead change at the school level even while they develop lesson improvements and pilot them in their own classrooms. The PD format requiring a one time, six hour workshop for each kit has been redesigned. First teachers view a one-hour online component focused on materials and management. Then they meet for discipline-based look at NGSS teaching practices, in three two-hour face to face meetings that combine three grades into a grade band, that is, K-2 and 3-5 grades together (Tonyea Mead, personal communication, February 22, 2017). To a degree, some of the recommendations of this paper are already underway.

Chapter 5

SUPPORTING TEACHER IMPLEMENTATION OF ELEMENTARY ENGINEERING CURRICULUM

The purpose of this project is to describe teachers’ personal and curricular resources at the outset of Delaware’s educational policy initiative, Elementary Engineering Education, in order to inform a path forward in curriculum development and dissemination efforts. Chapter 3 surveyed Delaware’s K-5 teachers’ personal resources, i.e., their knowledge, goals and beliefs about this curricular shift. Chapter 4 examined a sample of teaching materials for examples of pedagogical support of two science and engineering practices specified in new science standards. They represent the physical and epistemic resources available to teachers. Chapter 5 integrates the two through Schoenfeld’s vision of teacher practice where her content knowledge, goals, and beliefs as well as her instructional routines are resources that impact her in-the-moment choices (Schoenfeld, 2009). A leader in the adoption of these new science policies and elementary engineering curricula, Delaware may have much to offer others who follow their example.

A number of requirements emerged in Chapters 1 and 2 related to teacher professional development and specifically to adopting elementary engineering. One, there are wide differences among teachers in their perceptions, attitudes, and their capabilities to teach engineering. Another, teachers' area of greatest pedagogical need is in developing student thinking such as recognizing and addressing students' prior misconceptions and developing their initial ideas and questions into more robust disciplinary concepts. Student thinking needs to be prompted and revealed when engaged in inquiry or in engineering design to ensure content achievement. Teachers need to learn to value, attend to and develop students' thinking as much as they need to focus on developing curricular knowledge of materials, devices, textbooks, and classroom resources. Yet another, teacher knowledge and awareness of engineering education does not equate with expertise in teaching engineering. Finally, existing teacher materials do not support the content knowledge or pedagogical practices required to stimulate and nurture the fledgling integrated STEM policy or standards.

The next section synthesizes the teacher survey and curriculum analysis to describe the resources available to and in use by Delaware's elementary engineering teachers in the first years of curriculum reform.

Teachers' Knowledge, Goals, Beliefs and Material Resources for K-5 Engineering

In Schoenfeld's view, teachers have knowledge of the subject concepts and content and they have pedagogical knowledge that may be seen, at times, in instructional routines, scripts and agendas (Törner. Rolka, Röskin, & Sriraman, 2010). Teachers need to know how it looks and what it means when students perform well on a task. While Delaware's choice of engineering curriculum, EiE, requires very little teacher knowledge of engineering content, when surveyed, Delaware teachers did not rate their knowledge of the content or standards very highly. Their concerns often mentioned a need for information or fear of not teaching the materials well.

By design, the EiE science content comes from other sources. EiE units supplement existing science curricula. Information about one particular common misconception regarding engineering is briefly addressed in every kit and manual, "At first, students may struggle with the concept that processes are technologies (Hester, et al, 2010, p. 8).” As one expert teacher interviewed here noted, after students have worked on the curriculum units for a year or two, this simple message is just no longer relevant. Also in EiE, broader knowledge of learning progressions regarding the engineering and science content or of typical student cognitive development are indirectly addressed by margin notes offering options for basic and advanced level students. This advice was not found to represent the level or depth envisioned by the NGSS for either of the SEPs examined. At times the fifth grade Teacher manual gave advice that seemed to impede student thinking rather than support it. Too many prompts and too smooth a path to learning can in fact be a program’s weakness (Schunn, 2009).

Beliefs guide teachers toward the resources they think are available and will help them attain their goals. Epistemic beliefs infuse our knowledge and through this, our identities (Törner, et al, 2010). This highlights one important finding from the survey of Delaware teachers that was later affirmed by the expert teachers: Whether or not they had attended teacher training in engineering, teachers valued engineering and the initiative to introduce it into elementary science. They tended to believe students could master the content regardless of gender or race.

This finding fits well with the adopted program, EiE. In the unit overview, program developers reveal their values and beliefs about elementary engineering: that it is important to understand the designed world we live in; that it is important to develop engineering and technological literacy in all people; that young children are naturally curious and easily interested in building and taking things apart to see how they work.

Teachers' beliefs about their own self-efficacy have been associated with student outcomes. Teacher confidence and efficacy have been characterized in classroom studies of STEM integration as a constellation of beliefs balancing knowledge, pedagogical skill, resources available, and requirements of the task (Stohlmann, et al, 2012). Delaware's teachers, when surveyed in Year 2 of the engineering roll-out, did not express confidence to teach the new curriculum. This included many of those who had been through training and had already used the kits. Interviews with expert teachers more than one year later affirmed this may still be true for some. One teacher felt that her district's professional development helped many to overcome their fears, but even with that, she thought some teachers would resist if changing caused difficulty or discomfort. This discomfort was clear in the survey's statements of concerns from teachers who had been already trained: "inadequate time to properly teach," "my background knowledge is very limited," "take down and put [student work] back up is a hassle," "What will my students retain pertaining to science?" "Is there another way to measure progress?"

To Schoenfeld, different goals will interact and change in their precedence as a lesson develops. It is the teachers' beliefs that will determine which goals to pursue or to reprioritize in any given activity or interaction (Törner, et al., 2010). Teachers rely on instructional routines, materials, and agendas to attain those goals.

Delaware's goals and pacing guide relieve some of the teachers' need for decision making. They are to follow the engineering curriculum plans as offered by EiE. Their interpersonal goals and shifting priorities are considerations they can negotiate within those parameters. Delaware districts may provide support to teachers who have questions or who struggle to follow the kit's plan and manual. It is the teachers' duty to reflect on these inconsistencies and ask about or report anomalies. While the teacher manual is the authority to the lessons, it does not prompt teachers to act in ways that enact either of the two language-intense SEPs. It does not offer them sturdy, adaptable teaching routines that facilitates attention toward student cognition and concept development. However, in interviews, expert teachers suggest it is permitted to re-order and re-focus the lessons to meet students' learning needs. For them, doing that additional work was energizing, allowing them to expand the options and *local goals* they can conceive.

Teachers in both interviews and surveys stated their goals in teaching the new engineering curriculum. Almost all surveyed teachers said their goals were to improve student academic skill, to help them understand the technical world and the role of engineering, to promote enjoyment of learning and to prepare them for the world of work. Expert teachers who were interviewed promoted additional outcomes beyond those stated in the survey. They transformed goals into expectations, encouraging and developing their students' ability to understand science, to apply math skills in real-world contexts, and to think.

Recommendations

Together these three factors- knowledge, goals, and beliefs—influence what the teacher is able to notice, what she attends to, and how she acts among the myriad of possibilities in a typical science classroom—making choices based on resources available to attain those goals (Harris, et al, 2012; Lotter, et al, 2013; Mellone, 2011; Talanquer, Tomanek, & Novodvorsky, 2013). Curricular resources have the potential to make teachers aware, but ultimately do not help them make instructional decisions in the moment. These are shaped by beliefs about goals and efficacy (Guzey, et al, 2014; Harris, et al, 2012). Similarly, in-service training that provides information and attends solely to mechanics and materials that accompany a kit also cannot support her noticing emerging concepts via language-rich SEPs such as Asking questions, Defining problems, or Arguing from evidence. Investing in teachers' personal resources *and* in their curricular resources will be required if Delaware teachers are to build new pedagogies that help students achieve the impacts envisioned, i.e., pair ongoing professional development focused on SEPs with curricular materials that enable instructional routines and support formative assessment.

Professional development that is ongoing and focused on cognitive developmental theory can support teachers as they acquire new routines that help students' to investigate and think about natural phenomenon. New content and new pedagogies take time to develop and for experienced teachers, may require some awkward unlearning. Allowing teachers to try out a new strategy then reflect on its effect on student behavior and learning, may also redirect their values and beliefs toward the innovation (Albanese, et al, 2004). Gradual gains in new Content Knowledge (CK) and PCK will provide an opening to new confidence (Stohlmann, Moore, & Roehrig, 2012).

Curriculum materials can and therefore must support teachers' decision making in the moment by bearing some of the cognitive burden, reminding them to pause for student input and guiding their estimation of students' growing understanding and skill. Consider using a similar SEP-focused curriculum analysis to identify gaps or areas in need of strengthening. Then weave instructional routines into the lesson plans that prompt teachers' attention on student thinking without oversimplifying the task and thereby robbing students of the struggle with the practices. Existing pedagogies might be useful starting places, and include the P-E-O (Predict, Explain, Observe) technique (Gunstone and White, 1981; Haysom and Bowen, 2010), the patterns of discourse around group data analysis as in the Annenberg video mentioned in Chapter 4, or the Language Frames for Argumentation in Science (Ross, Fisher, & Frey, 2009).

Next Steps Have Begun

Having described Delaware's teachers' knowledge and beliefs, explored some of the suggested best practices in engineering education for young children, and examined teaching materials for evidence of pedagogical support, it would be a helpful next step to identify and understand the knowledge, beliefs, and practices of exemplary elementary engineering teachers. What do they identify as most useful and effective at enabling instructional change? Alternatively, a next step might be the development of *educative curriculum materials* (Davis & Krajcik, 2005), in partnership with teachers of any stage of experience or confidence, meeting together and iterating toward a shared vision or goal.

In some ways this work has already begun in the districts and at the state level through the Science Coalition curriculum study groups—i.e., the analysis, modification, and piloting of new science resources. Final adoption of adapted curricula which were slated to be this year (DSC Timeline, February 2014) has been postponed, partly due to the time consuming analysis and the shortage of strong materials identified by the curriculum study groups (Tonyea Mead, personal communication, February 22, 2017).

If professional development requires an understanding of a teacher’s learning needs, of her personal experience, expectations, and of the culture in which she participates, then it is hoped that this study of teacher understanding, values, beliefs, and resources contributes to that effort. Engineering can be a powerful vehicle for learning, an opportunity to reach students who may be energized and excited by its opportunity for creative problem solving and real-world applications. In Delaware, engineering in elementary classrooms should be as familiar and common as knowing or meeting an engineer.

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Appendix

Appendix A

SURVEY OF ENGINEERING BELIEFS -ITEMS

Part 1 About yourself. Responses- Yes – No- Specify

1. Number years of experience teaching grades K-5
2. Number of years teaching with DSC science kits
3. Grade(s) you teach __________If multiple grades________
4. County your school is in? _________ Charter school? Yes-No
5. Currently assigned to teach science? Yes-No
6. Have you attended DSC training on engineering kit_________ If yes, please specify which training?_______________
7. Are you/ Have you been a trainer for DE Science Coalition kits? Yes-No
8. Do you have other experience with engineering activities or science clubs? _________
9. If yes, please specify____
10. Do you have specialized training or degree in science, mathematics, engineering, or technology? ____________________ If yes, please specify____________________
11. Did your preservice curriculum include any aspects of engineering? Yes-No

Part 2 About Engineering Education

12. Where or how did you learn about engineering? (Check all that apply)

- Course work in engineering
- -TV
- -Movies
- -Books, magazines
- Engineers (family, friends, neighbors, co-workers)
- -High school or college guidance, teachers, or advisors
- -Other (please specify)

I. Importance of Engineering- Not at all- Not much- Somewhat-Very much

13. I would like to be able to teach my students to understand the use and impact of engineering.

14. I would like to be able to teach my students to understand the science and/or math of engineering.

15. I would like to teach my students to understand the design process.

16. I would like to be able to teach students to understand the problems to which engineering can be applied.

17. My motivation for teaching science is to promote an understanding of how engineering affects society.

18. I am interested in learning more about engineering through in-service training.

19. I would like to be able to teach students to understand the process of communicating technical information.

20. My motivation for teaching science is to prepare young people for the world of work.

21. My motivation for teaching science is to promote an enjoyment of learning.

22. I believe engineering should be integrated into the K-12 curriculum.

23. I am interested in learning more about engineering through workshops.

24. I am interested in learning more about engineering through college courses.

25. In a science curriculum, it is important to include the use of engineering in developing new technologies.

26. I am interested in learning more about engineering through peer training.

27. My motivation for teaching science is to help students develop an understanding of the technical world.

28. My motivation for teaching science is to educate scientists, engineers and technologists for industry.

29. In a science curriculum, it is important to include planning of a project.

30. Engineering has positive consequences for society.

II. Familiarity with Engineering- Not at all- Not much- Somewhat-Very much

31. How familiar are you with engineering?

32. Have you had any specific engineering courses outside of your pre-service curriculum?

33. How confident do you feel about integrating more engineering into your curriculum?

34. Barrier in integrating engineering – lack of pre-service training.

35. I use engineering activities in the classroom.

36. Barrier in integrating engineering – lack of time for teachers to learn about engineering.

37. I know the national education standards related to engineering.

38. Barrier in integrating engineering – lack of administration support.

39. My school supports engineering activities.

40. Barrier to integrating engineering- lack of teacher knowledge

41. Was your pre-service effective in supporting your ability to teach engineering at the beginning of your career?

III. Characteristics of Engineers- Strongly disagree- disagree- agree-strongly agree

42. A typical engineer has good verbal skills.

43. A typical engineer works well with people.

44. Most people feel that minority students can do well in engineering education.

45. Most people feel that female students can do well in engineering education.

46. A typical engineer has good writing skills.

47. A typical engineer likes to fix things.

IV. Characteristics of Engineering- Strongly disagree- disagree- agree-strongly agree

48. A typical engineer does well in science.

49. A typical engineer has good math skills.

50. A typical engineer earns good money.

V. Please answer to the best of your ability.

51. Please describe in your own words- How would you describe engineering to a friend?

52. When I think about using this engineering curriculum in my classroom, my biggest concern is____. (Please elaborate. Use two or three complete sentences to explain what you mean.)

53. When I think about using this engineering curriculum in my science classroom, the biggest advantage I see is____. (Please elaborate. Use two or three complete sentences to explain what you mean.)

Appendix B

SURVEY RESULTS (ALL)

Table 1. Value for engineering and engineering education (%)

	Not at all	Not much	Somewhat	Very much	Total N
I believe engineering should be integrated into the K-12 curriculum.	0.7	14.7	42.6	41.9	136
Engineering has positive consequences for society.	0.7	0.7	35.8	62.7	134

Table 2. My motivation for teaching science (%)

My motivation for teaching science is to…	Not at all	Not much	Somewhat	Very much	Total N
Promote an understanding of how engineering affects society.	5.2	24.4	45.2	25.2	135
Prepare young people for the world of work.	4.2	9.5	32.8	53.3	137
Promote an enjoyment of learning.	0.7	3.7	28.7	66.4	136
Help students develop an understanding of the technical world.	0.7	9.5	49.3	40.4	136
Educate scientists, engineers and technologists for industry.	8.8	12.5	47.8	30.9	136

Table 3. Beliefs about engineering in science class (%)

In a science curriculum, it is important to include…	Not at all	Not much	Somewhat	Very much	Total N
The use of engineering in developing new technologies.	2.2	8.9	50.1	38.5	135
Planning of a project.	1.4	2.1	44.1	52.2	136

Table 4. I would like to be able to teach my students (%)

I would like to be able to teach my students to understand…	Not at all	Not much	Somewhat	Very much	Total N
The use and impact of engineering.	2.2	13.2	49.2	35.3	136
The science and/or math of engineering.	2.9	8.7	50.0	38.3	136
The design process.	2.9	10.3	45.6	41.2	136
The problems to which engineering can be applied.	1.4	9.7	47.0	41.8	134
The process of communicating technical information.	3.6	10.9	50.4	35.0	137

Table 5. Familiarity with Elementary Engineering Education (%)

	Not at all	Not much	Somewhat	Very much	Total N
How familiar are you with engineering?	13.9	40.9	39.4	5.8	137
Have you had any specific engineering courses outside of your pre-service curriculum?	65.7	21.2	8.0	5.1	137
How confident do you feel about integrating more engineering into your curriculum?	16.2	44.9	32.4	6.6	136
I use engineering activities in the classroom.	19.0	37.2	35.0	8.8	137
I know the national education standards related to engineering.	33.6	37.2	21.2	8.0	137
My school supports engineering activities.	13.9	37.2	36.5	12.4	137

Table 6.Barriers to integrating engineering (%)

Barriers to integrating engineering…	Not at all	Not much	Somewhat	Very much	Total N
Lack of pre-service training	2.2	9.6	59.3	28.9	135
Lack of time for teachers to learn about engineering	0.7	5.2	48.9	45.2	135
lack of teacher knowledge	1.5	8.9	52.6	37.0	135
Lack of administration support	5.2	38.5	40.0	16.3	135

Table 7. Most people think that an engineer (%)

Most people think that an engineer…	Not at all	Not much	Somewhat	Very much	Total N
Has good verbal skills	0.7	6.6	60.6	32.1	137
Works well with people	1.1	8.8	61.0	29.4	136
Has good writing skills	0	12.5	58.1	29.4	136
Does well in science	0	0	36.8	63.2	136
Has good math skills	0	0	20.0	80.0	135
Earns good money	1.1	0	52.5	47.0	136
Likes to fix things	1.5	5.2	53.3	40.0	135

Table 8. Most people feel that (%)

Most people feel that…	Not at all	Not much	Somewhat	Very much	Total N
Female students can do well in engineering	2.2	25.0	54.4	18.4	136
Minority students can do well in engineering	4.4	23.7	51.2	15.4	136

Table 9. Forms of PD: Percent interested

I am interested in learning more about engineering through…	Not at all	Not much	Somewhat	Very much	Total N
In-service training	5.8	16.2	47.4	30.7	137
Workshops	7.4	19.1	39.7	33.9	136
Peer training	7.4	30.9	39.7	22.1	136
College courses	29.4	41.2	19.1	10.3	136

Table 10. What grade(s) do you teach? (If more than one, please check multiple)

Grade(s) teaching	Response (N)	%
Kindergarten	15	11%
Grade 1	12	9%
Grade 2	39	28%
Grade 3	20	15%
Grade 4	23	17%
Grade 5	14	10%
Multiple grades	14	10%
Total	137	100%

Table 11. How many years have you taught grades K-5 including this year?

# Years	Response (N)	%
0	1	1%
1	6	4%
2-3	24	18%
4-6	19	14%
7-10	21	16%
11+	64	47%
Total	135	100%

Table 12. How many years have you taught Delaware science kits including this year?

# Years- kits	Response (N)	%
0-1	14	11%
2-3	21	16%
4-6	23	17%
7-10	31	23%
11+	44	33%
Total	133	100%

Table 13. Where is your school (county)?

County	Response (N)	%
New Castle	74	55%
Kent	45	33%
Sussex	16	12%
Total	135	100%

Table 14.Information about you

Do you	Yes %	No %	Responses (N)
Teach in a charter school?	3.7	96.3	136
Have teaching responsibilities that include science?	92.6	7.4	136
Have experience with other engineering or science activities or clubs? (such as after school, summer school, or other)	16.9	83.0	136
Are you/ have you been a Science kit trainer?	22.6	77.4	133
Have specialized training or degree in science, mathematics, engineering, or technology? If YES, please specify which area below.	10.4	89.6	135
If YES, please specify which area below.			

Table 15. Coded examples: The biggest advantages I see.... (N= 101)

Advantage	Coded excerpts from responses	% (N)
Increased student engagement/ motivation/enjoyment	The kids will enjoy it; The kids are excited and interested in it.	35.6 (36)
Opportunities for student collaboration[1]	Collaborative problem solving—students work together to develop ideas; It is a medium to engage students in higher-level thinking and collaboration.	7.9 (8)
Increased creativity, higher order thinking, problem solving		
Increased creativity, higher order thinking, problem solving	Help students to use their higher-order thinking skills; problem solving is key to engineering.	26.7 (27)
Hands on learning/ building/ manipulative materials	It's hands-on so it's better for visual learners. The students get to manipulate materials rather than be lectured to.	14.9 (15)
Real-world context	Will help to keep us up to date with technology and how it affects all the things around us in the world. It would take learning outside the classroom to real-life things.	28.7 (29)
Improved science and/or math learning	Deeper knowledge of math and science; Inspire and excite children to understand applications of science/math.	21.8 (22)
Learn design process/ engineering skills	Having students create a design and revise it when it [doesn't] work.	5.0 (5)
Increased vocabulary/ concept development (engineering or general)	The additional knowledge the children pick up and understanding of the concept of engineering; Kids will be able to use larger vocabulary.	5.9 (6)
Increased vocational awareness- science and/or engineering	Develop a sense of whether they want to work in this field.	25.7 (26)
Increased communication skills, including reading, writing, presentation, and ELA	The process of evaluating the situation and thinking through a solution will make them better readers, writers, and speakers.	6.9 (7)
Benefits to teacher	EiE units are easy for a regular classroom teacher to follow.	1.0 (1)
Yes- general or global benefits, improvements to student	Student growth; Teaching students new things.	3.0 (3)
None	I don't see how the engineering curriculum is benefitting my students; I think that engineering should be taught in middle school and higher grades.	3.0 (3)

[1] Collaboration theme was not characterized as a sole benefit. Responses were labeled with two or more themes.

Appendix C

RESULTS CHI SQUARE ANALYSIS

Likert-type items (Training vs. No training)

I. Beliefs about typical engineers: A typical engineer…

Has good verbal skills	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	38	0
Yes- Training	75	8
Chi-square	3.92*	
Degrees freedom	1	
P value	0.05	
Works well with people	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	34	4
Yes- Training	74	8
Chi-square	0.02*	
Degrees freedom	1	
P value	0.90	
Has good writing skills	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	31	7
Yes- Training	73	9
Chi-square	1.25	
Degrees freedom	1	
P value	0.26	
Does well in science	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	38	0
Yes- Training	82	0
Chi-square	0.0*	
Degrees freedom	1	
P value	1.00	

*Chi-sq. may be inaccurate due to small cell size (<6)

Has good math skills	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	38	0
Yes- Training	81	0
Chi-square	0.0*	
Degrees freedom	1	
P value	1.00	
Earns good money	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	38	0
Yes- Training	81	1
Chi-square	0.47*	
Degrees freedom	1	
P value	0.49	
Likes to fix things	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	35	3
Yes- Training	75	6
Chi-square	0.01*	
Degrees freedom	1	
P value	0.93	

*Chi-sq. may be inaccurate due to small cell size (<6)

II. Beliefs about engineers: Most people believe that…

Female students can do well in engineering	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	25	13
Yes- Training	64	18
Chi-square	2.04	
Degrees freedom	1	
P value	0.15	

*Chi-sq. may be inaccurate due to small cell size (<6)

Minority students can do well in engineering	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	23	15
Yes- Training	56	26
Chi-square	0.70	
Degrees freedom	1	
P value	0.40	

*Chi-sq. may be inaccurate due to small cell size (<6)

III. Beliefs about engineering education

I believe engineering should be integrated into K-5 curriculum	Somewhat/ Very much	Not at all/ Not much
No- training	29	9
Yes- Training	75	7
Chi-square	5.16	
Degrees freedom	1	
P value	0.02	
In a science curriculum, it is important to include planning of a project.	Somewhat/ Very much	Not at all/ Not much
No- training	35	3
Yes- Training	82	0
Chi-square	6.64*	
Degrees freedom	1	
P value	0.01	
Engineering has positive consequences for society.	Somewhat/ Very much	Not at all/ Not much
No- training	37	1
Yes- Training	79	1
Chi-square	0.30*	
Degrees freedom	1	
P value	0.59	

*Chi-sq. may be inaccurate due to small cell size (<6)

One barrier to integrating engineering into K-5 classrooms is…

Lack of pre-service training	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	38	0
Yes- Training	68	13
Chi-square	6.85	
Degrees freedom	1	
P value	0.01	
Lack of time for teachers to learn about engineering	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	36	2
Yes- Training	76	5
Chi-square	0.04*	
Degrees freedom	1	
P value	0.84	
Lack of teacher knowledge	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	35	3
Yes- Training	73	9
Chi-square	0.27*	
Degrees freedom	1	
P value	0.60	
Lack of administrative support	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	19	19
Yes- Training	47	35
Chi-square	0.56	
Degrees freedom	1	
P value	0.45	

*Chi-sq. may be inaccurate due to small cell size (<6)

My motivation for teaching science is to…

Prepare young people for the world of work	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	29	9
Yes- Training	77	6
Chi-square	6.50*	
Degrees freedom	1	
P value	0.01	
Promote an understanding of how engineering affects society	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	21	17
Yes- Training	65	17
Chi-square	7.37	
Degrees freedom	1	
P value	0.01	
To help students develop an understanding of the technical world	Strongly agree/ Agree	Strongly disagree/ Disagree
No- training	33	5
Yes- Training	75	7
Chi-square	0.62*	
Degrees freedom	1	
P value	0.43	
Educate scientists, engineers, and technologists for industry.	Strongly agree/Agree	Strongly disagree/Disagree
No- training	26	12
Yes- Training	69	13
Chi-square	3.89	
Degrees freedom	1	
P value	0.05	
To promote an enjoyment of learning.	Strongly agree/ Agree	Strongly disagree/Disagree
No- training	34	4
Yes- Training	89	0
Chi-square	8.93*	
Degrees freedom	1	
P value	0.0	

*Chi-sq. may be inaccurate due to small cell size (<6)

I would like to be able to teach my students to understand…

The use and impact of engineering	Somewhat/ Very much	Not at all/ Not much
No- training	31	7
Yes- Training	74	9
Chi-square	1.30	
Degrees freedom	1	
P value	0.25	
The science and/or math of engineering	Somewhat/ Very much	Not at all/ Not much
No- training	32	6
Yes- Training	76	6
Chi-square	2.07*	
Degrees freedom	1	
P value	0.15	
The design process	Somewhat/ Very much	Not at all/ Not much
No- training	31	7
Yes- Training	75	8
Chi-square	1.85	
Degrees freedom	1	
P value	0.17	
The problems to which engineering can be applied	Somewhat/ Very much	Not at all/ Not much
No- training	34	4
Yes- Training	73	7
Chi-square	0.10*	
Degrees freedom	1	
P value	0.76	
The process of communicating technical information	Somewhat/ Very much	Not at all/ Not much
No- training	34	4
Yes- Training	71	12
Chi-square	0.35	
Degrees freedom	1	
P value	0.55	

*Chi-sq. may be inaccurate due to small cell size (<6)

IV. Knowledge and training

How familiar are you with engineering?	Somewhat/ Very much	Not at all/ Not much
No- training	13	25
Yes- Training	43	40
Chi-square	3.25	
Degrees freedom	1	
P value	0.07	
Did your pre-service education include any aspects of engineering?	Somewhat/ Very much	Not at all/ Not much
No- training	3	35
Yes- Training	32	51
Chi-square	11.92	
Degrees freedom	1	
P value	0.00	
Have you had any specific courses outside of your pre-service curriculum?	Somewhat/ Very much	Not at all/ Not much
No- training	2	36
Yes- Training	15	68
Chi-square	3.54	
Degrees freedom	1	
P value	0.06	
Was your pre-service program effective at supporting you to teach engineering?	Somewhat/ Very much	Not at all/ Not much
No- training	4	34
Yes- Training	27	56
Chi-square	6.62	
Degrees freedom	1	
P value	0.01	
How confident do you feel about integrating more engineering into your curriculum?	Somewhat/ Very much	Not at all/ Not much
No- training	8	30
Yes- Training	41	41
Chi-square	9.01	
Degrees freedom	1	
P value	0.00	

*Chi-sq. may be inaccurate due to small cell size (<6)

I use engineering activities in the classroom.	Somewhat/ Very much	Not at all/ Not much
No- training	8	30
Yes- Training	48	35
Chi-square	14.18	
Degrees freedom	1	
P value	0.00	
I know the national science standards related to engineering.	Somewhat/ Very much	Not at all/ Not much
No- training	5	33
Yes- Training	34	49
Chi-square	9.23	
Degrees freedom	1	
P value	0.00	
My school supports engineering activities.	Somewhat/ Very much	Not at all/ Not much
No- training	17	21
Yes- Training	46	37
Chi-square	1.19	
Degrees freedom	1	
P value	0.27	

*Chi-sq. may be inaccurate due to small cell size (<6)

Results Chi square analysis of Likert-type items
(Personally knows an engineer vs. Does not know an engineer)

I. Beliefs about typical engineers: A typical engineer…

Has good verbal skills	Strongly agree/ Agree	Strongly disagree/ Disagree
YES- personally know an engineer	69	8
Do NOT personal know an engineer	54	1
Chi-square	*	
Degrees freedom	1	
P value	*	
Works well with people	Strongly agree/ Agree	Strongly disagree/ Disagree
YES- personally know an engineer	67	11
Do NOT personal know an engineer	52	2
Chi-square	*	
Degrees freedom	1	
P value	*	
Has good writing skills	Strongly agree/ Agree	Strongly disagree/ Disagree
YES- personally know an engineer	64	14
Do NOT personal know an engineer	52	3
Chi-square	*	
Degrees freedom	1	
P value	*	
Does well in science	Strongly agree/ Agree	Strongly disagree/ Disagree
YES- personally know an engineer	78	0
Do NOT personal know an engineer	55	0
Chi-square	*	
Degrees freedom	1	
P value	*	

*Chi-square not computed due to small cell size (<6)

(Cont.) Beliefs about typical engineers: A typical engineer…

Has good math skills	Strongly agree/ Agree	Strongly disagree/ Disagree
YES- personally know an engineer	78	0
Do NOT personal know an engineer	54	0
Chi-square	*	
Degrees freedom	1	
P value	*	
Earns good money	Strongly agree/ Agree	Strongly disagree/ Disagree
YES- personally know an engineer	77	1
Do NOT personal know an engineer	55	0
Chi-square	*	
Degrees freedom	1	
P value	*	
Likes to fix things	Strongly agree/ Agree	Strongly disagree/ Disagree
YES- personally know an engineer	72	5
Do NOT personal know an engineer	51	4
Chi-square	*	
Degrees freedom	1	
P value	*	

*Chi-square not computed due to small cell size (<6)

Beliefs about engineers: Most people believe that…

Female students can do well in engineering	Strongly agree/ Agree	Strongly disagree/ Disagree
YES- personally know an engineer	53	25
Do NOT personal know an engineer	44	11
Chi-square	0.498676904	
Degrees freedom	1	
P value	0.48	
Minority students can do well in engineering	Strongly agree/ Agree	Strongly disagree/ Disagree
YES- personally know an engineer	48	30
Do NOT personal know an engineer	41	14
Chi-square	0.481646332	
Degrees freedom	1	
P value	0.49	

Beliefs and knowledge about engineering education

I believe engineering should be integrated into K-5 curriculum	Somewhat/ Very much	Not at all/ Not much
YES- personally know an engineer	66	11
Do NOT personal know an engineer	45	10
Chi-square	0.947567079	
Degrees freedom	1	
P value	0.33	
Engineering has positive consequences for society.	Somewhat/ Very much	Not at all/ Not much
YES- personally know an engineer	74	1
Do NOT personal know an engineer	54	1
Chi-square	*	
Degrees freedom	1	
P value	*	
How familiar are you with engineering?	Somewhat/ Very much	Not at all/ Not much
YES- personally know an engineer	39	39
Do NOT personal know an engineer	21	34
Chi-square	0.610720261	
Degrees freedom	1	
P value	0.43	
How confident do you feel about integrating more engineering into your curriculum?	Somewhat/ Very much	Not at all/ Not much
YES- personally know an engineer	34	43
Do NOT personal know an engineer	17	38
Chi-square	0.498379742	
Degrees freedom	1	
P value	0.48	

*Chi square not computed due to small cell size (<6)

Appendix D

INTERVIEW PROTOCOLS EXPERT TEACHERS

Interview Guide for teachers

Verbal and Written Consent:

Hello, I am a graduate student in the School of Education at the University of Delaware. I am doing a study to learn about your opinions and practices teaching Delaware's elementary science curriculum and particularly the engineering units within the curriculum. The study will be part of my Executive Position Paper for a Doctorate in Education degree (EdD). In addition, findings from the research may be shared with others in the education system, such as members of DE Department of Education, the DE Science Coalition members, or other science educators to help them understand how elementary teachers view the integration of science and engineering and to offer ideas for supporting teachers' use of the Science and Engineering Practices within the Next Generation Science Standards (NGSS).

As part of a larger study that began by surveying teachers across the state for their understandings, beliefs, and opinions about the engineering curriculum, I have purposefully invited 3-5 experienced elementary science teachers to focus on issues of instructional practice related to student impact.

I would like you to participate in two interviews of approximately 45-50 minutes each. Your name and your school's name will be confidential; however, I would like to collect general information about you, e.g. years of teaching experience and education background, as well as your school's district or county to provide background to the study.

- The first interview will ask about three areas: your views of the integration of engineering into elementary science, your reflections on the findings of my initial survey, and whether or how the NGSS Science and Engineering Practices fit in your current pedagogies.
- The second interview will ask your opinions about the feasibility and efficacy of my proposed lessons and instructional supports.

Taking part in this study is voluntary. If you decide to not participate in the study, you do not have to. In addition, if you do participate, you can withdraw at any time or decide not to answer any specific question. There is no penalty for not participating or for changing your mind once the interview starts.

There is little risk to you and your participation will help me to understand the how to support successful elementary teacher practices within the new NGSS guidelines. I'd like to offer a gift card to an online or traditional bookstore as a thank you gift for your time.

Finally, I would like your permission to tape this interview so that I can ensure my notes are accurate. (*Ask for signed consent form)*

Do you have any questions for me before I begin?

Interview One

First, I'd like to ask you a little about yourself, then I'll ask you about the engineering curriculum and your own experiences as an elementary science teacher.

1) *Teacher-specific questions (10 minutes)*
    a. In which county and district is your school located?
    b. What grade(s) do you currently teach?
    c. How many years have you taught elementary grades?
    d. How long have you taught science? Engineering?
    e. What is your educational background (degree, field of study, special training in science, technology, engineering)? [Probe for sources of personal knowledge of engineering, e.g. relationships, media, other]
    f. Which DSC training events have you attended? Which, if any, have you led? [Probe for engineering kits if not mentioned.]
    g. Other experiences in teacher work groups, at either school, district or state level? [Extent of knowledge about others' opinions, beliefs, experiences.]

2) *Thinking about the engineering curriculum (10 minutes)*
    a. Using your own words, how would you describe engineering to a friend?
    b. When you think about using this engineering kits/curriculum in your classroom, what are your greatest concerns? Please talk more about why this concerns you.
    c. When you think about implementing the engineering kits/curriculum in your classroom, what are the biggest advantages that you see? Please talk more about these.

3) *Reflection on survey findings.(15-20 minutes)*

    In my initial survey of elementary teachers, I asked those same questions. To what extent do you think the following findings reflect the current opinions or beliefs of DE elementary teachers? Specifically, do you think these findings—?

    - *Very much represents opinions/beliefs teachers I know;*
    - *Somewhat represents opinions/beliefs teachers I know;*
    - *Does not or barely represents opinions/beliefs teachers I know.*

        a. Findings: engineering-
            i. Most all teachers see engineering as beneficial to society,
            ii. Most all see engineers as skilled in science and math.
            iii. All believed engineers make “good money.”
            iv. Most described engineering as a form of problem solving and/or design.
        b. Findings: concerns-
            i. Most, but not all believe engineering should be included in K-12 curriculum.
            ii. Almost two-thirds do not feel confident about teaching it.
            iii. Almost all believe that lack of teacher knowledge is a barrier to implementation.
            iv. Almost all believe the lack of time to learn about it is also a barrier to implementation.
            v. The majority (more than half) teachers expressed concern about their own lack of knowledge or ability to enact the new curriculum OR they expressed concerns about managing the time and materials the program requires
        c. Findings: Advantages-(Some teachers named more than one advantage)
            i. The largest percentages of teachers named these four advantages: improved student motivation and engagement; adding “real-world” context to the curriculum; increased student problem solving, creativity, and higher order thinking; or increased career awareness.

4) *Reflections on instruction regarding NGSS’ Science and Engineering Practices (5-10 minutes)*

Experts and leaders have urged integration of engineering into science curriculum as a way to enact STEM education, especially at elementary levels.

    a. How do you understand this?
    b. Do you see it as a part of YOUR OWN current instructional practice? How would this look to an outsider visiting your room?
    c. Would this work in other classes? What would have to be in place for it to be effective?

5) *General (1-2 minutes)*

    a. What else should I be thinking about to support teachers and schools to put these practices in effect?

Thank you for your time.

Interview Two

Thank you for agreeing to meet with me again and thank you for allowing me to record this conversation. I would like to talk about my findings from curriculum analysis project and a few recommendations. I'd like to get your feedback on this and any recommendations you have, too, focusing on proposed pedagogical supports to the Elementary science and engineering curriculum in Delaware today. This interview will take approximately 30- 45 minutes.

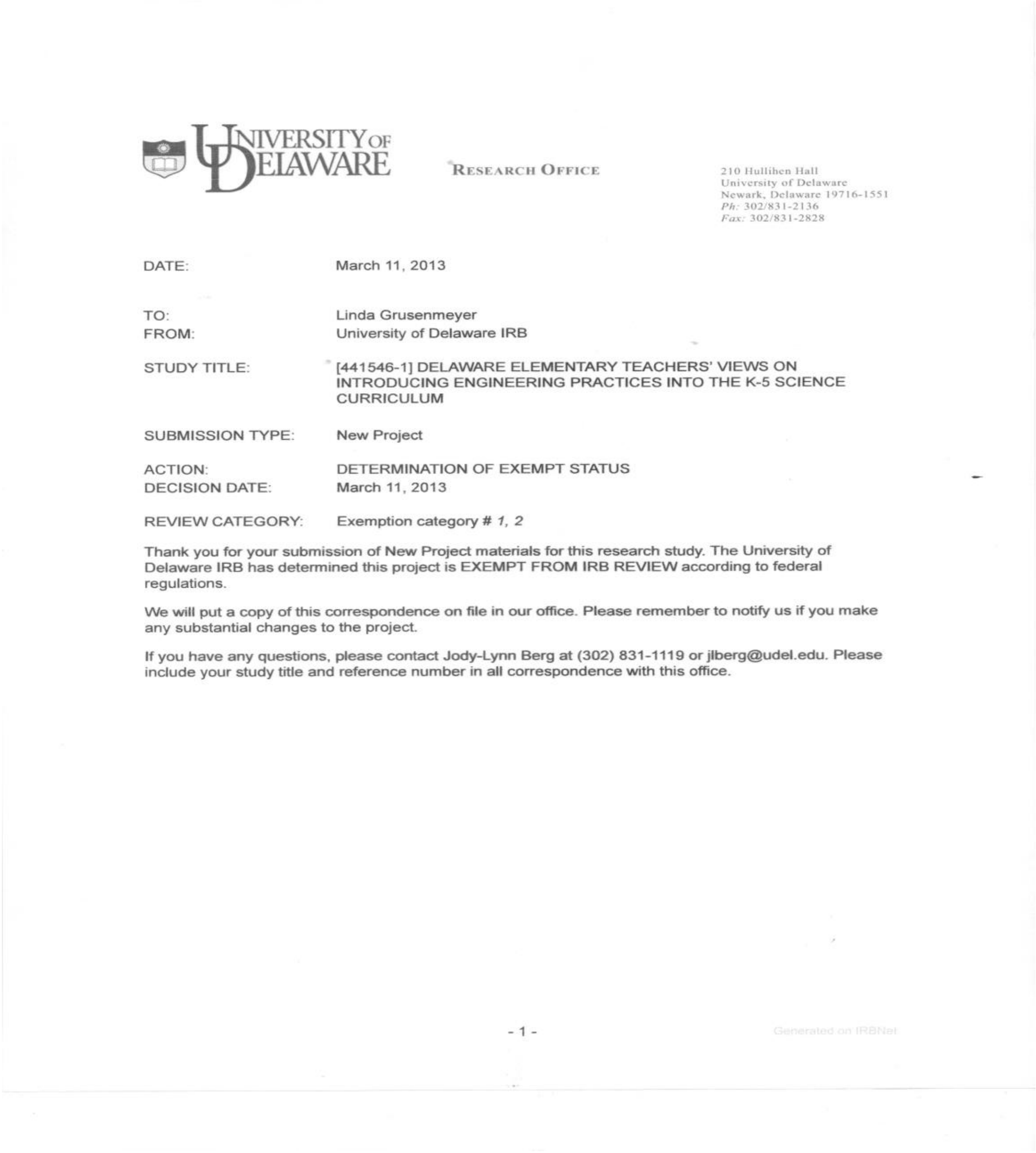
As before, your responses are voluntary and confidential. You do not have to participate in this interview. You can choose to answer or not answer any individual questions I might ask. Your responses, however, will be feedback regarding perceived efficacy and feasibility of my suggested lesson plans. I hope you feel free to critique and offer your opinions.

Do you have any questions before we begin?

1. First – the SEPs selected
2. Second— how I'm thinking about teaching and learning process in context of engineering and science
3. Third- each unit findings and recommendations
4. Last— any recommendations you have to offer?

Appendix E

INSTITUTIONAL REVIEW BOARD DETERMINATION LETTER



UNIVERSITY OF DELAWARE

RESEARCH OFFICE

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DATE: March 11, 2013

TO: Linda Grusenmeyer
FROM: University of Delaware IRB

STUDY TITLE: [441546-1] DELAWARE ELEMENTARY TEACHERS' VIEWS ON INTRODUCING ENGINEERING PRACTICES INTO THE K-5 SCIENCE CURRICULUM

SUBMISSION TYPE: New Project

ACTION: DETERMINATION OF EXEMPT STATUS
DECISION DATE: March 11, 2013

REVIEW CATEGORY: Exemption category # *1, 2*

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has determined this project is EXEMPT FROM IRB REVIEW according to federal regulations.

We will put a copy of this correspondence on file in our office. Please remember to notify us if you make any substantial changes to the project.

If you have any questions, please contact Jody-Lynn Berg at (302) 831-1119 or jlberg@udel.edu. Please include your study title and reference number in all correspondence with this office.

Appendix F

INFORMED CONSENT TEACHER INTERVIEWS

University of Delaware

Informed Consent Form

Title of Project: DELAWARE ELEMENTARY TEACHERS' VIEWS ON INTRODUCING ENGINEERING PRACTICES INTO THE K-5 SCIENCE CURRICULUM

Principal Investigator (s): Linda Grusenmeyer

Other Investigators: Danielle Ford, Advisor

You are being asked to participate in a research study. This form tells you about the study including its purpose, what you will do if you decide to participate, and any risks and benefits of being in the study. Please read the information below and ask the research team questions about anything we have not made clear before you decide whether to participate. Your participation is voluntary and you can refuse to participate or withdraw at any time without penalty or loss of benefits to which you are otherwise entitled. If you decide to participate, you will be asked to sign this form and a copy will be given to you to keep for your reference.

WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this study is to describe the understandings and beliefs DE elementary teachers as they implement new initiative introducing engineering curriculum into K-5 science classes. In addition, it is a design study to examine curriculum materials for cohesiveness and coherence in teaching science and engineering practices across materials. The goal is to provide better support for elementary science teachers in the future. This study is one part of a doctoral study being conducted by Linda Grusenmeyer, an Ed D student at the University of Delaware.

You are being asked to take part in this study because we are seeking 3-5 public or charter elementary teachers who have …

- Several years of experience teaching elementary science.
- Been recommended for their expertise and/or their reflective practices regarding science instruction.
- Trained and have used the engineering curriculum materials.

WHAT WILL YOU BE ASKED TO DO?

- If you agree to participate, you will be asked to participate in two semi-structured interviews, each approximately 45 minutes long.
- I will interview you at your convenience to learn about your opinions and beliefs regarding the engineering and science integrated curriculum. I will also ask your opinions regarding the feasibility and efficacy of my proposed improvements to support the integration.
- To help me with note taking, I would like your permission to tape record these interviews. I will email typed transcripts for you to review for accuracy.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

No harm or discomfort is anticipated for the participants in this study, which consists of participating in two informal and confidential interviews.

WHAT ARE THE POTENTIAL BENEFITS?

You will not benefit directly from taking part in this research. However the knowledge gained from this study may contribute to our understanding of how to better support elementary teachers as they implement engineering curriculum in science classrooms.

HOW WILL CONFIDENTIALITY BE MAINTAINED?

I will make every effort to keep all research records that identify you confidential to the extent permitted by law. I will take precautions in data handling and in reporting to ensure your confidentiality. There is some oversight that I am obligated to adhere to in order to ensure your rights are protected.

Confidentiality in data handing- I will ask your permission to tape record the interview, but it will not be required.

- Unique ID numbers will be used to link the digital recordings and final interview transcripts.

- An encrypted document of ID numbers and names will be kept in a separate location.

- All data will be in electronic files that will be encrypted and stored on CEHD server; (i.e., taped and de-identified, transcribed interviews)

- Any paper forms (consent forms, transcripts) will be stored in locked cabinets.

- Taped interviews will be erased two weeks after transcripts have been verified/ checked by participants.

- Three years after defense of this doctoral project (EPP), all related electronic data and records on the CEHD/SOE server will be deleted by Office of Education Technology. Paper records will be shredded by Research office/University Archive, no later than 12/31/2018.

Confidentiality in reporting-

- Data will be analyzed and reported in the aggregate. No names will be used. If any quotations are used to illustrate important representative theme(s), pseudonyms will be used.

- In the event of any publication or presentation resulting from this research, no personally identifiable information will be shared. This includes the planned presentation and publication of my student research (Executive Position Paper) and a report of recommendations regarding teacher support and professional development that I will develop and report to DE Department of Education at the end of the study.

Confidentiality in oversight-

- Your research records may be viewed by the University of Delaware Institutional Review Board, and the confidentiality of your records will be protected to the extent permitted by law.
- My faculty advisor, Danielle Ford, PhD, will also have the right to view the research data.

WILL THERE BE ANY COSTS RELATED TO THE RESEARCH?

There are no costs associated with participation in this study

WILL THERE BE ANY COMPENSATION FOR PARTICIPATION?

Once your involvement in the study is complete (all online reflections and final interview done) you will receive a one-time payment for your participation- a $50 gift certificate to Amazon.com or another bookstore of your choice.

DO YOU HAVE TO TAKE PART IN THIS STUDY?

Taking part in this research study is entirely voluntary. You do not have to participate in this research. If you choose to take part, you have the right to stop at any time. If you decide not to participate or if you decide to stop taking part in the research at a later date, there will be no penalty or loss of benefits to which you are otherwise entitled. Your refusal will not influence current or future relationships with the University of Delaware, the DE Department of Education, or the DE Science Coalition.

WHO SHOULD YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?

If you have any questions about this study, please contact the Principal Investigator, Linda H. Grusenmeyer at Lgrusen@udel.edu or at 302-234-1985 or Danielle Ford at djford@udel.edu or -302-831-6254.

If you have any questions or concerns about your rights as a research participant, you may contact the University of Delaware Institutional Review Board at 302-831-2137.

Your signature below indicates that you are agreeing to take part in this research study. You have been informed about the study's purpose, procedures, possible risks and benefits. You have been given the opportunity to ask questions about the research and those questions have been answered. You will be given a copy of this consent form to keep.

By signing this consent form, you indicate that you voluntarily agree to participate in this study.

________________________________ ______________

Signature of Participant Date

____

Printed Name of Participant

Appendix G

EXAMPLE OF DATA COLLECTION TABLE

CODES: Yes-No- Partial/optional

Unit: A Slick Solution (Engineering is Elementary) SEP: Asking questions, Defining problems					
Student questions consider phenomena of the natural world		No[9]	No[1]		
Identify the scientific nature of the question	P/O[2]		No[3]	Yes[4]	No[9]
Identify the problem to be solved				P/O[5]	NO[6]
Define criteria for and constraints to the successful solution				Yes[7]	P/O[8]
	Introduction/ overview	Investigation 1	Investigation 2	Investigation 3	Investigation 4

[1] P.62- students are given the question in advance

[2] Extension activities - p. 55, "What connections do they notice…?"

[3] Ch.2 p.66- question is given

[4] Following 'web' activity in Ch. 3 Part1- students relate knowledge of phenomenon to predict what will happen within the ecosystem p.90

[5] Partial, teacher presents guiding question in Ch3 Part2- (What materials and methods can we use to clean an oil spill?) introducing methods and materials to be used; student then test type and quantity of materials to use—*highly scaffolded*, pp.96-99

[6] P.116- students told to design an oil spill removal process using info from activity in Ch.3 Part 3

[7] Ch.3- p. 99 "How will you know if the materials work well as a boom?"

[8] Optional, p.113

[9] Students are asked how to evaluate success and to speculate about cost of real oil spill clean-up BUT THEN, worksheets with criteria for success are provided prior to their design and test pp.118-119