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Identifying Characteristics of Technology and Engineering Teachers Striving for Excellence Using a Modified Delphi

Teaching excellence is an expectation for teachers oft expressed by policy makers, parents, taxpayers, professional organizations, and students. Preparing a technology and engineering (TE) teacher who strives for teaching excellence is a fundamental mission of TE teacher education programs in the United States. However, a recent focus upon engineering design concepts within the TE curriculum (Gattie & Wicklein, 2007) and urgent calls to align, coordinate, or integrate TE curriculum in K-12 schools within science and mathematics education (Presidents' Council of Advisors on Science and Technology, PCAST, 2010) compels teacher education programs to reevaluate their curricular programs.

Purpose

In 2012, the International Technology and Engineering Educators Association (ITEEA, formerly the International Technology Education Association, ITEA) Council on Technology and Engineering Teacher Education (CTETE, formerly the Council on Technology Teacher Education) Teacher Preparation and Revitalization Committee was tasked to identify the characteristics of a TE teacher striving for excellence. To this end, the committee conducted a Delphi study with the purpose of identifying basic competencies that a pre-service teacher striving for excellence would have upon successfully completing a TE teacher preparation program. This competency profile could assist teacher educators as they evaluate and revise their teacher preparation programs.

Literature Review

The desire for teaching excellence, also referred to as highly effective teaching, is driven by numerous factors, including perceptions of inadequate student achievement in science, technology, engineering, and mathematics (STEM) education (Gonzalez & Kuenzi, 2012) and critics of traditional teacher preparation programs who perceive university teaching degrees as burdensome (e.g., U.S. Department of Education, USDOE, 2002). Possibly the most compelling is that empirical evidence gained through statistical modeling indicates that high quality teaching is an important predictor of student achievement (Aaronson, Barrow, & Sander, 2007).

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Attempts to characterize teaching excellence, especially in terms of the competencies of an exemplary, highly-qualified teacher, are evident within state and national teacher standards (e.g., Council of Chief State School Officers, CSSO, 2011), the scholarly literature (e.g., Office of Educational Innovation and Evaluation, 2008), and teacher evaluation systems (e.g., Grossman, Cohen, Ronfeldt, & Brown, 2014). A broad range of competencies are mentioned, such as "high verbal ability" (USDOE, 2002), maintaining an "effective public relations program" (Roberts & Dyer, 2004), and being "reflective about their own cultural frames of reference" (Rychly & Graves, 2012). However, most include a core set of skills, knowledge, and dispositions related to learners, pedagogy, content (subject matter), communication, and professionalism. Other theorists and practitioners, namely Shulman (1987), conceptualize these teacher competencies as being an integrated, complex set of knowledge and skills known as Pedagogical Content Knowledge (PCK). PCK requires a thorough grounding in the concepts, principles, and frameworks of the subject matter, pedagogy (the processes and methods of teaching), and a deep understanding of how students think and learn. As Shulman (1987) suggests, "PCK, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p. 8).

Focused upon state education agencies responsible for teacher licensing, the Interstate New Teacher Assessment and Support Consortium (InTASC) Model Core Teaching Standards (CCSSO, 2011) consists of 10 standards within four organizational categories: The Learner and Learning, Content, Instructional Practice, and Professional Responsibility. In a recent revision, the CCSSO (2013) characterizes these as professional practice standards that occur along a developmental continuum articulated as learning progressions. Each attempts to differentiate basic competence from more complex teacher practice by capturing clusters of key indicators (performance, essential knowledge, and critical dispositions) that when combined exemplify increasingly more sophisticated teacher practice.

Content Knowledge: Technology & Engineering Education

With historical roots in manual arts, industrial education, and industrial arts education, TE has long been associated with technical and industrial content. Historically, teachers were expected to demonstrate technical competence regarding materials and processes in domains such as woodworking, metalworking, and drafting. Throughout the 1970's and 80's, prominent leaders argued that TE curriculum was concerned with a study of technological systems. The CTTE (as cited in Miller, 1991) indicates that an effective technology teacher would provide laboratory instruction in the study of manufacturing, communication, construction, and transportation systems at a specified level of technical competence" (p. 63).

Later, a call for *technological literacy for all* guided the K-12 content standards called the *Standards for Technological Literacy* (STL, ITEA, 2000). Among the 20 STLs are standards explicitly identifying content related to the attributes and application of design, engineering design, and the relationship of technology to other fields. *Advancing Excellence in Technological Literacy* (ITEA, 2003), a companion set of standards, addressed desired teacher competencies related to professional development, student assessment, and program development. These standards identify competencies of teachers, e.g., assessing student learning that will be consistent with STLs (p. 20).

Now, with increasing expectations that teachers help charge the engineering and science pipeline with innovative designers and entrepreneurs that can maintain a competitive edge in the world marketplace through innovation (PCAST, 2010), there are increasing pressures to more deeply focus TE content upon an engineering pathway that applies the concepts, principles, and processes of science and mathematics. Yet, Litowitz's (2014) survey of 24 TE teacher education programs in the U.S. suggests that a significant proportion of TE teacher preparation programs may require few high-level science and mathematics courses that could build pre-service teachers' competence in these areas. The dynamic nature of the TE content domain makes it difficult to assume where the acceptable range of content competence might lie for a TE teacher striving for excellence.

Methodology

A three round modified Delphi study was used to characterize competencies of a TE teacher striving for excellence. The Delphi research methodology is portrayed as an efficient technique to identify content (Hacker, de Vries, & Rossouw, 2009), critical issues (Wicklein, 1993), and competencies (Scott, Washer, & Wright, 2006) for TE curriculum improvement. The Delphi method was established in the 1950s by the Rand Cooperation, and is a technique used to establish meaning and consensus from experts that may be geographically spread out from one another (Stitt-Gohdes & Crews, 2004).

Participants

Participants for the Delphi panel were purposively selected from TE teacher education faculty, classroom TE teachers, state TE administrators, school administrators, and STEM professionals working outside of TE education. A concerted attempt was made to create a geographically diverse panel. The panel was comprised of members from 16 states and one international participant. Of the 43 potential participants contacted, 23 originally agreed to participate in the study. Due to the low number of classroom teachers that completed the first round, 10 additional teachers were invited to participate; seven teachers agreed to participate in subsequent rounds. Table 1 outlines participation in the Delphi panel.

Table 1
Delphi Panel Participants

	Round One	Round Two	Round Three
TE Faculty	6	7	6
Classroom Teachers	3	9	8
Administrators: State TE & CTE	5	4	3
Administrators: School	2	1	2
STEM Professionals	2	1	1
Total	18	22	20

Instrument Development

During fall 2012, program level goals and outcomes were requested from 10 TE teacher preparation programs in the U.S.; five responded. These elements were compiled along with InTASC standards (CCSSO, 2011) to generate a list of 95 outcome statements. The researchers independently coded each outcome statement using a cross-matrix comparison noting the occurrence of themes. This resulted in 45 discrete issues, concepts, or skills.

The researchers then independently coded each of the 45 emerging issues, concepts, or skills into mega-level organizers representing five types of competencies including the knowledge, skills, and dispositions that enable teachers to demonstrate:

- Pedagogical Competence, i.e., successfully plan and implement effective learning experiences.
- Evaluation and Assessment Competence, i.e., effectively plan, implement, analyze, and interpret an educational outcome or the merit or worth of a learning activity or curricular program, product, or policy.
- Technological Competence, a combination of technological knowledge, technological skills, and technological will (Autio, 2011) which enable people to design, use, manage, assess, and understand technology (ITEA, 2000), including interdisciplinary concepts and principles categorized as STEM.
- Interpersonal Competence, i.e., abilities to adapt to dynamic social situations and effectively interact, communicate, cooperate, and collaborate.
- Professional Competence, i.e., commitment to lifelong learning, abilities to influence others, and contribute to the advancement of the profession.

Overall there was 100% agreement among the researchers on 67% of characteristics with Technological Competence being the most consistent. After collaboratively reconsidering items receiving 75% agreement until consensus was reached, 86 statements of teacher characteristics were included on the round one instrument, including: Pedagogical = 20; Evaluation and Assessment = 16; Interpersonal = 11; Technological=27; and Professional=11.

Results

The purpose of the first round of the study was to solicit panelists' recommendations as to the characteristics of a TE teacher striving for excellence and validate the characteristics gleaned from a review of the TE teacher preparation programs and the InTASC standards. The instrument was organized into five subsections representing the five categories of competencies. Each subsection began with an open-ended question asking panelists to list the most critical knowledge, skills, and dispositions related to that competence. Then, panelists rated the aforementioned characteristics on a 5-point scale (1=Not at All Important to 5=Critically Important). At the end of each subsection, panelists were asked to "list any other competencies that should be on this list."

Round 1 Results & Discussion

Panelists offered 310 responses to the open-ended questions on the round one instrument. After eliminating redundancies and cross-referencing with the original 86 characteristics, 76 of the panelists' responses were deemed unique adding new qualities to the list of characteristics. Table 2 offers examples of these items.

Panelists' ratings of the 86 core characteristics generated consistent averages of 4 or higher for 3 of 5 competence categories, including Evaluation and Assessment, Interpersonal, and Professional Competence. Although planning instruction that aligns with state TE standards (M=4.24, S=.56) and the STLs (M=4.24, S=.66) ranked 15th and 16th, respectively, panelists did not perceive abilities to design curriculum and facilities as critically or very important pedagogical competencies (Table 3). This suggests that the traditional role of the teacher as a curriculum developer (Zuga, 1991) has subsided; this may be in response to the widespread adoption of externally-produced curriculum, such as Project Lead the Way. Relative to technological competence, the panelists' low ranking of "Understanding contemporary systems related to biotechnology, medical technology, nanotechnology, and agricultural technology" supports Litowitz's (2014) contention that there is a "lack of extensive acceptance within the field" to these aspects of technology (p. 78).

Table 2
Round One Panelist Contributions to Open-Ended Questions

Technological Competence	Pedagogical Competence	Evaluation and Assessment Competence	Interpersonal Competence	Professional Competence
61 Responses	73 Responses	57 Responses	58 Responses	61 Responses
8 Unique	19 Unique	21 Unique	11 Unique	17 Unique
Knowledge of certifications available in technical professions	Inspires students' curiosity, creativity, ingenuity, and innovative spirit	Selects and uses assessment strategies that require students to use inquiry and critical thinking skills	Enjoys teaching	Possess a degree in an engineering discipline
Knows how technical information and skills connect to careers and workplace practices	Anticipates student mistakes when introducing new technologies	Selects and uses assessment tools that meet the needs of business and industry	Demonstrates love and excitement for technology and engineering content	Active in curriculum committees, school boards, and strategic partners
	Creates a learning environment where students are willing to take risks and persist through difficulty	Identifies student characteristics for which baseline data should be collected	Promotes equity in the classroom, including issues of gender, race, disability, and nationality	Fosters the next generation of teachers
			Fosters relationships with business and industry leaders	Attempts to inform educational policy

Table 3
Round One Results: Low Ratings[1] of 86 Core Characteristics

		M	*SD*
Pedagogical Competence (20 items, *n* = 18)			
Rank	Item		
18	Designs TE curriculum	3.78	.65
19	Plans instruction based upon community needs and priorities	3.72	.83
20	Designs laboratories and classroom spaces	3.61	.85
Technological Competence (27 items, *n*=18)			
Rank	Item		
27	Understands contemporary systems related to biotechnology, medical technology, nanotechnology, and agricultural technology.	3.78	0.18

[1]Less than 4 on a 5-point Importance Scale

Round Two Results and Discussion

The purpose of the second round of the study was to gauge panelists' judgments regarding ONLY those unique characteristics individually provided by the panel in the open-ended response portion from the first round. The round two survey asked the participants to rate each item using a 5-point scale (1=Not at All Important to 5=Critically Important).

The data were analyzed to find the mean and standard deviation of the responses. Twenty-four of the unique items received a mean rating of 4.5 or higher with the highest mean scores occurring for a pedagogical and interpersonal competency.

Nine of the 76 unique items did not receive ratings of 4 or better on a 5-point importance scale (Table 4). Several of these lower rated items might indicate an emerging trend or important concern for teacher educators. Looking across competence categories in Table 4, several characteristics demonstrate direct connections with business and industry through technical certifications, assessments, technical standards, and professional experience. These concerns echo initiatives of the National Research Center for Career and Technical Education and Southern Regional Education Board to develop an induction model for teachers seeking alternative certification to be used by all states (Sass, 2011) or efforts attempting to require that teachers of engineering courses in public schools possess an engineering degree or engineering experience (Virginia Board of Education, 2013). These concerns may emphasize long-held tensions between TE teacher preparation programs dedicated to the mission of *technological literacy for all* with those dedicated to the mission of career education and *workplace readiness*.

Table 4
Round Two Results: Low Ratings[1] of Panelists Unique Recommendations

	Rank	*n*	*M*	*SD*
Pedagogical Competence (19 items)				
Encourages participation in student organizations	18	22	3.95	0.79
Provides opportunities for students to control energy and produce and test products and systems	19	22	3.91	0.75
Evaluation & Assessment (21 items)				
Selects and uses assessment tools that meet the needs of business and industry	20	20	3.95	0.83
Technological (8 items)				
Identifies and applies relevant technical standards, e.g., those of ANSI or ASTM International	21	22	3.91	0.61
Knowledge of certifications available in technical professions	22	22	3.86	0.89
Professional (17 items)				
Shares scholarly work through writing, presentations, and research	14	22	3.82	0.66
Active in curriculum committees, school boards, and strategic partners	14	22	3.82	0.66
Possesses professional experience in business or industry and education	16	22	3.68	0.78
Possesses a degree in an engineering discipline	17	22	3.18	0.66

Round Three Results & Discussion

The purpose of the third round of the Delphi study was to validate the top 50% of the responses from both the first and second rounds. In this final round, the panel was given the full knowledge of the judgments of the panel. For each competency, items were presented in rank order with the Delphi panels' mean response, standard deviation, and the round. Tables 5-9 present the ranked order list of items deemed critically important by at least 50% of the panelists; shaded items were provided by the panel in the open-ended response portion of the round one survey.

Pedagogical Competence. Ten characteristics were considered critically important relative to Pedagogical Competence (Table 5) with the highest agreement among panelists for "Inspires students' curiosity, creativity, ingenuity and the innovative spirit" and "maintains a safe learning environment that promotes the well-being of the learner". While the latter is consistent with a maxim of "do no harm" or beneficence, the former is in concert with a widespread national vision that to be competitive in a global marketplace the U.S. must foster a creative workforce that continuously develops innovative products.

Most of the top-rated pedagogical items have components that are either directly or indirectly consistent to those found in the InTASC (CCSSO, 2011) or ITEA (2003) standards. For example, "Strategically uses a variety of instructional strategies" is reflected in InTASC Standard #8: Instructional Strategies and "Devises learning experiences for students to design, produce, use, and assess technology" is the definition of technological literacy offered by ITEA (2000).

With current emphasis upon STEM education, it is instructive to note two items receiving important, but not critically important ratings, including: "applies appropriate math and science knowledge" (13th in Round 3), and "aligns curriculum and instruction with other subjects at the same grade level" (34th in Rounds 2 & 3). While many of the panelists considered these characteristics important in a TE teacher, the goal of STEM integration and the alignment of subjects were not perceived as critical.

Table 5
Round Three Results - Pedagogical Competence

	A Technology and Engineering Teacher Striving for Excellence …	Critically Important 75-99%
1	Inspires students' curiosity, creativity, ingenuity, and innovative spirit	85%
2	Maintains a safe learning environment that promotes the well-being of the learner	85%
3	Makes subject matter meaningful for students	75%
4	Inspires and motivates students to learn and perform by developing relevant and engaging learning experiences	70%
5	Enhances students' development of reasoning, problem solving, and critical thinking skills	63%
6	Implements relevant real-world learning experiences	55%
7	Devises learning experiences for students to design, produce, use, and assess technology	55%
8	Inspires students to achieve at increasing levels of difficulty	55%
9	Understands how students learn and develop	50%
10	Strategically uses a variety of instructional strategies	50%

Evaluation and Assessment Competence. A teacher who "adjusts instruction based upon assessment evidence" was the highest-ranking item relative to Evaluation and Assessment (Table 6). This competency appears congruent with the current pressures on teachers and districts to adopt evidence-based teaching strategies (Groccia, & Buskist, 2012). Other highly ranked items, were strongly consistent with InTASC Assessment Standard #6 (CCSSO, 2011) and ITEA's (2003) Student Assessment standards.

Table 6
Round Three Results – Evaluation and Assessment Competence

	A Technology and Engineering Teacher Striving for Excellence …	Critically Important 75-99%
1	Adjusts instruction based upon assessment evidence	84%
2	Selects and uses assessment strategies that require students to use inquiry and critical thinking skills	68%
3	Provides opportunities for students to demonstrate learning in a variety of ways	68%
4	Provides timely and useful feedback to students regarding their progress toward learning goals	63%
5	Uses performance-based assessments that reflect real-world problems or contexts	63%
6	Develops valid assessment tools (e.g., tests and rubrics)	63%
7	Plans meaningful, effective assessment experiences for students that measure progress toward important learning goals	58%
8	Helps students learn how to self-assess	53%

The 2nd highest ranked item—"Selects and uses assessment strategies that require students to use inquiry and critical thinking skills" — likely exhibits panelists' value for embedding assessment throughout students' design and problem-solving process (Custer, Valesey, & Burke, 2001) or evidence of a growing practice of assessing students' reasoning abilities through scenario-based assessment as demonstrated within the *Technology and Engineering Literacy Assessment* (National Assessment of Educational Progress, 2014). However, the results of Kelley and Wicklein's (2009) survey of high school teachers suggest that teachers may not emphasize the analysis phase where critical thinking is required (p.19).

Technological Competence. In the third round, the panel rated 20 characteristics in the Technological Competence category; 11of 20 were deemed critically important by the panelists. Three of the most critically important technological competencies concerned the skills required to control hazards and safely use tools (Table 7, #1, 3, & 4). Maintaining a safe educational environment demands an advanced set of knowledge and skills regarding the nature of processing materials and energy. Similarly, Cannon, Kitchel, Duncan and Arnett's (2011, Table 2) survey of educators in Idaho indicated that the 1st and 2nd highest ratings of teaching responsibilities were for proper "safety practices" and "safety attitudes," respectively.

Three other critically important characteristics (Table 7, #2, 5, and 6) spoke to an interrelated set of cognitive and psychomotor skills, including engineering design, problem solving, analysis, modeling, and testing. Although problem solving has long been the focus of curricular goals in industrial arts and technology education, a design process is narrower, having been characterized as the "engineering approach to identifying and solving problems" (Katehi, Pearson, & Feder, 2009, p. 4). For both, analysis typically refers to a fundamental cognitive skill required to decompose, break-down, and isolate elements of the problem during problem solving or design. While modeling and testing provides the problem solver or engineer with the empirical evidence used to assess or make design decisions.

Given that Ritz's (2009) Delphi study identified the *must have* goal for technological literacy programs as describing "social, ethical, and environmental impacts associated with the use of technology" (p. 59), readers may be interested in parallels in the current study. Although not deemed critically important by 50% of the panelists during Round 3, "know and apply systems thinking (e.g., systems are interrelated)" and "know that technical systems interact with and affect other systems, including economic, political, and environmental systems" ranked 10th and 12th, respectively.

Supporting Litowitz's (2014) survey of TE teacher preparation programs, these results also demonstrate a lower acceptance of agricultural, biotechnologies, medical technologies, and nanotechnologies in the field of technology and engineering education, which obviously vary based upon state-level curriculum standards.

Table 7
Round Three Results – Technological Competence

	A Technology and Engineering Teacher Striving for Excellence …	Critically Important 75-99%
1	Understands and appropriately controls hazards, including materials, processes, equipment, and energy	84%
2	Knows and is able to apply an engineering design process to design a potential solution	68%
3	Possesses the knowledge and ability to competently and safely use a variety of modern and traditional technologies	68%
4	Safely uses a variety of tools in order to process materials and energy	63%

5	Develops and implements solutions to open-ended problems	58%
6	Can analyze a prototype or create a model to test a design concept	58%
7	Exemplifies a spirit of inquiry, creativity, and innovation	53%
8	Understands how technological progress promotes the advancement of science, technology, engineering, and mathematics	53%

Interpersonal Competence. In round three, eleven interpersonal competencies were deemed critically important by the panelists (Table 8), the highest being "exemplifying sound ethical behavior" which is consistent with InTASC (CCSSO, 2013) Standard #10. The panel also agreed that a TE teacher must possess the interpersonal abilities to "think critically and analyze a problem" and "demonstrate flexibility in accommodating and adjusting to unexpected problems." Also referred to as classroom management, behavior management, conflict resolution, and counseling skills, variations of interpersonal competencies are sometimes identified as "needs" in surveys of graduates from TE teacher education programs (Hill & Wicklein, 2000) and practicing secondary teachers (Cannon, Kitchel, Duncan, & Arnett, 2011).

Table 8
Round Three Results – Interpersonal Competence

	A Technology and Engineering Teacher Striving for Excellence …	Critically Important 75-99%
1	Exemplifies sound ethical behavior	90%
2	Demonstrates the ability to think critically and problem solve	84%
3	Demonstrates flexibility in accommodating and adjusting to unexpected problems	75%
4	Demonstrates love and excitement for technology and engineering content	75%
5	Is respectful of differences	70%
6	Promotes equity in the classroom, including issues of gender, race, disability, and nationality	70%

7	Enjoys teaching	60%
8	Exhibits a positive attitude	60%
9	Understands and values diversity	60%
10	Listens to and considers the contributions of others	55%
11	Fosters relationships with school colleagues, parents, and people in the larger community	50%

Professional Competence. Nine of 14 professional competencies presented to panelists during the third round were deemed critically important (Table 9). The ability to "exemplify sound ethics" was, once again, the highest ranked item. Characteristics such as "making decisions based on professional standards", "staying current with professional issues", and "understanding the role of technology and engineering in STEM" were also highly rated. These are reflected in InTASC's (CCSSO, 2013) critical disposition that states "a teacher understands the expectations of the profession including codes of ethics, professional standards of practice, and relevant law and policy" (p. 41).

The panel also proposed that a TE teacher "advocates for technology and engineering education's role in the K-12 curriculum and community" with a 68% agreement of critical importance. This is closely reflected by the ITEA's (2003) Management Program Standard that advises that "teachers promote technology programs and technological literacy as essential components of education to parents, the local school board, and civic and economic development groups (p. 93).

With 32% agreement of critical importance, the Delphi panel identified that TE teachers should "accept leadership opportunities within the profession" and "share resources and best practices with others." This is a strong indication that the panelists agree with Ritz and Martin (2013) that the "advancement of a profession relies heavily on the participation of its members" (p. 65).

Table 9
Round Three Results – Professional Competence

	A Technology and Engineering Teacher Striving for Excellence …	Critically Important 75-99%
1	Exemplifies sound ethics	89%
2	Make decisions based upon professional standards and ethical criteria	74%
3	Seizes opportunities to stay current with professional issues, technical developments, best practices, and educational research	74%
4	Demonstrates an understanding of the role of technology and engineering in STEM education	74%
5	Advocates for technology and engineering education's role in the K-12 curriculum and the community	68%
6	Actively seeks out opportunities for professional growth; pursues life-long learning	63%
7	Demonstrates abilities to learn about new technologies	53%
8	Models best practices of the profession	53%
9	Possesses a teaching license or teaching credentials from the state	53%

Study Limitations

Several limitations existed within this Delphi study. The first instrument was derived from only five programs, thus it may not be representative of all TE teacher preparation programs. In addition, the relative value of mega-level competencies was not verified. Finally, the Delphi panel was populated with a diverse set of educational professionals; the combination may not be representative of the population of TE professionals.

Conclusions & Recommendations

This Delphi study was an attempt to characterize the qualities of TE teachers in the U.S. who strive for excellence. A questionnaire was developed from a review of the valued outcomes of TE teacher education programs and standards. A Delphi panel consisting of professional educators rated these outcomes and offered their own characterizations. After three rounds, these results indicate a clear focus upon learners and strong parallels to InTASC (CCSSO, 2011) and ITEA (2000 & 2003) standards. The highest ranked characteristics deemed important by at least 80% of the panelists for pedagogical competence were "inspires students' curiosity, creativity, ingenuity and innovative spirit" and "maintains a safe learning environment that promotes the well-being of the learner". For evaluation and assessment competence, it was "adjusts instruction based upon assessment evidence". "Exemplifies sound ethical behavior" and "demonstrates the ability to think critically and problem solve" were the highest ranked interpersonal competencies. For professional competence, the highest ranked was that a teacher "exemplifies sound ethics". Lastly, the highest ranked technological competence was that a teacher "understands and appropriately controls hazards, including materials, processes, equipment, and energy".

These results indicate that *teaching excellence* requires an interrelated set of skills, knowledge, and dispositions. In addition, the panelists' revealed values that were not explicit in the original outcome statements, technological literacy is a valued mission, and the expectations of teacher responsibilities may be narrowing.

Interrelated Skills, Knowledge & Dispositions

The results of this study support Shulman's (1986; 1987) and Mishra and Koehler's (2006) conceptualization of Pedagogical Content Knowledge in that panelists did not assign skills, knowledge and dispositions into mutually-exclusive categories; instead several parallels were drawn between pedagogical and technological competencies. First, the panelists associated the technical knowledge and skills required to safely use tools and control hazards (Table 7, #1, 3, & 4) with the pedagogical disposition and skills required to "maintain a safe learning environment that promotes the well-being of their learners" (Table 5, #2). Second, the emphasis upon enhancing "students' …problem solving… skills" (Table 5, #5) and devising learning experiences for students to design technology (Table 5, #7) is parallel to the panelists' value for technological competencies of being able to apply an engineering design process (Table 7, #2), and to develop and implement solutions to open-ended problems (Table 7, #5). Third, a parallel exists between a critically important technological competence—"exemplifies the spirit of inquiry, creativity, and innovation" (Table 7, #7)—and the highest rated pedagogical competence of "inspires students' curiosity, creativity, ingenuity, and innovative spirit" (Table 5, #1) . This prominence suggests that the panelists have internalized these qualities and have accepted the call to promote innovation and entrepreneurial activity in an attempt to enhance the competitive edge of the U.S. in a world marketplace.

Technological Literacy

There is substantial evidence among the pedagogical, technological, and assessment competencies that *technological literacy* is a valued mission for teachers pursuing excellence. The ITEA's (2000) definition of technological literacy—*design, produce, use, and assess technology*—appears as the 8th critically important pedagogical competence. However, the critical importance of engineering design (Rank 2nd) and lower importance of systems thinking (Rank 10th) and "knowing that technical systems interact with and affect other systems, including economic, political, and environmental systems" (Rank12th) among technological competencies may suggest a reprioritization of the essential goals reported within Ritz's (2009) Delphi study.

Narrowing Teacher Expectations

Beyond the highest rated items, the results of current study highlights issues of perceived less importance by TE professionals. This study suggests that the traditional role of a TE teacher is narrowing to an implementer of curricula because competencies related to fulfilling roles of curricular developer, curriculum evaluator, and facility developer were not among those competencies judged to be critically important.

Recommendations to Teacher Educators and Researchers

The competency profile that emerged from this study could assist TE teacher educators as they evaluate and revise teacher preparation programs in a profession that continues to evolve and remain dynamic. Of special interest to teacher educators are the unique competencies suggested by the panel because these were not prominent among the outcome statements of the teacher preparation programs originally reviewed by the researchers. Teacher educators might evaluate the extent to which their curriculum provides pre-service teachers with opportunities to:

- experience, compare, and use assessment strategies that demand the application of inquiry and critical thinking skills;
- engage in professional activities, including service, presentations, and research;
- analyze the role of TE as part of integrated STEM education; and
- analyze and develop strategies to resolve interpersonal problems (social and behavioral) that might arise in the classroom relative to issues of gender, race, disability, and nationality.

Consistent with the idea that pedagogical content knowledge represents an integrated and complex set of teacher competencies related to content knowledge and pedagogical skills, teacher educators should also consider the integrative nature of the mega-level competencies—pedagogy, evaluation and assessment, technological, interpersonal, and professional—examined in this study. One recommendation for additional research is to develop a model that depicts the interrelationships among mega-level competencies and then test how this model could be used to guide TE teacher preparation programs.

Researchers should explore how exemplary teachers inspire ingenuity, creativity, and innovation among their students. Future research should also seek to identify competencies directly related to the delivery of STEM-integrated curriculum, especially as it applies to technical skills and mathematics and science knowledge.

Although this study investigated the characteristics of TE educators striving for excellence, it did not analyze the development of these characteristics. Many different factors contribute to the development of desired teacher competencies including teacher experience, preparation programs, work experiences, and the certification route taken by the educator (Rice, 2003). The researchers recommend further study into the different factors that contribute to the development of ideal TE teaching competencies.

References

Aaronson, D., Barrow, L., & Sander, W. (2007). Teachers and student achievement in the Chicago Public High Schools. *Journal of Labor Economics, 25*(1), 95-135.

Autio, O. (2011). The development of technological competence from adolescence to adulthood. *Journal of Technology Education, 22*(2), 71-89.

Cannon, J. G., Kitchel, A., Duncan, D. W., & Arnett, S. E. (2011). Professional development needs of Idaho technology teachers: Teaching and learning. *Journal of Career and Technical Education, 26*(1). Retrieved from http://scholar.lib.vt.edu/ejournals/JCTE/v26n1/cannon.html

Council of Chief State School Officers. (2013, April). *InTASC: Model core teaching standards and learning progressions for teachers 1.0.* Washington, DC: Author.

Council of Chief State School Officers. (2011, April). *Interstate teacher assessment and support consortium (InTASC) model core teaching standards: A resource for state dialogue*. Washington, DC: Author.

Custer, R. L., Valesey, B. G., & Burke, B. N. (2001). An assessment model for a design approach to technological problem solving. *Journal of Technology Education, 12*(2), 5-20.

Gattie, D. K., & Wicklein, R. C. (2007). Curricular value and instructional needs for infusing engineering design into K-12 technology education. *Journal of Technology Education*, *19*(1), 6-18.

Gonzalez, H. B., & Kuenzi, J. J. (2012, August 1). *Science, technology, engineering, and mathematics (STEM) education: A primer.* Congressional Research Service (Report No. 7-5700, R42642). Retrieved from http://fas.org/sgp/crs/misc/R42642.pdf

Groccia, J. E., & Buskist, W. (2012). The need for evidence-based teaching. In W Buskist & J. E. Groccia (Eds.). *Evidence-based teaching. New directions in teaching and learning*, no. 128 (pp. 5-11). San Francisco, CA: Jossey-Bass.

Grossman, P., Cohen, J., Ronfeldt, M., & Brown, L. (2014). The test matters: The relationship between classroom observation scores and teacher value added on multiple types of assessment. *Educational Researcher, 43*(6), 293-303.

Hacker, M., de Vries, M. J., & Rossouw, A. (2009). *CCETE project: Concepts and contexts in engineering and technology educatio*n. Hofstra University and Delft University of Technology. Retrieved from http://www.hofstra.edu/pdf/academics/colleges/seas/ctl/ctl_finalreport_ccete_nov_6.pdf

Hill, R. B., & Wicklein, R. C. (2000). Great expectations: Preparing technology education teachers for new roles and responsibilities. *Journal of Industrial Teacher Education, 37*(3).

International Technology Education Association. (2003). *Advancing excellence in technological literacy: Student assessment, professional development, and program standards.* Reston, VA: Author.

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

Katehi, L., Pearson, G., & Feder, M. (Eds.). (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. National Academy of Engineering and National Research Council. Washington, DC: The National Academies Press.

Kelley, T. R., & Wicklein, R. C. (2009). Examination of assessment practices for engineering design projects in secondary technology education. *Journal of Industrial Teacher Education*, *46*(2), 6-25.

Litowitz, L. S. (2014). A curricular analysis of undergraduate technology & engineering teacher preparation programs in the United States. *Journal of Technology Education, 25*(2), 73-84.

Miller, C. D. (1991). Programs to prepare teachers of technology education. *The Journal of Epsilon Pi Tau, 17*(1), 59-70.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for integrating technology in teacher knowledge. *Teachers College Record, 108*(6), 1017-1054.

National Assessment of Educational Progress. (2014). *Technology & engineering literacy assessment*. Retrieved from http://nces.ed.gov/nationsreportcard/tel/

Office of Educational Innovation and Evaluation, Kansas State University. (2008). *Exemplary teacher characteristics: National survey results and alignment with the DeBruyn Institute for Teaching Excellence® core beliefs*. Retrieved from Netsuite.com

Presidents' Council of Advisors on Science and Technology. (2010). *Prepare and inspire: K-12 education in science, technology, engineering, and math (STEM) for America's future*. Executive Office of the President of the

United States. Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stemed-report.pdf

Rice, J. K. (2003). *Teacher quality: Understanding the effectiveness of teacher attributes*. Washington, DC: Economic Policy Institute.

Ritz, J. M. (2009). A new generation of goals for technology education. *Journal of Technology Education, 20*(20), 50-64.

Ritz, J., & Martin, G. (2013). Perceptions of new doctoral graduates on the future of the profession. *Journal of Technology Studies, 39*(2).

Roberts, T. G., & Dyer, J. E. (2004). Characteristics of effective agriculture teachers. *Journal of Agricultural Education, 45*(4), 82-95.

Rychly, L., & Graves, E. (2012) Teacher characteristics for culturally responsive pedagogy. *Multicultural Perspectives,14*(1), 44-49.

Sass, H. B. (2011). Advancing a new image of CTE via high-quality teacher preparation. *Techniques: Connecting Education and Careers, 86*(4), 24-27.

Scott, D. G., Washer, B., & Wright, M. (2006). A Delphi study to identify recommended biotechnology competencies for first-year/initially certified technology education teachers. *Journal of Technology Education, 17*(2), 44-56.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1-23.

Stitt-Gohdes, W. W., & Crews, T. B. (2004). The Delphi technique: A research strategy for career and technical education. *Journal of Career and Technical Education, 20*(2), 55-67.

U.S. Department of Education, Office of Postsecondary Education, Office of Policy Planning and Innovation. (2002). *Meeting the highly qualified teachers challenge: The secretary's annual report on teacher quality.* Washington, DC. Retrieved from https://www2.ed.gov/about/reports/annual/teachprep/2002title-ii-report.pdf

Virginia Board of Education. Advisory Board on Teacher Education and Licensure. (2013, June 27). *Licensure regulations for school personnel*. Virginia: Virginia Board of Education. Retrieved from http://www.doe.virginia.gov/boe/meetings/2013/06_jun/agenda_items/item_i.pdf

Wicklein, R. C. (1993). Identifying critical issues and problems in technology education using a modified-Delphi technique. *Journal of Technology Education, 5*(1), 54-71.

Zuga, K. (1991). Technology teacher education curriculum courses. *Journal of Technology Education, 2*(2).

Who Is Doing the Engineering, the Student or the Teacher? The Development and Use of a Rubric to Categorize Level of Design for the Elementary Classroom

Science, technology, engineering, and mathematics (STEM) professional development for K–5 teachers often includes engineering design as a focus. Because engineering applications provide perspective to both teachers and their students in terms of how mathematic and scientific principles are employed to solve real-world problems (Baine, 2004; Roden, 1997), there is great interest in using engineering as a context for studying STEM education. Engineering as a context for learning mathematics and science is documented in the National Research Council's review of K–12 engineering curricula (National Research Council, 2010). Further, engineering has become integrated into the *Next Generation Science Standards* (NGSS Lead States, 2013), which provide a mandate for the formal integration of engineering into the K–5 curriculum.

Although it may suggest fluidity in curriculum and instruction among the four disciplines, "the STEM acronym is more often used as shorthand for science and mathematics education" (Katehi, Pearson, & Feder, 2009, p. 12). The increased attention to engineering in elementary curriculum (e.g., the *Next Generation Science Standards*), teacher preparation, and professional development provided the motivation for our research. Our project provided teachers with professional development opportunities designed to enhance their knowledge and preparation for teaching using engineering design. Following the professional development course, we observed how the teachers implemented engineering design lessons with students in their classrooms.

In recognition of the limited preparation of elementary level teachers to teach engineering content and pedagogy, we created and implemented a professional development opportunity for grade K–5 teachers to enhance their knowledge of engineering and the design process. Specifically, our collaboration sought to enhance the participating teachers' understanding of the work of engineers. We also explored the procedures for engineering design as approaches to solving problems and conducting research while recognizing the developmentally appropriate application and use of these approaches for teaching STEM to elementary level learners.

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Our STEM education intervention consisted of a three-day summer institute that combined presentations, workshops, hands-on activities, and curriculum planning and development. Our research was based on the anticipated influence of engineering-focused professional development on teacher practice and the subsequent increase in student engagement in engineering design-based learning activities (Fox-Turnbull, 2006). Specifically, we examined the elements of the design process that teachers emphasized in their instruction and the student-generated artifacts inspired by the lessons, and we classified the design assignments by the extent of responsibility taken by the teacher and student in terms of the structure of the elements in the design process. We gathered empirical data detailing teacher knowledge of the design process, their instructional use of engineering design, and student response to design assignments at the elementary, K–5 level. Our report presents a new level of design classification rubric developed for categorizing levels of responsibility of the students and teachers in the design process. The rubric was designed to classify design lessons based on the student and teacher (or instructional resource) responsibility for decision making in determining the structure of the elements of design.

Engineering Design in Elementary Level Education

Engineering design is becoming more popular to include as a K–5 instructional approach, usually in conjunction with engineering, technology, and related contexts (Davies, 1996; Lachapelle & Cunningham, 2007). Using design as a focus for instruction and learning, curricular programs such as Project Lead the Way (Bottoms & Anthony, 2005) and Engineering is Elementary (Cunningham & Hester, 2007) provide structure and materials for teaching engineering content, concepts, and processes. Additional outreach programs and a growing number of teacher professional development offerings (e.g., Nadelson, Seifert, & Moll, 2011) have been implemented to prepare elementary teachers to teach using design and engineering as contexts for teaching a range of STEM content. Nadelson and colleagues (Nadelson et al., 2010; Nadelson et al., 2011) have established that such professional development offerings can increase teacher content knowledge and comfort with teaching engineering related content, concepts, and the design process.

The increased interest in supporting engineering in elementary teacher preparation and subsequent professional development suggests that there may be multiple justifications for providing continuing education opportunities designed to enhance teacher knowledge of engineering design (Felder, Brent, & Prince, 2011; Guzey, Tank, Wang, Roehrig, & Moore, 2014; Lewis, 2006). We speculate that the increase in teacher knowledge of how to engage their students in the engineering design process happens most effectively by engaging teachers in engineering design projects that adhere to student-centered instructional practices.

The majority of the research on K–12 teacher professional development in engineering design has been directed toward secondary teachers (Burghardt & Hacker, 2007; Fontenot, Talkmitt, Morse, Marcy, Chandler, & Stennett, 2009; Tufenkjian & Lipton, 2007). We argue that the increased awareness and consideration of engineering and design in the curriculum necessitates a greater understanding of how to prepare elementary teachers to effectively teach engineering design. Recognition of the potential for engineering design to provide learning contexts that are rich with opportunities to engage students in STEM habits of mind (e.g. problem solving, critical thinking, evidence based decision making—also see Berland, 2013) suggests that there is benefit to continued exploration of how design is and can be effectively taught in the K–5 curriculum. Thus, there are a number of anticipated benefits to preparing K–5 teachers to teach using design as well as a need to document how teachers are engaging their students in engineering design (Lewis, 2006).

We recognize the need to increase teacher content and pedagogical knowledge associated with engineering design to enhance their capacity to effectively influence their students' learning (Darling-Hammond & Bransford, 2005). We also recognize the need to support the development of teacher pedagogical content knowledge (Niess, 2005; Shulman, 1987), particularly in the teaching of engineering (Fransson, & Holmberg, 2012), and teacher creativity in their STEM teaching practice. Creative expression has been deemed necessary for teachers to generate the mental dexterity associated with being flexible, adaptable, and original in their practice (Dobbins, 2009), which is likely critical when exploring new curricular areas such as teaching engineering design. Kampylis Berki, and Saariluoma (2009) argue that teachers influence their students' development of creativity through modeling, which provides justification for enhancing and encouraging teachers to express their creativity in their teaching practice. Thus, a key element in providing teachers with experiences in design and engineering is encouraging them to think creatively and to reflect deeply on student-centered lessons. We assert that K–5 engineering professional development offerings need to expose teachers to design as a creative endeavor. This exposure is likely to foster teachers' creative expression, increasing their instructional use of design and engaging students in a wide range of novel, student-centered engineering challenges

Classifying the Level of Instructional Use of Engineering Design

One of the challenges with researching the instructional use of engineering design is the wide range of possible implementation configurations, from very teacher centered to very student centered. In order to investigate this, we needed to develop a tool that would allow us to classify engineering lessons with respect to levels of responsibility for teacher and student. A similar situation with scientific inquiry motivated Schwab (1962) to develop a rubric to classify the *level of inquiry* with respect to teacher and student responsibility. Schwab's rubric provides a means of classifying inquiry lessons based on the level to which the teacher or instructional resources are responsible for the structure of inquiry and the level to which students are responsible for the structure of the inquiry. In Schwab's rubric, for a Level 0 inquiry assignment, teachers or instructional resources provide the structure for all elements of inquiry, and the students simply follow instructions as they engage in the inquiry process. Level 0 inquiry is essentially an exercise in confirming the results from prior research and established outcomes. In contrast, a Level 3 inquiry (based on Schwab's rubric) engages students in investigations in which they are responsible for generating and responding to all aspects of inquiry, a situation equivalent to full discovery learning.

We were not able to locate a similar rubric or classification scheme that has been specifically developed to evaluate the responsibility level of students and teachers in engineering design instruction. We addressed this gap and developed and validated a rubric which can be used to classify the level of design used in engineering design instruction. In the development of our Level of Design Rubric we consulted several models of engineering design that are being promoted in the elementary engineering curriculum (Cunningham, 2009; National Aeronautics and Space Administration [NASA], 2008; The Works Museum, 2011). Although each of these models was unique in the representation of engineering design, the models share some common elements or processes. Common to the models were identifying problems, exploring ideas, brainstorming, building products, gathering data, and evaluating the results. Further, the models of engineering design associated with elementary education also recognized the iterative nature of engineering. We combined the common elements presented in these models with our knowledge of the engineering design process, adding identification and listing of constraints and criteria to create a framework for the critical elements of engineering design that should be included in K–5 lessons (see Table 1). It is important to note that we present the essential elements here and rely on the details of the various other models explained in the literature for the finer gain details (Cunningham, 2009; NASA, 2008; The Works Museum, 2011).

We used the elements in our engineering design model to guide the development of our Level of Design Rubric. Throughout the development process, we made decisions to collapse some design elements from the model to form the principal categories of our Level of Design Rubric. For example, we combined the engineering design processes of *generating ideas* and *select a solution* into one element, and we also combined the two processes of *present results* and *evaluate outcomes* into a single element. The essential elements contained within our engineering design instructional model and a brief description of the processes within each of the elements are presented in Table 1.

Table 1
Essential Elements of the Design Process Used in Instruction and the Associated Processes

	Design Element				
	Problem Statement	Criteria and Constraints	Generate Ideas and Select Solution	Process Used to Build the Product	Present Results and Evaluate
Description of the Associated Process(s)	The problem to be solved is identified and explained	Criteria to which the solution must conform, and the specifications for the product are listed The constraints, limitations, or bounds for the product are recognized	Brainstorming about possible solutions to the problem Identifying what seems to be the best solution Justification and assurance that the preferred solution conforms to criteria and constraints	The solution is prototyped A solution is selected A working solution is created The solution is tested, data are gathered	The final solution is presented to others The solution is evaluated for conformity to criteria and constraints and effectiveness in solving the problem Evaluation is used to plan for the next generation of the solution

Similar to Schwab's (1962) rubric for classifying the level of inquiry used in instruction, our rubric classifies the level of engineering design used in instruction by the level of responsibility assumed by students and the teacher for the structure of the engineering design elements. In the use of the Level of Design Rubric, each of the five design elements are considered and scored such that if a teacher (or the teacher-provided resources) provides *all* of the structure of the design element, the element would be scored as a 0. By contrast, if the student is responsible for all of the structure of the element, the element would be scored as a 1. If an element in our rubric is not present in a design assignment, such as *presenting products and evaluating results*" the element should be scored 0 because it is assumed that the teacher (or resource developer) made the decision not to include the design element process and, therefore, took full responsibility for that element of the design activity. We anticipate that students and the teacher (or resources) will share the responsibility for the structure of the design process elements, so fractional scores of 1 are encouraged. For example, an equal sharing of the responsibility for identifying and developing a *problem statement* by the teacher (or teacher-provided resources) and the student may result in a score of .5 for the problem statement element on the rubric. After each element has been scored with a value from 0 to1, the element scores are summed, and an overall Level of Design score is established. Thus, the final score for a level of design used for instruction evaluation and research on how elementary teachers (and other teachers) are structuring their engineering design lessons would be a value between 0 and 5.

Structure Responsibility Score 0 to 1 [If teacher or resources solely responsible—Score 0] [If student is solely responsible—Score 1]	Design Element					Level of Design *Sum of Element Scores* (From 0–5)
	Problem Statement	Criteria and Constraints	Generate Ideas and Select Solution	Process Used to Build the Product	Present Results and Evaluate	
Responsibility for Element Structure Score (From 0–1)						

Figure 1. The Level of Design Rubric.

As with Schwab's (1962) rubric, because level of design is somewhat subjective, we constructed our level of engineering design classification scheme to be used and interpreted on an ordinal scale based on what the observer focuses on during a lesson observation. The outcome from our rubric should be considered as a general indicator of the level of design. For example, a sum of scores of 2.75 may be rounded to "level 3" engineering design lesson which would indicate that the student assumed slightly more responsibility for the elements in the engineering design assignment than the teacher (or instructional resources). Thus, similar to those using Schwab's rubric to classify instructional level of inquiry it is up to the discretion of the users of our Level of Design Rubric to apply their understanding of engineering education. The conditions of a design lesson that is under evaluation should be taken into consideration when interpreting the significance of the level of design which is observed.

To illustrate what different levels of the instructional implementation of design rankings might represent, we provide the following examples of design assignments that would be ranked from Level 0 to Level 5. The examples we provide detail the level of responsibility of the student, the teacher, and expected design assignment outcomes.

A Level 0 design would be equated with situations in which the student (through direct instruction by the teacher or instructional resources) is provided with all design element structure for all aspects of the design activity. Thus, a Level 0 design assignment would have a highly prescriptive structure with students following provided directions to replicate the construction of an existing solution or structure. In a Level 0 design assignment, the teacher (or instructional resources) is responsible for the structure of all design elements. A Level 1 design assignment would be structured such that students have some (but rather little) responsibility for the design elements structure and thus would be engaging in a design process that is likely to permit them to make slight modifications to an expected outcome or process. In a Level 1 design, the deviations the students may be permitted to take would be slight, and expectations would be for the students to essentially follow a detailed process that allows minimal decision making. At Level 2, the students assume some responsibility for the design process elements, which may allow them to make significant alternations toward the development of an expected outcome or product. A Level 2 design assignment would allow students to take responsibility for the design product as long as the spirit and outcome of the assignment design product is maintained. At Level 3, the students are given more responsibility for finding a solution to a problem and are afforded the opportunity to add new features and alternative solutions to a predetermined outcome. Thus, at Level 3, students have some freedom and responsibility to explore possibilities and seek unique solutions within the bounds of a proposed problem. At Level 4, the students assume a great deal of responsibility for the design process and develop new ideas and designs to solve a problem they have identified that is likely to lack a solution or model. At Level 4, students are approaching the work of professional engineers, but they are provided some structure and direction for their work. A Level 5 design assignment would place the full responsibility for all of the design elements on the students with minimal to no structure provided by the teacher (or instructional resources). Hence, in a Level 5 design assignment, the teacher's role is almost exclusively shifted to that of a resource guide or consultant while the students take responsibility for seeking and identifying problems, designing and building unique solutions to meet the criteria and constraints that they identified, and evaluating, scrutinizing, and making modifications to their products to optimize their designs, as a professional engineer might do.

We do not advocate for a specific level of design but rather the right level of design for the corresponding level of instruction to meet student learning needs and developmental capacity. Similar to Schwab's (1962) level of inquiry rubric, we envision our Level of Design Rubric as a way of determining the extent to which engineering design lessons are student centered or teacher centered. The degree of responsibility for a lesson interpreted in the context of a level provides a means of determining the appropriate structure of an engineering design lesson and the possible needs for curriculum and teacher professional development to assure an appropriate engineering design lesson structure. Further, the Level of Design Rubric provides a means of documenting how engineering design assignments evolve over time as students become more familiar with the elements of design.

Learning and the Level of Design

Some may argue that students are likely to learn more at higher levels of design because of the necessity for a greater degree of engagement due to higher levels of responsibility. However, we maintain that the instructional success of a design lesson is directly associated with student learning capacity; therefore, success is dependent on the experience of the students and the teacher with design, the context of the design assignment, and the prior content knowledge necessary to effectively engage in finding a solution to a problem. Further, we assert that there is no guarantee that student engagement in an assignment and associated learning will be positively correlated with the level of design; students may become highly engaged in lower level design or become disengaged with higher levels. The key to student engagement and learning may be the alignment between the level of design and the capacity and knowledge of students to effectively complete an engineering design challenge. Our Level of Design Rubric could provide a means of documenting factors associated with the alignment between level of responsibility and students engagement in an engineering design assignment.

We think it is wise for teachers to implement lower level design lessons when initially exposing their students to engineering design because students need to learn the processes. To help students learn the process, it is most effective if the teacher assumes a greater level of responsibility for the structure of the design and models or scaffolds the design elements for the students (Bruning, Schraw, Norby, & Ronning, 2004). Thus, a lower level design may be necessary to help student learn the steps of the engineering design process. Similarly, we suggest that when teachers use engineering design to introduce new concepts or content, they should consider using lower level teacher-centered engineering design lessons. Removing the responsibility from the students for providing the structure for the engineering design elements lowers the cognitive demand on the students so that they may attend to learning the new concepts or content without also having to attend to the design process, which may reduce their capacity for learning new content (Bruning et al., 2004).

As students gain a deeper understanding of engineering design and are given assignments in which they can elaborate on their prior knowledge, they are more likely to be able to take increased responsibility for design elements. Thus, we maintain that engineering design as an instructional approach is likely to be most effective and result in the greatest learning success when teachers scaffold and adjust the level of student responsibility for elements based on the students' content knowledge and design experience. Our Level of Design Rubric could be used to document the evolution of lessons and determine how lessons are being structured in conjunction with other tools that document student learning or performance.

Methods

Research Questions

The goals of our research project were to document increases in teachers' knowledge of engineering design and how teachers use the engineering design process to teach STEM content. Of particular interest to us were the engineering design elements that the teachers selected, how they structured the lessons they developed, and how the lessons were taught in terms of levels of responsibility. Thus, we recognized the need to develop and use a tool to document the level of design of the lessons that the teachers created and taught. We formed the following questions to guide our research:

- Did our participating teachers' knowledge of engineering design increase due to participation in our summer institute, and if so, was the shift sustained over time?
- What was the challenge focus of the engineering design lessons that the teachers taught?
- What elements of engineering design did the teachers emphasize in their lessons?
- What was the level of engineering design of the observed lessons?
- How did the students engage in the engineering design lessons?

We speculated that our participating teachers would experience a sustained increase in their knowledge of engineering design due to their participation in our summer professional development institute and the follow-up support for teaching engineering design that they received during the school year. Further, we anticipated that our participating teachers would develop a diversity of creative engineering design lessons that utilized all the basic design elements. We predicted that we would find that the teachers had implemented engineering design lessons in a range of levels of design. Based on the structure and context of engineering design lessons, we speculated that the students would be highly engaged in the design lessons.

Participants. Our data were drawn from observations of the 142 K–5 elementary teachers who voluntarily participated in our STEM-focused professional development project. The participants all worked in the same school district in one of six partnering elementary schools. The mean age for teachers was 40.7 years old ($S = 10.2$) with 10.5 years of teaching experience ($S = 7.4$). Ninety percent were female. The participants had completed an average of 3.6 college level mathematics classes and 3.2 college level science classes.

Eighty-four percent declared a major endorsement in elementary education with other relevant major endorsements including biology or life science (3%), physical science (1%), and mathematics (1%). The participants' teaching assignments were nearly equally distributed among Kindergarten to Grade 5.

During the three years of our professional development program, the participants voluntarily engaged in a free, three-day intensive summer institute for which they received continuing education credit. For the small minority of cases in which teachers did not attend the professional development program, we provided an equivalent professional development opportunity for them at their schools. In addition, the participants received mentoring and follow-up professional development during the academic year. Because our summer institute was not focused specifically on engineering and design but rather on STEM in general, not all of our summer institute participants are included in this report of our research project. Thus, our current report of design lesson structure and content is based on observation data collected on our project participants who were teaching engineering design lessons on the days we conducted classroom observations.

STEM Professional Development Summer Institute

Our three-day professional development summer institute was designed to enhance the participating K–5 teachers' knowledge of STEM content as well as their use of scientific inquiry and engineering design as instructional approaches. The institute theme and content were focused on exploring the processes used by STEM professionals in their work as contexts for teaching and learning in K–5 education. A portion of the institute was dedicated to exploring the use of plastic brick manipulatives (Lego®-like bricks marketed as *PCS BrickLab®* by PCS Edventures!) for teaching STEM. Our primary goal was to provide a curriculum to our participants that allowed them to gain a deeper understanding of the best practices used to teach STEM and, in particular, to increase their knowledge and capacity to teach engineering design.

During the summer institute, we engaged the teacher participants in a number of engineering design activities, including making the most efficient paper helicopter, building the tallest structure possible on an inclined plane, and creating a "lander" that, when released from a third floor balcony, was to slowly descend to a target on the ground floor (Carpinelli, Kimmel, & Rockland, 2014). These and other activities provided explicit instruction and models of engineering design and provided many opportunities for the participants to think about and plan for how to teach engineering design. Further, to enhance participants' STEM pedagogical content knowledge, we explicitly compared and contrasted the goals and processes of inquiry and design and encouraged the teachers to think about creative and unique solutions and possible opportunities for implementation of engineering design within their curriculum.

Following the summer institute, the participants were expected to develop and implement four lessons that utilized the plastic brick manipulatives to teach lessons from each of the four STEM domains. Teachers were encouraged to get creative, to adapt and adopt extant lessons, and to develop interesting and engaging STEM learning opportunities for their students. We observed the participants at least twice during the academic year while they were teaching a STEM lesson (approximately 30–60 minutes in length) to their students using the plastic brick manipulatives. We provided the teachers with observation data and feedback, extending beyond the summer institute, in order to situate the professional development in the classroom.

Data Collection

Design Process Knowledge. To assess our participants' knowledge of engineering design, we adapted and adopted items from an extant instrument, the Design Process Knowledge Test, which had been validated for undergraduate engineering majors (Sims-Knight, Upchurch, & Fortier, 2006). The original instrument used a selected response format to assess engineering design knowledge across a range of related concepts. Because of the difference in our study population (K–5 teachers) as compared with the original instrument targeted population (undergraduate engineering majors), we determined it necessary to screen the items in the instrument and select only those that were aligned with general knowledge of engineering design and remove items associated with idiosyncratic engineering definitions, engineering coursework, or engineering degree program structures or activities. The resulting instrument contained 18 items such as, "Which of these is the best definition of engineering design?" and "Which is not a benefit of preliminary design or prototype?" and alternatives that represented a range of possible views from naïve or misconceived to informed. Our version of the instrument also included several items such as, "Successful design involves breaking a problem down into smaller problems" which required responses along a Likert-type scale ranging from 1 (*almost always true*) to 5(*almost always false*), including *I don't know*. In the original study, Sims-Knight, Upchurch, and Fortier (2006) report a Cronbach's alpha of .84, indicating a good level of instrument reliability. We gave participants our modified version of the knowledge of design instrument as a pre and posttest.

Classroom Observations. Following the summer institute, we conducted classroom observations of the participants to determine the extent to which they utilized the summer institute concepts to teach STEM content. We used an observation rubric that we successfully used in prior research (Nadelson et al., 2010) to document our observations. The observation rubric was structured to assure that data collection was consistent in that the same kinds of data were collected during each observation. The observation rubric was also structured to be flexible enough to document variations in the nature of the learning and instruction that took place that we could associate with our summer institute content. Each lesson was observed in its entirety, most of which were about 50 minutes in duration. It was our goal to observe each participant teach two STEM lessons, but it was up to the teacher to select what area of STEM lesson was taught and the STEM pedagogy that was used in the lesson. Thus, the STEM content area under observation was not restricted to an engineering design lesson but could be from any of the STEM domains.

During the observations, our field researchers did not participate in the instruction, but they may have interacted with the students by asking the children to explain what they were doing, which allowed for the accurate completion of the observation rubric. We also utilized Livescribe Smartpens® to audio record the observed lessons to provide an additional means of accurately documenting the lessons for the completion of the observation rubric. The audio recordings were not retained once the observation rubrics were completed.

In some circumstances, video recordings were made of the students' interactions while building and explaining their products. We were authorized to gather the video as long as student names, faces, or other information was not gathered that would allow the students to be readily identifiable. These video recordings were also useful for completing the observation rubrics.

Classification of the Level of Design. We utilized our Level of Design Rubric to document the engineering design elements that the teachers emphasized in their lessons and to quantify the level of engineering design. Thus, we used our Level of Design Rubric to document the level of responsibility that the teachers (or teacher-provided instructional resources) and students took for the elements associated with an observed engineering design lesson. Again, the Level of Design Rubric score is interpreted as a basis for documenting the source of the responsibility for element structure in a design activity. If an overall level of design score is near 0, indicating a low level of design, it is because most (or all) of the responsibility for the design structure was provided by the teacher (or instructional resources). In contrast, if a level of design score is near 5, indicating a high level of design, a major amount (or all) of the responsibility for the structure for the design activity was assumed by the student.

To establish the inter-rater reliability of the instrument we had two researchers independently score the lessons. The level of agreement was approximately 85%, with differences resolved though conversation. Thus, we were confidence that the 85% level of inter-rater reliability was acceptable and that our data could be examined without concerns of consistency or bias.

Results

Teacher Knowledge of Design

Our first research question asked: *Did our participating teachers' knowledge of design increase due to participation in our summer institute and if* *so was the shift sustained over time?* Before we conducted our analysis, we calculated the reliability of our modified design process instrument which we found to have a Cronbach's Alpha of .78, indicating that we had an acceptable level of instrument reliability and could proceed with our analysis with the assumption of consistent measures of our participants' knowledge of design. To answer our research question, we conducted a paired samples *t*-test using our participants' pretest, immediate posttest, and delayed posttest scores. Our paired samples *t*-test analysis revealed a significant increase in design knowledge t (46) = 4.94, $p < .01$, with the pre-institute composite scores 10.17 (S = 3.60) shifting upward post-institute to 12.91 (S = 2.07), a .35 partial eta squared effect size. Our analysis did not reveal a significant change in design knowledge from posttest to delayed posttest. Our results indicate that our participants experienced significant and sustained gains in their knowledge of the engineering design process. This finding led us to consider how the participating teachers transferred their knowledge of and experience with the design process into their instruction and interactions with their students.

Lesson Content

Our second research question asked: *What was the challenge focus of the engineering lessons that the teachers taught?* To answer this question, we conducted a content analysis of our 169 STEM lesson observations, 36 of which were categorized as engineering design lessons that included a design challenge. The balance of the lessons focused on other content areas such as mathematics or science. Our content analysis of the observed lessons revealed the teachers implemented an array of design challenges, representing a diversity of creative expression and focusing on a range of topics. For example, in one lesson, students were challenged to design a container to hold the largest number of Silly Bandz given certain budget constraints. Our analysis exposed a number of design lessons in which students were presented with challenges of building model structures such as houses and bridges. For example, in one lesson, the students were challenged to construct a bridge that could withstand a simulated lateral motion earthquake. In another bridge activity, the students were instructed to build a bridge that could span two desks. Thus, our observation data analysis revealed that the teachers utilized a range of topics and ideas to engage the students in design challenges and were creative in their selection and organization of their lessons.

Our analysis also revealed that several teachers implemented lessons focused on developing models of existing objects or structures. For example, we observed several lessons in which the teacher instructed the students to "design" and build an element from nature, such as a flower, which we interpreted as the process of constructing a model of a flower. Similarly, in another lesson, students were instructed to design a model of the life stages of a pumpkin. The modeling lessons raised an unanticipated situation, provoking questions as to how to classify the lessons and whether it was necessary to distinguish between engineering design lessons and modeling lessons in our analysis. The overlap between the problem-solving strategies and the stages of development (elements) that the teachers or students used in the model construction and analysis and the engineering design process provided us with justification for grouping the modeling lessons with the engineering design lessons. The grouping of the modeling and design lessons is particularly defensible when examining the structure of the lessons. The observed instructional steps that teachers implemented in their modeling lessons were essentially the same as those that we observed in the teachers implementing design lessons. However, we also explicitly recognized that the teachers in our project mixed the processes of model building and engineering design and creatively utilized the elements of design as pedagogical approaches for a variety of lesson orientations.

Emphasized Elements

Our third research question asked: *What elements of engineering design did the teachers emphasize in their lessons?* To answer this question, we did a content analysis of our classroom observations, seeking evidence of the elements of the design process that were emphasized in the lessons. Our analysis revealed that all of the lessons included the *problem statement*, *generate ideas and select solution*, and *process used to build product* elements. The *establishing criteria and/or constraints* element and the *present results and evaluate* were present in only approximately half of the observed lessons, yet, our analysis of the lessons by design and modeling did not reveal significant shifts in the presence of the elements. Thus, our analysis indicates that teachers consistently placed emphasis on some design elements but were less uniform in their implementation of other design elements.

Level of Design

Our fourth research question asked: *What was the level of design of the observed lessons?* To answer this question, we used our Level of Design Rubric to analyze the observations and determine the level of design used on the lessons. We analyzed all 36 of the observed design lessons and scored the observations (see Table 2). We used the criteria that we established in our introduction of the rubric, using 0 for instances when the teacher (or instructional resources) provided the element structure and 1 when the students were responsible for all the structure with values between 0 and 1 corresponding to mixed levels of responsibility. We then summed the outcomes of the analysis of the individual lessons and calculated the average to produce an overall mean (and standard deviation) for each of the elements. In addition, we identified the maximum and minimum values observed.

Table 2
Average Level of Design Scoring of Our 36 Design Lessons

Structure Responsibility Score 0 to 1 [If teacher or resources solely responsible—Score 0] [If student is solely responsible—Score 1]	Design Element					Level of Design *Sum of Element Scores* (From 0–5)
	Problem Statement	Criteria and Constraints	Generate Ideas and Select Solution	Process Used to Build the Product	Present Results and Evaluate	
Responsibility for Element Structure Score (From 0–1)	.69	.53	.27	.99	.21	2.68
Average Element Score (*SD*) [min, max]	.69 (.14) [.3, 1]	.53 (.21) [0, 1]	.27 (.27) [0, .8]	.99 (.08) [.5, 1]	.21 (.30) [0, 1]	2.68 (.64) [1.5, 3.7]

Our level of design analysis revealed that, on average, there was a distributed range of level of element structure responsibility. For the *problem statement*, the teachers (or instructional resources), on average, took less responsibility, while the students assumed more responsibility. Our analysis indicated that there was a nearly equally shared responsibility of the structure of the *constraints and criteria* element. In terms of the level of the *generate idea and select solution* element, our analysis revealed that, on average, the teachers (or instructional resources) assumed a large part of the responsibility for providing the structure of the element. We found a similar outcome for the *present results and evaluate* element. For the *process used to build the product*, our analysis revealed that the students almost exclusively assumed all responsibility for this element in the design processes.

Overall, our analysis revealed that, on average, the level of design (M = 2.68, S = .64) documented in the observed lessons indicated a nearly equally shared responsibility by the teachers and students for establishing the structure of the design activities. The range of level of design structure of the lessons fell between a low of 1.5 and a high of 3.7. The range of design structure indicates that shared responsibility was present in all the observed lessons. Overall, the observed lessons extended beyond a comprehensively teacher (or resource) structured level of design. Similarly, there were no instances in which the structure for design was comprehensively the responsibility of the students. Thus, our observations revealed that, on average, the teachers implemented design lessons sharing the responsibility for the structure of the engineering design elements with their students as the students engaged to design challenges.

Student Engagement

Our final research question asked: *How did the students engage in the design lessons?* To answer this question, we again did a content analysis of our classroom observation data and reviewed the video recordings taken during the implementation of the design lessons. Our analysis revealed high levels of student motivation and engagement. Beyond their excitement about engaging in the building of solutions, students were also eager to develop and refine their products. Many of the observations recorded eagerness by the students to explore possibilities and make modifications to enhance or optimize their products, a critical aspect of design that was not necessarily an explicit instructional aspect of the lessons. Our data also revealed high levels of pride and willingness to share and explain their products. In some situations, the students did wander off task and decided to engage in their own activities, which interestingly was more common in the lower level design lessons in which students were not required to provide the structure for the design elements.

We have provided several video clips that typify the high levels of student engagement in design lessons at the end of our article. These clips provide insight into how the students explained and evaluated their products and, in some instances, suggested or made modifications to optimize their designs.

Discussion and Implications

With the increased emphasis on engineering as part of the K–5 STEM curriculum, as promoted in the *Next Generation Science Standards* (NRC, 2013), there is a need to enhance teacher capacity to teach engineering design based lessons (Lewis, 2006; Wilson, 2013). Our results indicate that a rather brief professional development intervention with follow-up classroom support can significantly influence teacher knowledge of the engineering design process. Our results are promising because they suggest that teachers can gain lasting knowledge of engineering design with relatively brief but appropriately structured interventions. We attribute the increase in our participants' knowledge to the format of our summer institute or the comparable in-school professional development and subsequent follow-up sessions, which placed the teachers in situations where they actively interacted in design challenges in the context of the classroom. The design activities conducted during the summer institute provided the teachers with both knowledge of the design process and an instructional model for implementing an engineering design lesson. We contend that the active engagement in design activities or equivalent is instrumental to increasing teachers' understanding of design while enhancing their pedagogical knowledge of how to use design in teaching. Thus, modeling and engaging teachers in design activities appears to be a very effective way to increase both their procedural and content knowledge of engineering design and, therefore, their preparation to teach engineering design lessons.

The wide range of lessons that we observed suggests that our participating teachers were willing to seek out new ideas and creatively implement engineering design lessons. We find their willingness encouraging because it suggests that there is potentially a wide range of teacher initiated, highly engaging design lessons that will be developmentally, cognitively, and instructionally aligned for K–5 students. Our exposure of a possible conflation of modeling and engineering design suggests that if we want teachers to understand the distinction between modeling and design, we may need to be more explicit about the difference in the preparation of teachers to teach using design. It may also be possible that the teachers are creatively adopting and adapting design lessons and are not concerned with adhering to the engineering professionals' conception of design but rather engaging their students in active learning. Teacher feedback about using design and their conceptions of design as compared to modeling is an excellent direction for future research.

Our analysis of the level of emphasis that teachers placed on the design elements revealed a range of attention to the processes. As we reviewed the observations, it became apparent there was consistent emphasis placed on the *problem statement*, *generate ideas and select solution*, and *process used to build the product* elements. We speculate that these elements were consistently emphasized because they are closely aligned to project-based learning instruction, a pedagogical practice that most teachers are familiar with or use in their practice. We also exposed a reduced level of emphasis on the *criteria and constraints* and *present results and evaluate* elements. The lack of emphasis on these components may be due to the lack of experience of the teachers with using design in instruction and the importance of criteria, constraints, and evaluation to the design process. Perhaps additional reinforcement of these elements in the professional development program would result in a greater emphasis in the instruction. It may also be that these are the most nebulous and cognitively demanding elements of design and that teachers do not feel the students are developmentally prepared to address these as issues in their learning. Further, our field observers noted that the impact of time constraints of the classroom often seems to be involved in teacher determination of lesson flow and structure. Thus, the time intensive nature of these elements may deter teachers from implementing these aspects of design. We speculate that teachers may have chosen to focus on certain aspects of the design process that allow students to develop STEM habits of mind and were not necessarily concerned with students' mastery of the design process as a whole. Again, why teachers emphasize certain elements and how the students' abilities may influence their decisions for implementing design lessons is an excellent direction for future research.

As we applied our rubric to classify the level of design of the observed lessons, we found that, on average, the students and teachers (or instructional resources) equally shared responsibility for the structure of the activity. We speculate that the teachers structured their design assignments to engage students in the process while maintaining significant responsibility for the structure to assure that the students were successful at completing the task. Thus, it is likely that the teachers did not think that their students were ready to engage in the highest levels of design because of lack of experience with the process. It may also be possible that the teachers' lack of experience in teaching using design constrained their ability to create design assignments that could give students most or all of the responsibility for the structure of the design activity. Regardless, we conjecture that as teachers' experience in teaching using design increases, they will shift to implementing higher level design activities. It is important to note that our classroom observers and the teachers they observed did not use or even have knowledge of the design elements in the rubric; the data was extracted post-classroom observation. Using the rubric during observations may enhance our ability to expose conditions that could be useful in explaining why teachers choose the structure level for their students. Further, the data may also provide insight into what conditions might be in place that prompts teachers to develop higher level design assignments.

The students' enthusiasm for engaging in the design activities suggests that engineering design is an effective instructional format for motivating students to be actively involved in their learning. In our observations, it became apparent that design activities provide an excellent mechanism for creating rich learning context for engaging students in problem solving and thinking. Further, it appears that well-organized lessons are very effective in engaging students in the design activity and focusing their attention. Perhaps it is due to the students need for order, but student focus and attention to task was not correlated with the level of design or grade level. Thus, when using design as a context for instruction, it is critical that the activities be orchestrated, paced, and guided in an organized manner to maximize their potential to influence learning.

In our review of learner engagement data we uncovered what appeared to be an innate desire of the students to refine and modify their builds to optimize their products. The motivation and interest of the students is very encouraging and should be capitalized upon when considering approaches to instruction that most effectively enhance student learning. We assert that students' innate desire to modify their builds and optimize their products indicates that students are eager and capable of taking the responsibility for structuring the *present results and evaluate* design element. Ironically, our data also indicated that the teacher (or resources) provided the majority of the structure for the *present results and evaluate* design element. Thus, modification to design instruction to enhance student development of problem-solving and critical-thinking skills may be easily achieved by shifting a greater level of responsibility for the structure of the *present results and evaluate* design element by allowing students to critically evaluate their work. The outcome of a shift to a greater level of student responsibility for the structure of the *present results and evaluate* design element is an excellent direction for future investigation.

We also speculate that student engagement in modifications to their builds can be attributed to the plastic brick manipulatives (BrickLabs®) that they were using in the lesson which allow for a low "cost of change," meaning that the nature of the bricks encourages students to add to, subtract from, or change the shape of their builds, making bricks an ideal platform for teaching design. Further, the bricks can be assembled into an array of configurations making them attractive as an instructional tool to address a wide range of curriculum. The presence of the bricks in the classrooms may also encourage teachers to be more exploratory and creative with design curriculum and instruction and encourage their students to consider alternatives in their builds. How student engagement is linked to the nature of the instructional materials such as BrickLabs® and how the materials influence student desires to evaluate and modify their builds is an excellent direction for future research. Further exploration to expose additional manipulatives that encourage similar levels of engagement in design would also be another fruitful avenue of investigation.

Limitations

Although we observed each of our participating teachers twice during the academic year, we had no specific criteria for the STEM lessons that they were to teach during the observations. As we pointed out, there may be a conflation of teacher understanding of modeling and design. Yet, our data do not necessarily expose the relationship between teachers' focus on modeling as a design activity and their understanding and perceptions of engineering design. Additional observations along with interviews of teachers teaching modeling lesson may resolve this limitation and lead to a greater understanding of the teachers' choices of lessons and understanding of design and modeling.

Similarly, only about a quarter of our STEM lesson observations were engineering design lessons. Thus, the other three quarters of the participants may have taught design lessons from a different STEM perspective. Yet, the 36 lessons we observed were not specifically selected because they were engineering design lessons but occurred in an arbitrary fashion such that we predict the observed lessons were likely representative of the study population. Additional observations and interviews to confirm our prediction would be an excellent direction for future research.

As with all observation protocols, our rubric has limitations. Although we have refined our observation protocol over a three -year period it is still limited in terms of the data it is designed to collect. Thus, there may be other activities and nuanced variations in our participants' design lesson implementation that we are not explicitly capturing. However, we did use an observation tool with established consistency and inter-rater reliability to collect our observational data, which should have minimized possible variations in the perceptions of research personnel. Perhaps video recording the lessons and then reviewing them several times may expose subtle variations in observation data, which is an excellent direction for future research. The challenge will be gaining access to public school classrooms to gather video data for such research.

Finally, as previously mentioned, we applied our Level of Design Rubric to the observation data that was gathered using a different protocol and instrument. Although the observers were able to substantiate our scoring and assessment of the observation data based on their experience, the data were not collected using the Level of Design Rubric. We were also using our general observation rubric to capture data from an array of STEM lessons because the STEM content of the observed lessons was not known prior to the observations. The application of our elements table and Level of Design Rubric in observations of design lessons is one of the goals of our continued research.

Conclusions

As engineering design grows as an instructional approach for teaching a range of STEM content it is critical that we develop a framework for preparing teachers to teach the content and the tools to examine the implementations. In our research project, we explored the effectiveness of a teacher professional development offering intended to enhance teacher capacity to teach engineering design. We developed and used some tools for classifying the elements of design and the level of the design in terms of teacher and student level of responsibility for the structure of the design lessons. We hope others will find our work useful as they plan professional development offerings for K–5 teachers and then study teacher implementation of engineering design in the curriculum and student engagement in the design activities. In addition, we hope that those who use our Level of Design Rubric will provide us with feedback as we seek to refine and increase the accuracy of our tool for evaluating the instructional use of design.

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References

Baine, C. (2004). *Is there an engineer inside you? A Comprehensive guide to career decisions in engineering* (2nd ed.). Belmont, CA: Professional Publications.

Berland, L. K. (2013). Designing for STEM integration. *Journal of Pre-College Engineering Education Research (J-PEER)*, *3*(1), 22–31. Retrieved from http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1078&context=jpeer

Bottoms, G., & Anthony, K. (2005). *Project lead the way: A preengineering curriculum that works* (Research Brief). Atlanta, GA: Southern Regional Education Board. Retrieved from http://publications.sreb.org/2005/05V08_Research_PLTW.pdf

Bruning, R. H., Schraw, G. J., Norby, M. M., & Ronning, R. R. (2004). *Cognitive psychology and instruction* (4th ed.). Upper Saddle River, NJ: Prentice Hall.

Burghardt, D., & Hacker, M. (2007). *Engineering professional development*. Paper presented at the National Symposium to Explore Effective Practices for Professional Development of K–12 Engineering and Technology Teachers, Dallas, TX. Retrieved from http://hub.mspnet.org/media/data/BurghardtHacker.pdf?media_000000006150.pdf

Carpinelli, J., Kimmel, H., & Rockland, R. (2014). *Paper drop design competition*. Denver, CO: Regents of the University of Colorado. Retrieved from https://www.teachengineering.org/view_activity.php?url=collection/cub_/activities/cub_paper/cub_paper_activity1.xml

Cunningham, C. (2009). Engineering is elementary. *The Bridge, 39*(3), 11–17. Retrieved from https://www.nae.edu/Publications/Bridge/16145/16170.aspx

Cunningham, C. M., & Hester, K. (2007). *Engineering is elementary: An engineering and technology curriculum for children*. Paper presented at the American Society for Engineering Education Annual Conference and Exposition, Honolulu, HI. Retrieved from http://eie.org/sites/default/files/research_article/research_file/ac2007full8.pdf

Darling-Hammond, L., & Bransford, J. (Eds.). (2005). *Preparing teachers for a changing world: What teachers should learn and be able to do*. San Francisco, CA: Jossey-Bass.

Davies, D. (1996). Professional design and primary children. *International Journal of Technology and Design Education*, *6*(1), 45–59. doi:10.1007/BF00571072

Dobbins, K. (2009). Teacher creativity within the current education system: A case study of the perceptions of primary teachers. *Education 3-13, 37*(2), 95–104. doi:10.1080/03004270802012632

English, L. D., & Mousoulides, N. (2009). Integrating engineering education within the elementary and middle school mathematics curriculum. In B. Sriraman, V. Freiman, & N. Lirette-Pitre (Eds.), *Interdisciplinarity, creativity, and learning: Mathematics with literature, paradoxes, history, technology, and modeling* (pp. 165–176). Charlotte, NC: Information Age Publishing.

Felder, R. M., Brent, R., & Prince, M. J. (2011). Engineering instructional development: Programs, best practices, and recommendations. *Journal of Engineering Education*, *100*(1), 89–122. doi:10.1002/j.2168-9830.2011.tb00005.x

Fontenot, D., Talkmitt, S., Morse, A., Marcy, B., Chandler, J., & Stennett, B. (2009). *Providing an engineering design model for secondary teachers*. Paper presented at the Frontiers in Education Conference, San Antonio, TX. doi:10.1109/FIE.2009.5350738

Fox-Turnbull, W. (2006). The influences of teacher knowledge and authentic formative assessment on student learning in technology education. *International Journal of Technology and Design Education*, *16*(1), 53–77. doi:10.1007/s10798-005-2109-1

Guzey, S. S., Tank, K., Wang, H.-H., Roehrig, G., & Moore, T. (2014). A High-Quality Professional Development for Teachers of Grades 3–6 for Implementing Engineering into Classrooms. *School Science and Mathematics*, *114*(3), 139–149. doi:10.1111/ssm.12061

Kampylis, P., Berki, E., & Saariluoma, P. (2009). In-service and prospective teachers' conceptions of creativity. *Thinking Skills and Creativity, 4*(1), 15–29. doi:10.1016/j.tsc.2008.10.001

Katehi, L., Pearson, G., & Feder, M. (Eds.). (2009). *Engineering in K–12 education: Understanding the status and improving the prospects.* Washington, DC: National Academies Press.

Lachapelle, C. P., & Cunningham, C. M. (2007). *Engineering is elementary: Children's changing understandings of science and engineering*. Paper presented at the American Society for Engineering Education Annual Conference and Exposition, Honolulu, HI. Retrieved from http://eie.org/sites/default/files/research_article/research_file/ac2007full9.pdf

Lewis, T. (2006). Design and inquiry: Bases for an accommodation between science and technology education in the curriculum? *Journal of Research in Science Teaching, 43*(3), 255–281. doi:10.1002/tea.20111

Nadelson, L., Callahan, J., Pyke, P., Hay, A., & Schrader, C. (2009). *A SySTEMic solution: Elementary teacher preparation in STEM expertise and engineering awareness*. Paper presented at the American Society for Engineering Education Annual Conference and Exhibition, Austin, TX. Retrieved from http://search.asee.org/search/fetch?url=file%3A%2F%2Flocalhost%2FE%3

A%2Fsearch%2Fconference%2F19%2FAC%25202009Full939.pdf&index=conference_papers&space=129746797203605791716676178&type=application%2Fpdf&charset=

Nadelson, L., Callahan, J, Pyke, P., Hay, A., & Schrader, C. (2010). *Teaching inquiry-based STEM in the elementary grades using manipulatives: A SySTEMic solution report*. Paper presented at the American Society for Engineering Education Annual Conference & Exhibition, Louisville, KY. Retrieved from http://search.asee.org/search/fetch?url=file%3A%2F%2Flocalhost%2FE%3A%2Fsearch%2Fconference%2F32%2FAC%25202010Full1218.pdf&index=conference_papers&space=129746797203605791716676178&type=application%2Fpdf&charset=

Nadelson, L. S., Pyke, P., Callahan, J., Hay, A., Pfiester, J., & Emmet, M. A. (2011). *Connecting science with engineering: Using inquiry and design in a teacher professional development course*. Paper presented at the American Society of Engineering Education Annual Conference, Vancouver, BC, Canada. Retrieved from http://www.asee.org/public/conferences/1/papers/441/view

Nadelson, L. S., Moll, A. J., & Seifert, A. L. (2011). *Living in a materials world: Materials science engineering professional development for K-12 educators*. Paper presented at the American Society of Engineering Education Annual Conference, Vancouver, BC, Canada. Retrieved from http://www.asee.org/public/conferences/1/papers/2432/view

National Aeronautics and Space Administration. (2008) *Elementary school standards-based engineering design process*. Retrieved from http://www.nasa.gov/audience/foreducators/plantgrowth/reference/Eng_Design_K4.html

National Research Council. (2010). *Rising above the gathering storm, revisited: Rapidly approaching category 5*. Washington, DC: National Academies Press.

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

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education*, *21*(5), 509–523. doi:10.1016/j.tate.2005.03.006

Roden, C. (1997). Young children's problem-solving in design and technology: Towards a taxonomy of strategies. *Journal of Design & Technology Education*, *2*(1), 14–19. Retrieved from http://ojs.lboro.ac.uk/ojs/index.php/JDTE/article/view/375

Schwab, J. J. (1962). The teaching of science as inquiry. In J. J. Schwab & P. F. Brandwein (Eds.), *The teaching of science* (pp. 3–103). Cambridge, MA: Harvard University Press.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard educational review*, *57*(1), 1–23.

Sims-Knight, J., Upchurch, R., & Fortier, P. (2006). Developing Assessments That Help Students Learn to Develop Open-ended Designs. In D. Deeds & B. Callen (Eds.), *Proceedings of* the *National STEM Assessment Conference* (pp. 274–289), Washington, DC. Springfield, MO: Drury University. Retrieved from http://openwatermedia.com/downloads/STEM%28for-posting%29.pdf

The Works Museum. (2011). *Engineering design process.* Retrieved from https://theworks.org/wordpress/wp-content/uploads/2013/03/Engineering-Design-Process.pdf

Tufenkjian, M,. & Lipton, E. (2007). *A professional development model to infuse engineering design content into the high school curriculum*. Paper presented at the American Society for Engineering Education Annual Conference, Honolulu, HI. Retrieved from http://search.asee.org/search/fetch?url=file%3A%2F%2Flocalhost%2FE%3A%2Fsearch%2Fconference%2F14%2FAC%25202007Full2518.pdf&index=conference_papers&space=129746797203605791716676178&type=application%2Fpdf&charset=

Wilson, S. M. (2013, April 19). Professional development for science teachers. *Science*, *340*(6130), 310–313. doi:10.1126/science.1230725

Examining Students' Proportional Reasoning Strategy Levels as Evidence of the Impact of an Integrated LEGO Robotics and Mathematics Learning Experience

In many school districts in the United States, the *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) outline what students should understand and be able to do in their study of mathematics. These standards are composed of content standards and practice standards that must be connected in order to allow students to engage more deeply with the subject matter. Engagement and learning in context can support understanding in a couple of ways. The first is by increasing student motivation and interest in the curriculum itself. The second is by enhancing transfer of learning through the demonstration of connections between abstract mathematics and real-world problems. Students must be prepared to apply this knowledge in multiple external situations, often through creative and personally meaningful situations, as well as to learn to address mathematical problems in a variety of situations and contexts.

The presented study used a problem-solving experience in engineering design with LEGO robotics materials as the real-world mathematics-learning context. The goals of the study were (a) to determine if a short but intensive extracurricular learning experience would lead to significant student learning of a particular academic topic and (b) to explore the differences in mathematical problem-solving strategies used by students when solving problems of ratio and proportion in two different learning environments. It was important to first determine if indeed a short-term but intensive extracurricular learning experience could be effective, given the reliance of such an experience as the framework for conducting the educational research. The experimental research explored student learning in mathematics but deliberately limited the specific topic of exploration to integrated concepts of proportional reasoning within LEGO robotics challenges in engineering design. The impact of this experience upon students' proportional reasoning was measured and is described with a focus on proportional reasoning strategy levels.

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Two research questions guided this study:

- *Research Question 1:* Can a significant change in students' understanding of ratio and proportion take place during a short but intense learning experience?
- *Research Question 2:* How do students' demonstrated proportional reasoning strategy level use compare for students learning ratio and proportion concepts within the integrated LEGO robotics and mathematics program versus when using a traditional textbook-based mathematics program?

A prior study by the author (Martínez Ortiz, 2011) describes the comparison of resulting student group performance based only on correct answers to proportional reasoning questions.

Literature Review

LEGO Robotics in K–12 Engineering

Research exploring the cognitive impact of engineering education at the kindergarten through twelfth grade level (K–12 engineering) suggests that such learning experiences can build creative design skills and foster the utilization of higher order thinking and problem solving skills (Amsel, Goodman, Savoi, & Clark, 1996; Foster & Wright, 2001; Roden, 1995). Furthermore, K–12 engineering can serve as a vehicle to effectively integrate and teach across content areas (Barlex & Pitt, 2000; Cross, 2007; Martínez Ortiz, 2004; Moundridou & Kaniglonou, 2008). There are longstanding debates across STEM education about whether the T (technology content) and the E (engineering content) should be stand-alone K–12 subjects or integrative activities (Katehi, Pearson, & Feder, 2009; U.S. Department of Education National Assessment Governing Board, 2014). The merits of the stand-alone approach are that engineering and technology would be given the spotlight and focus paralleling their importance in the educational and workplace landscape allowing clear career connections to be made. However, the major challenge still lies in the difficulty of finding time during the school day to dedicate to these additional content areas. Therefore, in this study, the integrative approach was explored. In this study, K–12 engineering was utilized as a curricular framework for the integrated exploration of proportional reasoning concepts. In addition, the use of robotics allowed opportunities and specific problem solving contexts for the teaching and learning of ratio and proportion. K–12 engineering, with an emphasis on technology, can serve as a platform for providing inquiry-based learning with real-world contexts and collaborative problem solving.

The design of this study was motivated by the work of Papert (1980), who pioneered and investigated how technology could be used to help children learn mathematics differently. He developed a philosophical approach called *constructionism* and a supporting programming language called Logic Oriented Graphic Oriented (LOGO) language. Massachusetts Institute of Technology researchers then collaborated with the LEGO® Company to design a control unit (the brick) embedded with computational power that could accommodate the mounting of traditional LEGO blocks to design and build controllable LEGO construction projects. This control brick, known as a Mindstorms RCX, runs basic programs written by students using a simple graphical interface on a personal computer. Together, the LEGO blocks and the programmable brick can empower children with the capability to design and interact with the physical world through their own insight and programming determination. The LEGO blocks can be used in a collaborative design environment that allow for team design and variable setting that is further facilitated by the additional controllable options such as motor settings, use of add-on sensors, and infrared communication devices (Resnick, Martin, Sargent, & Silverman, 1996). Several generations of this tool have followed the original LEGO Mindstorms RCX; however, due to cost and material limitations at the school district level, the original version was used in this study.

Integrated Engineering and Mathematics

This study is based on the proposition that engineering robotics can be integrated with mathematics and serve as a context to offer students the opportunity for improving their proportional reasoning. The hypothesis is that learning in the context of engineering robotics may be more meaningful and long lasting for students than learning with a non-engineering, textbook-based mathematics curriculum (Martínez Ortiz, 2008). The interconnected concepts of multiplication, division, fraction, ratio, and rational numbers often appear in problem situations that students encounter in real-world experiences. These concepts are also related mathematically to such an extent that when taken all together, they may define a unique mathematical conceptual field. Vergnaud (1983) calls this the *multiplicative conceptual field* (MCF) and defines it as “a set of problems and situations for the treatment of which concepts, procedures, and representations of different but narrowly interconnected types are necessary” (p. 127). Vergnaud suggests that the MCF includes concepts in multiplication and division, linear and bilinear functions, dimensional analysis, linear mapping, and linear combinations of magnitudes as well as ratio, rate, fraction, and rational numbers. He maintains that these mathematical concepts do not exist in isolation but rather in a network of conceptual relations and problem situations. Similarly, student mathematical reasoning develops and is called upon to consider various mathematical problem-solving situations.

The Role that Contexts Play in Assessment Problems in Mathematics

Using the terminology of Chevallard (1990, 2007), the assessment instruments used in this study were designed in order to allow for the determination of the influence of the context of the assessment task on students' performance. The intra-mathematical problems or pure mathematical questions utilized only numbers and letters. Alternately, extra-mathematical questions appeared to the student in contexts outside of pure mathematics. The definition for context in this case provided by Borasi (1986) is appropriate: "a characteristic of a task presented to the students: referring either to the words and pictures that help the students to understand the task, or concerning the situation or event in which the task is situated" (p. 129). Results from this study showed that after instruction, students performed better on the extra-mathematical assessment as compared to the intra-mathematical questions. This suggests that extra-mathematical contexts in mathematics assessment can offer the students more opportunity for demonstrating their abilities due to the opportunity for sense making that these contexts provide and the multiple approaches that students can take to solve the problem when presented along with extra-mathematical contexts. In contrast, an intra-mathematical problem generally relies on a specific operation to be performed and is therefore limiting in that it does not provide the opportunity for students to focus on making sense of the situation, whereas a contextually based problem might otherwise contribute to this sense making. These observations are supported by the work of many researchers in mathematics education such as Carraher, Carraher, and Schliemann (1985), Carpenter and Moser (1984) and Clements and Sarama (2007).

Proportional Reasoning Research

Research on proportional reasoning at the elementary school level (Tourniaire, 1986) has shown that children in Grades 3, 4, and 5 may demonstrate a grasp of the concept of proportion, but it begins as a fragmented ability that relies on the context of the problem. There remain gaps in the research in regards to the most effective methods for teaching proportional reasoning. Some evidence suggests that simply structured ratio and proportion problems that utilize small numbers and integer ratios are within the grasp of the elementary school child and that when coupled with appropriate manipulatives, high quality teaching and critical thinking-based curricula can improve student understanding of ratio and proportion (Karplus, Pulos, & Stage, 1983; Tourniaire, 1986).

Proportional reasoning is a kind of mathematical reasoning that students use when solving problems in the multiplicative conceptual field. Research indicates that the ability to reason proportionally is important for students' mathematical development and is essential for learning advanced topics in mathematics (Behr, Harel, Lesh & Post, 1987; Kaput & West, 1994). However, there is also evidence that students perform better when "encouraged to construct their own . . . knowledge . . . through collaborative problem solving activities" involving proportion than when they participate more passively in "more traditional, teacher-directed instructional experiences" (Ben-Chaim, Fey, Fitzgerald, Benedetto & Miller, 1998, p. 247). Proportional reasoning is important to this study because the engineering robotics context includes collaborative problem-solving activities that directly call upon the use of proportional reasoning. Proportional reasoning calls upon the understanding and application of skills within the MCF to make sense of mathematical relationships using ratios and equations involving ratios. Mathematical problems of ratio and proportion can be analyzed by using the concepts of multiplication, division, fractions, and linear functions. Proportional reasoning involves the understanding of the relationship of two numbers (ratio) as the critical multiplicative comparator. Researchers propose that although proportional reasoning does not appear to be an automatically developed concept, students do encounter many opportunities for developing proportional reasoning in their daily lives as well as in the elementary and middle school classroom (Karplus, Pulos, & Stage, 1983; Lamon, 1993). Harel, Behr, Post, and Lesh (1987) have called proportional reasoning a watershed concept, a cornerstone of higher mathematics and the capstone of elementary concepts.

Methods

This study examined the impact of using LEGO robotics engineering in support of students' learning of ratios and proportion in intra-mathematical contexts, various extra-mathematical contexts not involving engineering (word problems not involving hands-on engineering design), and extra-mathematical contexts involving engineering. The study utilized an experimental mixed-methods repeated-measures design with a small sample of students ($n = 30$) in which one group of students ($n = 15$) participated in each treatment condition. Student participants applied for a 1-week mathematics program and were assigned to either the intervention group or the comparison group, therefore allowing internal validity for group result comparisons. There were two conditions included in this study: The first condition was the learning of ratios and proportions in a non-engineering textbook-based mathematics intervention program (i.e., the control group), and the second condition was the learning of ratio and proportion in an integrated engineering and mathematics intervention program (i.e., the experimental group). The repeated measures design was intended to compare students' understanding of ratio and proportion between experimental and control-group students after a weeklong intervention program. Each student was assessed at three different time points. Measures were collected at the beginning (T1) and end (T2) of each intervention program, and an additional measure was collected 10 weeks after the intervention programs (T3), as shown in Figure 1.

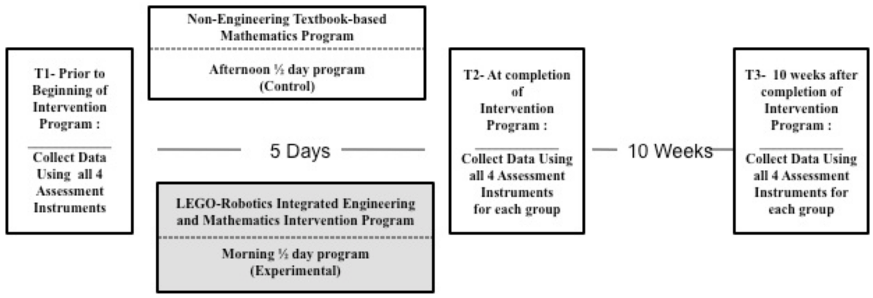


Figure 1. Experimental design with control group and repeated measures.

Intervention Program Curricula

In the state of Texas, the Texas Education Agency (TEA) directs the state learning frameworks for K–12 students in the state of Texas by defining specific content standards. These standards are known as the Texas Essential Knowledge Standards (TEKS). Towards the end of fifth grade, the mathematics TEKS begin introducing concepts of ratio and proportion in preparation for sixth grade, a year of focus upon proportional reasoning development (Texas Education Agency, 2008). For this reason, this study included fifth grade students and offered unique extracurricular learning programs guided by sixth grade TEKS in each program: a non-engineering textbook-based intervention program and a LEGO-based engineering robotics program.

LEGO-based Engineering Robotics Program. The goal of the LEGO-based engineering robotics program was to teach ratio and proportion using theory-based principles within an engineering design context in a small group peer-learning environment. One major curricular component of the engineering design context was the engineering design process. The eight-step engineering design process defined within the Massachusetts state standards (Massachusetts Department of Education, 2001is a robust model for teaching engineering design concepts to students. However, the eight steps require substantial explanation and practice and may be a more appropriate model to use with older students and certainly in a longer duration learning opportunity that offers more time for focus on each of the eight steps of the engineering design process. A simple four step engineering production improvement model called the Plan, Do, Check, Act Cycle (Deming, 1986; Shewhart, 1986) was modified as Plan, Build, Check, Improve (PBCI), as shown in Figure 2, and was shared with the students in the engineering intervention program. This four-Step Engineering Design Process model (named *Fusion* by the author) was therefore selected over others models (Museum of Science, n.d.; Puntambeker, 2005), to include in the curriculum of the engineering intervention program.

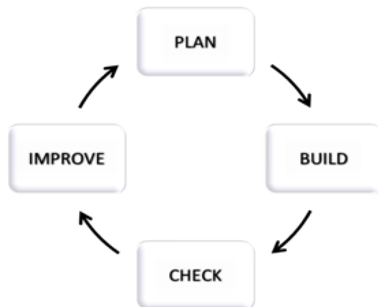


Figure 2. The four-step *Fusion* engineering design process model.

Students were encouraged to approach their mathematics problem solving and design challenges using the systematic nature of the engineering design process as well as the feedback data and support skills emphasized in this process (e.g., use of symbols and sketches, systemic testing of variables, use of graphic organizers). The program instructor encouraged students to learn and use this approach by introducing the engineering design process, by posting a graphic of it in the classroom, by modeling and providing mathematics problem solving examples using the engineering design process, and by providing worksheets with prompting questions and a graphic organizer that integrated this process. In addition to this process standard, five additional learning objectives, unique to the LEGO robotics engineering program, were defined in order to clearly guide in the teaching of this program. Although the experimental program students participated in the same number of instruction hours as the control group, their instructional program addressed mathematics and engineering content as guided by mathematics TEKS and research-based standards for elementary engineering learning from the Massachusetts state standards (Massachusetts Department of Education, 2001). The Massachusetts standards for elementary engineering were used because at the time, Texas did not have adopted state standards for engineering learning at the elementary level. In addition, the experimental program curriculum used in this study was developed as a modified curriculum that was previously utilized in an elementary engineering and mathematics integrated teaching program with LEGO robotics developed by the author (Martínez Ortiz, 2005).

Experimental Group. The experimental group consisted of 15 fifth grade students from a low income inner-city elementary school in Austin, Texas. This group participated in a weeklong integrated engineering and mathematics intervention program (titled "Engineering Fusion") through which they received an engineering robotics curriculum that integrated LEGO robotics and mathematics instruction in ratio and proportion. The program was delivered as a five-session program totaling 15 instructional hours, supported by one teacher as instructor along with one teacher aid. Both teachers were school campus teachers, but not regular fifth-grade classroom teachers. The principal teacher for both intervention programs was an experienced mathematics specialist teacher whose usual role included providing some classroom mathematics lessons, so she and the students were familiar with each other. The teacher aid was a campus afterschool instructor who was knowledgeable in the use of LEGO robotics and was also familiar with the school and with some of the students.

Non-engineering Textbook-based Intervention Program. A non-engineering textbook-based curriculum is the accepted pedagogical approach for teaching students the mathematics TEKS in most Texas school districts. In the textbook-based intervention program (or control) program, the daily lessons were designed by selecting material from the district-adopted fifth-grade mathematics resource book. This material is usually provided as an optional set of lesson plans because it addresses sixth grade TEKS for ratio and proportion at the end of the fifth grade. The sixth-grade TEKS were used because ratio and proportion learning expectations do not formally appear until the sixth grade. This also allowed for greater confidence in the assertion that program students had not received prior instruction in the topic. In the control condition, students received five 3-hour sessions of textbook mathematics lessons on ratio and proportion to address four major mathematics TEKS regarding proportional reasoning. These included specific TEKS for sixth grade from the strand of mathematical concepts labeled as “number, operation, and quantitative reasoning” (Texas Education Agency, 2008). This strand of mathematical concepts describes the knowledge expectation that students use and represent rational numbers in a variety of equivalent forms. In addition, TEKS for sixth grade from the strand of mathematical concepts labeled as “patterns, relationships, and algebraic thinking” (Texas Education Agency, 2008) were included in which students were expected to solve problems involving proportional relationships, specifically representing and using rational numbers in a variety of equivalent forms. Students also had extended opportunities to work with non-engineering mathematics manipulatives (such as Cuisenaire rods) and to carry out mathematics worksheet practices.

Control Group. A second group of 15 fifth grade students from the same low income inner-city elementary school in Austin, Texas participated as the control group. Control students participated in a 15-hour non-engineering mathematics intervention program through which they received mathematics instruction in ratio and proportion based on the school district adopted textbook. This program was also delivered as a five-session program totaling 15 hours, supported by the same principal teacher and teacher aid as in the experimental group. Non-engineering mathematics refers to the pedagogical approach of one classroom of students learning in a classroom directed by one teacher providing a textbook-based lecture with worksheet practice and some use of manipulatives.

Assessment Instruments: Computational vs. In-Context

Data were collected to assess the students' proportional reasoning strategy levels demonstrated in solving each of the assessment problems selected to assess the learning of students in each of these intervention programs. The contexts were three- computational (paper and pencil) proportional reasoning, general contexts, and engineering design contexts using each of the three assessment instruments shown in Table 1: (a) Intra-Prop assessment, (b) Extra-Prop assessment, and (c) Engin-Prop assessment.

Table 1
Assessment Instruments

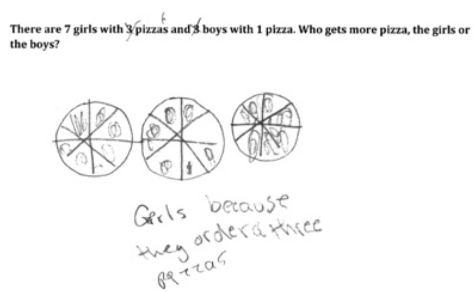
Instrument	Context	Scoring for Proportional Reasoning Strategy Level
Intra-Prop	Measures the understanding of ratio and proportion concepts by numerical computation problem solving [only included number sentences].	Included 10 questions. Each student answer sheet was reviewed and assigned a numeric level assessment score (0, 1, 2, or 3) to each question using the Langrall and Swafford modified scale (described in the following section). The total score = mean score.
Extra-Prop	Measures the understanding of ratio and proportion in general-context mathematical word problems.	Included 10 questions. Each student answer sheet was reviewed and assigned a numeric level assessment score (0, 1, 2, or 3) to each question using the Langrall and Swafford modified scale (described in the following section). The total score = mean score.
Engin-Prop	Measures the understanding of ratio and proportion in a LEGO engineering problem solving context.	Included 8 questions. Each student answer sheet was reviewed and assigned a numeric level assessment score (0, 1, 2, or 3) to each question using the Langrall and Swafford modified scale (described in the following section). The total score = mean score.

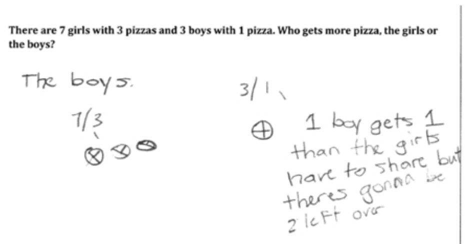
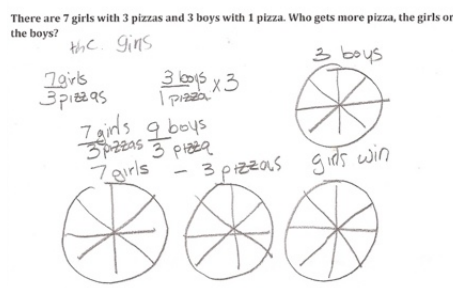
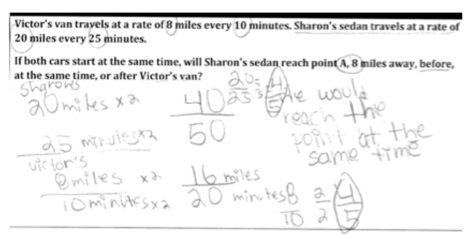
The instruments, specifically designed for this study, were administered to capture background information, measure students' basic understanding of some engineering and mathematics definitions, and to measure students' understanding of ratio and proportion. The understanding of ratio and proportion through numerical computation was measured using the Intra-Mathematical Proportional Reasoning Test (Intra-Prop). The understanding of ratio and proportion in general-context mathematical word problems was measured using the Extra-Mathematical Proportional Reasoning Test in a General Context (Extra-Prop). The understanding of ratio and proportion in a LEGO engineering context was measured using a mathematical tool called the Extra-Mathematical Proportional Reasoning Test in an Engineering Context (Engin-Prop).

Assessment of Proportional Reasoning: Selection of a Scale. Although there is a wealth of research on the development of children's proportional reasoning (Hart, 1984; Kaput & West, 1994, Lamon, 1994; Harel, Behr, Post, & Lesh, 1987), there is much less focus on the development of diagnostic instruments for assessment of proportional reasoning. A few diagnostic instruments and/or assessment guidelines (Baxter & Junker, 2001; Langrall & Swafford, 2000; Misailidou & Williams, 2003) were reviewed to determine if their research-based scales or guidelines might support the data analysis of student proportional reasoning strategy levels for this study. These were found to be qualitatively similar to each other (level to level), and all three were based on similar bodies of established developmental proportional reasoning research. Langrall and Swafford (2000) proposed a proportional reasoning scale. They classified the strategies that students use in proportional reasoning into four different levels: levels 0, 1, 2, and 3. Level 0 students do not display any proportional reasoning at all. Level 1 students do not use proportional reasoning strategies yet may arrive at the correct answer by relying on qualitative strategies using pictures, models, or manipulatives to help solve proportional problems. Level 2 students begin to use numeric strategies such as the simple additive strategy as well as build-up scalar strategies that employ multiplication and division. Level 3 students show formalized proportional thinking using functional strategies and use of ratio variable comparison and manipulation. This scale was consistent with the research base reviewed and the focus on younger students, such as the 10–11 year olds in this study. This scale was therefore selected for the interpretation of students' strategic thinking and the coding of the data collected using the ratio and proportion instruments discussed.

In addition, a repeated-measures design was used to compare the mathematics achievement in proportional reasoning of intervention students over a longitudinal period of a school trimester. Descriptive statistics and ANOVA statistics were utilized to determine if there were any significant differences in the performance of these two groups. Students in the engineering LEGO *Fusion* program received instruction in mathematics, an overview of the engineering design process, and instruction regarding building and programming with LEGO robotics. The programming instruction was pared down to a limited introduction using a visual programming language. Robolab was used as the graphical programming language because that was available to students for future use. Student were provided design challenges that allowed them to consider the robots' physical environment, control basic functions and variables through structural design, and programming and evaluating the performance of their robots by utilizing mathematical understanding and skills of measuring and comparing variable relationships.

Table 2
Langrall and Swafford's Proportional Reasoning Scale with Modifications and Examples Added

Level	Strategies Exhibited	Author Selected Student Example of the Proportional Reasoning Level
Level 0: Non-proportional reasoning	"Guesses or uses visual clues . . . Is unable to recognize multiplicative relationships Randomly uses numbers, operations or strategies Is unable to link the two measures" (Langrall & Swafford, 2000). Does not lead to correct solutions or development of more mature proportional reasoning	

Level 1: Informal reasoning about proportional situations	"Uses pictures, models, or manipulatives to make sense of situations Makes qualitative comparisons" (Langrall & Swafford, 2000).	
Level 2: Quantitative reasoning	"Unitizes or uses composite units Finds and uses unit rate Identifies or uses scalar factor or table Uses equivalent fractions Builds up both measures" (Langrall & Swafford, 2000) . Uses scalar strategies	
Level 3: Formal proportional reasoning	"Sets up proportion using variables and solves using cross-product rule or equivalent fractions Fully understands the invariant and covariant relationships" (Langrall & Swafford, 2000). Displays functional reasoning	

Results

The research questions were addressed by analyzing the quantitative results of both groups of students (engineering based and non-engineering based) and their changes in correct responses to proportional reasoning questions set in different contexts as well as ratings of the level of proportional reasoning strategies used at each of the three time points. The scale used to assign a score for proportional reasoning level to each student's work was Langrall and Swafford's (2000) scale, which was discussed in the previous section, with possible scores of 0, 1, 2, and 3. Each item in the student's assessment was assigned a single proportional reasoning score, a mean was calculated for each student's assessment, and then a mean was derived for the 15 students' scores from each group. Each of the three assessments was scored first for percentage of correct answers and second for mean level of proportional reasoning using the Langrall and Swafford scale. The assessment instruments included the same questions when scored for percentage correct, as when scored for mean level of proportional reasoning. In the following sections, the assessment results that were used in the analysis of variance (ANOVA) runs were the level of proportional reasoning strategy-use results for each of the three assessments: the Intra-Prop, Extra-Prop, and Engin-Prop.

Proportional Reasoning Levels Analysis: Intra-Prop

Table 3 shows the descriptive statistics for each program group's performance on the Intra-Prop at each of the three time points. Figure 3 displays the mean level of strategy-use scores (0–3) on intra-prop for program groups across three time points.

Table 3
Intra-Prop Descriptive Statistics—Mean Strategy Rating by Student Groups

Time of Intra-Prop Assessment	Program Group	Mean	*SD*	*N*
T1	Control Group	.27	.458	15
	Experimental Group	.47	.516	15
	Total	.37	.49	30
T2	Control Group	.67	.617	15
	Experimental Group	.67	.617	15
	Total	.67	.606	30
T3	Control Group	.87	.640	15
	Experimental Group	.80	.561	15
	Total	.83	.592	30

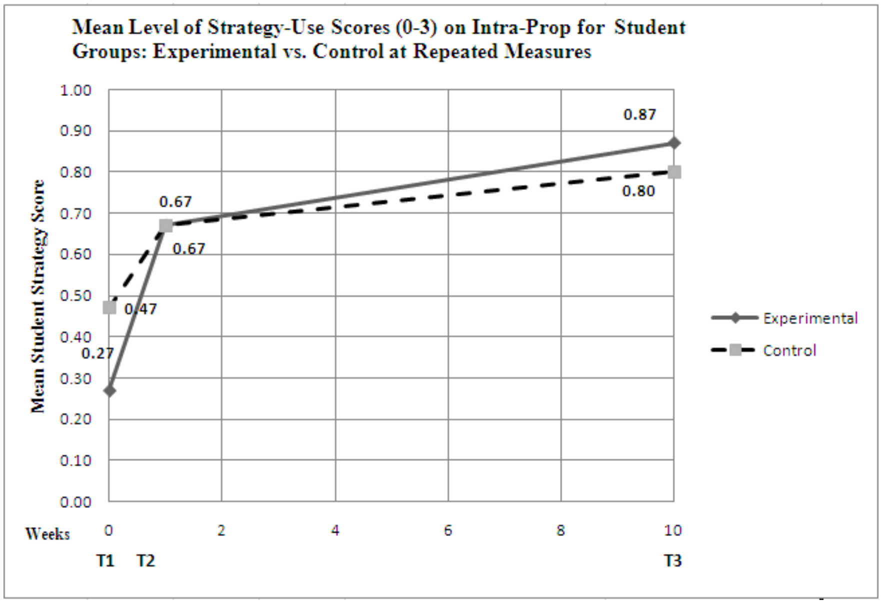


Figure 3. Mean level of strategy-use scores (0–3) on intra-prop for program groups across three time points.

The experimental group's mean score was .27 at T1. This implies that the majority of students were closer to Level 0 of proportional reasoning at T1. This same group of students achieved a .67 mean score immediately after the conclusion of the intervention program. This implies that the majority of the students were closer to Level 1 of proportional reasoning. At this level, proportional reasoning strategies are not yet clearly used, but students rely on qualitative strategies such as the use of pictures, and they are able to use some multiplicative thinking to arrive at the correct answer. At T3, the use of proportional reasoning strategies increased even more, to the level of .87. Although students show an increase in use of statistical reasoning at the 10-week post-post assessment, the scale score only defines integer values, so the changes at each time point are all still within the zero (0) score of the scale, meaning that students were not judged to have demonstrated proportional thinking.

A mixed between–within subjects ANOVA was conducted to assess the impact of the two different interventions (non-engineering textbook-based mathematics intervention program versus LEGO robotics integrated engineering and mathematics intervention program) based on the level of proportional reasoning strategies used by the participants, as reflected by their level of strategy-use scores on the Intra-Prop at T1, T2, and T3. There was no significant interaction between program type and time, Wilks' Lambda = .951, $F(2,27) = .690$, $p = .510$, partial eta squared = .049. There was a substantial main effect for time, Wilks' Lambda = .625, F(2,27) = 8.114, *p* = .002, partial eta squared = .375, with both groups showing an increase in the level of proportional reasoning strategies used, as measured by their overall level of strategy-use scores on the Intra-Prop. The main effect comparing the two types of intervention was not significant, F(1,28) = .07, *p* = .791, partial eta squared = .002, suggesting no difference in the effectiveness of the two teaching approaches when measured by the level of strategy-use score on the Intra-Prop. The control group's mean score on the Intra-Prop was stronger (.47) than the experimental group (.27) at T1. However, this score is somewhat deceptive because the strategic reasoning scores assigned to each problem were integer values of 0, 1, 2, and 3; at the levels reported, both groups were determined to be at between 0 (non-proportional reasoning) and 1 (informal reasoning about proportional situations). After the intervention, both groups improved with the levels becoming a lot more similar (.67) but still under Level 1. This indicates that students learned to use slightly higher levels of proportional reasoning strategies. It could also mean that the types of problems presented did not require these students to use higher level strategies and that given the straightforward intra-mathematical nature of the assessment, students were equally prepared to solve the problems regardless of their learning experience.

Proportional Reasoning Levels Analysis: Extra-Prop

Table 4 shows the descriptive statistics for each program group's performance on the Extra-Prop at each of the three time points.

Table 4
Extra-Prop Descriptive Statistics—Strategy Rating by Student Groups

Time of Extra-Prop Assessment	Program Group	Mean	*SD*	*N*
T1	Control Group	1.20	.941	15
	Experimental Group	1.27	.704	15
	Total	1.23	.817	30
T2	Control Group	2.13	.640	15
	Experimental Group	2.47	.516	15
	Total	2.30	.596	30
T3	Control Group	2.13	.640	15
	Experimental Group	2.47	.516	15
	Total	2.30	.596	30

Figure 4 displays the mean score for strategy level use on the Extra-Prop assessment by each group (experimental and control) at each of the three time points.

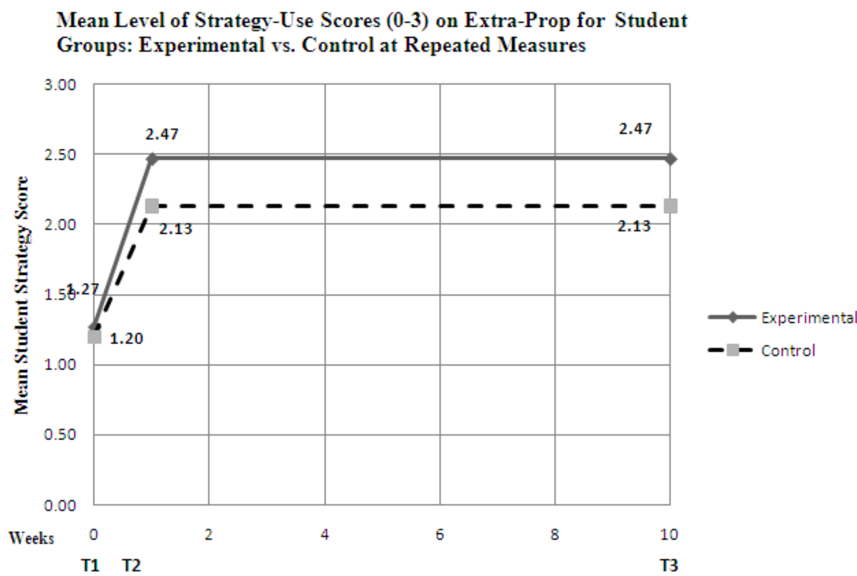


Figure 4. Mean strategy level scores (0–3) on extra-prop for program groups across three time points.

There is an indication of students' improvement from an average of Level 1 of proportional reasoning strategies demonstrated to an average of Level 2 of proportional reasoning strategies. However, both groups changed similarly, regardless of the teaching approach they were exposed to. Level 2 is quantitative, and perhaps their prior school experiences had reinforced quantitative and algorithmic strategies over higher level reasoning strategies. Level 2 proportional reasoning allowed them to achieve a relatively high percentage of correct answers (experimental mean score = 77.3%; control group mean score = 62%), so they did not need to go further. As seen in Figure 3 above, student mean strategy levels for both groups do not drop after 10 weeks. Perhaps this indicates that students in both intervention groups have learned to apply quantitative proportional reasoning strategies (at an average level of 2) and they retain this knowledge over time. This is an important accomplishment that might not have been apparent if only measured by the percentage correct score on the same test at T3. Student work displays their use of proportional reasoning strategies, even though their final answer may be incorrect. A mixed between–within subjects ANOVA was conducted to assess the impact of two different interventions (non-engineering textbook-based mathematics intervention program and LEGO robotics integrated engineering and mathematics intervention program), based on the level of proportional reasoning strategies used by the participants as reflected by their level of strategy-use scores on the Extra-Prop at T1, T2, and T3. There was no significant interaction between program type and time, Wilks' Lambda = .973, F (2, 27) = .772, *p* = .387, partial eta squared = .027. There was a substantial main effect for time, Wilks' Lambda = .362, F(2,27) = 49.434, *p* = .000, partial eta squared = .638, with both groups showing a large increase in the level of proportional reasoning strategies used, as measured by their overall level of strategy-use scores on the Extra-Prop. The main effect comparing the two types of intervention was not significant, F (1, 28) = .1.483, *p* = .233, partial eta squared = .050, suggesting no difference in the effectiveness of the two teaching approaches when measured by the level of strategy-use score on the Extra-Prop.

Proportional Reasoning Levels Analysis: Engin-Prop

Table 5 shows the descriptive statistics for each program group's performance on the Extra-Prop at each of the three time points.

Table 5

Engin-Prop Descriptive Statistics—Strategy Rating by Student Groups

Time of Engin-Prop Assessment	Program Group	Mean	*SD*	*N*
T1	Control Group	1.07	.704	15
	Experimental Group	1.13	.640	15
	Total	1.10	.662	30
T2	Control Group	1.00	.655	15
	Experimental Group	2.47	.516	15
	Total	1.73	.944	30
T3	Control Group	.87	.640	15
	Experimental Group	2.40	.507	15
	Total	1.63	.964	30

Figure 5 displays the mean score for strategy level use on the Engin-Prop assessment by each group (experimental and control) at each of the three time points.

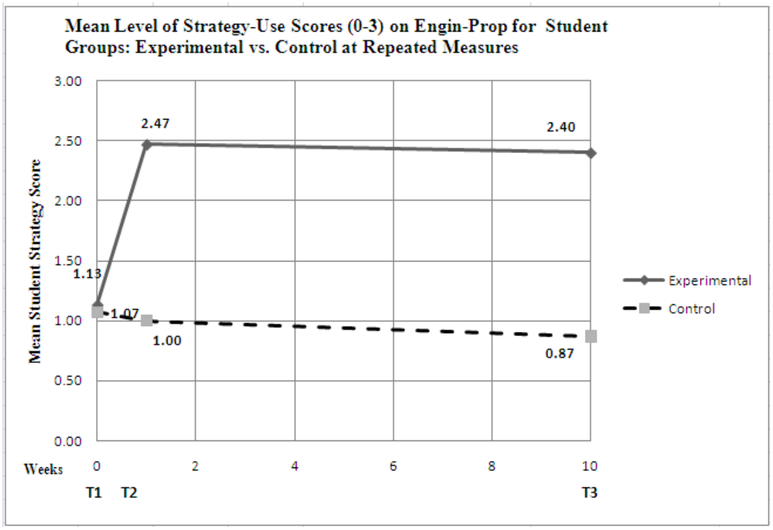


Figure 5. Mean strategy level scores (0–3) on engin-prop for program groups across three time points.

The range of the proportional reasoning score for the Engin-Prop assessment was 0–3. The mean strategy score for the 15 students in the experimental group began with a strategy score of 1.13. Students achieved a score of 2.47 at T2 and 2.40 at T3. The data for the control students are shown as a benchmark. However, it is not expected that students would demonstrate any change because control group students did not receive instruction in the use of LEGO robotics. It is noteworthy, nonetheless, that the accomplishments of the experimental group were achieved within the same overall program instructional time as that of the control group.

A mixed between–within subjects ANOVA was conducted to assess the impact of two different interventions (non-engineering textbook-based mathematics and LEGO robotics integrated engineering and mathematics) based on the level of proportional reasoning strategies used by the participants as reflected by their level of strategy-use scores on the Engin-Prop at T1, T2, and T3. In this case, there was significant interaction between program type and time, Wilks' Lambda = .419, $F(2,27) = 18.684$, $p = .000$, partial eta squared = .581. There was also a substantial main effect for time for the experimental group, Wilks' Lambda = .502, $F(2,27) = 13.377$, $p = .000$, partial eta squared = .498, with the experimental group showing an increase in the level of proportional reasoning strategies used, as measured by their overall level of strategy-use scores on the Engin-Prop. The main effect comparing the two types of intervention was significant, F(1,28) = .31.381, p = .000, partial eta squared = .528, suggesting a significant difference in the effectiveness of the two teaching approaches when measured by the Engin-Prop. This main effect was to be expected given that the Engin-Prop included many items that were better understood by students that had actually received instruction in engineering LEGO robotics as well as ratio and proportion mathematics.

Discussion

This study was designed to determine the possible impact of an integrated engineering and mathematics teaching approach using LEGO robotics upon students' learning of concepts of ratio and proportion. The results of this study indicated that the students were able to make significant progress in learning new concepts of ratio and proportion while also learning basic definitions related to LEGO robotics engineering design and programming when this learning took place in an integrated engineering and mathematics context. It has been shown that a statistically significant change in students' understanding of ratio and proportion took place during the relatively short but intense learning experience, regardless of the type of intervention to which the students had been exposed. Even students who were exposed to a traditional textbook curriculum experienced changes in their scores. This confirms that the 3 hours of instruction daily in a 5-day program during a normal planned school-year break (that included no other schoolwork) allowed students to focus on and learn about the academic topics taught. These students were motivated to attend a program that was advertised to be of an academic nature, so perhaps they were intrinsically motivated to learn. However, the more important finding is that the 15 hours of focused instruction with quality curricula (textbook-based and non-textbook-based) was sufficient to allow students to significantly increase the number of correct responses to problems of ratio and proportion.

The performance of students in the experimental group on the Intra-Prop was not significantly higher than that of the performance of students in the control group. This might indicate that students that are taught concepts of ratio and proportion in a focused intervention program will learn how to solve problems of ratio and proportion in intra-mathematical contexts just as well, regardless of the differences in instructional methodology and with or without engineering integrated into their learning experience. The performance of students in the experimental group on the Extra-Prop was significantly higher than the performance of students in the control group. These results indicate that students that learn about ratio and proportion in an engineering-related context improve in their understanding significantly and retain their learning for a longer period of time when they encounter these situations in an extra-mathematical context versus in an intra-mathematical context.

The performance of students in the experimental group on the Engin-Prop was significantly different than the performance of students in the control group. However, even these students did not use particularly high levels of proportional reasoning strategies. It may be unrealistic to expect students to achieve higher levels of proportional reasoning in such a short intervention program. In addition, the young students in this class seemed to be more comfortable with solving problems as simply as possible and were able to "get the right answer" with only Level 2 proportional reasoning strategies.

The main message of these findings is that educational robotics can serve as a motivating context that may be very beneficial as an instructional tool in the integrated engineering mathematics classroom when teaching concepts of ratio and proportion and potentially many others. It is important and productive for students to be allowed the opportunity to learn mathematics concepts accompanied with meaningful constructionist experiences such as those provided by LEGO educational robotics in an integrated engineering and mathematics design setting. Perhaps these experiences influence the level of engagement and thoughtful approaches that lead to deeper student understanding of mathematics concepts—in this case, ratio and proportion concepts. One finding of special note to practitioners is the fact that students in the experimental group were able to learn at least as much and as well (if not more) of the mathematics content topic of ratio and proportion as compared to the control group of students. Additionally, within the same amount of time, experimental group students learned and retained engineering and related applied ratio and proportion mathematics concepts.

Limitations of the Study and Future Research

The experimental intervention program described in this study was a program that integrated engineering design and educational robotics application opportunities in addition to the same mathematics objectives regarding ratio and proportion as the non-engineering mathematics intervention program. The intervention and control programs took place in the same school setting as extracurricular programs occurring during a holiday week when school was not in session. The experimental program took place in the morning, and the control program took place in the afternoon. This introduced a variable (learning in the morning versus learning in the afternoon) that was beyond the control of this study and is certainly a limitation. The study was designed and carried out in spite of this limitation in order to maintain the same instructor for both student groups. Although morning versus afternoon course time is a factor that may certainly have affected the performance of the students, introducing a different instructor may have introduced much greater variability.

Another limitation of this study was that only one student group received the opportunity to learn about LEGO robotics and use LEGO robotics in engineering design challenges requiring mathematical thinking. Although this was precisely the intent of the study in order to compare the impact of the two differing learning experiences, it limited the ability of comparison of learning in the engineering context between the two groups. In this study, it is not appropriate to compare learning differences of LEGO engineering concepts between the two groups because one group was not exposed to LEGO engineering concepts. However, the analysis presented in this study does show a comparison only as a benchmark as to how much students might already know about LEGO engineering concepts without explicit instruction. Given the low socioeconomic status of both student groups, it is not likely that students have access to expensive LEGO robotics materials at home or at school.

Another limitation of this study was the short duration of the learning experience. This limitation was driven by the interest in controlling the mathematics learning levels of the participating students. Because students were in different classrooms and in different households, the mathematics learning experiences that each might be exposed to would increase as the time increased. However, as was shown, all had a significant change in their learning of the proportional reasoning concepts expected. This supported that even a short duration learning experience, if purposefully designed and intense, can support significant and sustained student learning.

This research study focused primarily on students, and the author sought to measure student mathematical learning and skill development. In order to capture detailed qualitative data, the overall sample size of $n = 30$ was small, which limited the power of statistical analysis and generalization of results. Although there was pretesting (P1) conducted for all students, a more in-depth analysis could be conducted using the P1 scores as a covariate to describe the differences between the groups. Future studies can be repeated with the support of additional research and instructional support that will allow for a larger number of participants. External validity can be addressed by repeating this study at multiple schools, both with similar and differing student demographics. Finally, in light of the conclusions regarding the positive impact of the integrated content teaching approach for mathematics and engineering using LEGO robotics, a future direction would be to analyze the specific techniques that expert teachers utilize to effectively teach integrated content, specifically when working with educational robotics and mathematics. Such research would help to better identify the pedagogical skills and content knowledge necessary to teach well in such a setting.

References

Amsel, E., Goodman, G., Savoi, D., & Clark, M. (1996). The development of reasoning about causal and noncausal influences on levers. *Child Development, 67*(4), 1624–1646. doi:10.1111/j.1467-8624.1996.tb01818.x

Barlex, D., & Pitt, J. (2000). *Interaction: The relationship between science and design and technology in the secondary curriculum*. London, United

Kingdom: Engineering Council.
Baxter, G., & Junker, B. W. (2001, April). *Designing cognitive-developmental assessments: A case study in proportional reasoning*. Paper presented at the Annual Meeting of the National Council of Measurement in Education, Seattle, WA. Retrieved from http://www.stat.cmu.edu/~brian/rpm/baxterjunkerncme.pdf
Ben-Chaim, D., Fey, J. T., Fitzgerald, W. M., Benedetto, C., & Miller, J. (1998). Proportional reasoning among 7th grade students with different curricular experiences. *Educational Studies in Mathematics, 36*(3), 247–273. doi:10.1023/A:1003235712092
Behr, M., Harel, G., Post, T., & Lesh, R. (1987). Theoretical analysis: Structure and hierarchy, missing value proportion problems. In J. C. Bergeron, N. Herscovics, & C. Kieran (Eds.), *Proceedings of the Eleventh International Conference: Psychology of Mathematics Education PME-XI* (Vol. II, pp. 269–274). Montreal, Canada: International Group for the Psychology of Mathematics Education.
Borasi, R. (1986). On the nature of problems. *Educational Studies in Mathematics, 17*(2), 125–141. doi:10.1007/BF00311517
Carpenter, T. P., & Moser, J. M. (1984). The acquisition of addition and subtraction concepts in grades one through three. *Journal for Research in Mathematics Education, 15*(3), 179–203.
Carraher, T. N., Carraher, D., & Schliemann, A. D. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology, 3*, 21–29. doi:10.1111/j.2044-835X.1985.tb00951.x
Chevallard, Y. (1990). On mathematics education and culture: Critical afterthoughts. *Educational Studies in Mathematics, 21*(1), 3–27. doi:10.1007/BF00311013
Chevallard, Y. (2007). Readjusting didactics to a changing epistemology. *European Educational Research Journal, 6*(2), 131–134. doi:10.2304/eerj.2007.6.2.131
Clements, D. H., & Sarama, J. (2007). Early childhood mathematics learning. In F. K. Lester, Jr. (Ed.), *Second handbook of research on mathematics teaching and learning* (Vol. 1, pp. 461–555). Charlotte, NC: Information Age.
Cross, N. (2007). Forty years of design research. *Design Research Quarterly, 2*(1), 3–5. Retrieved from http://www.drsq.org/issues/drq2-1.pdf
Foster, P. N., & Wright, M. D. (2001). How children think and feel about design and technology: Two case studies. *Journal of Industrial Teacher Education, 38*(2), 40–64. Retrieved from http://scholar.lib.vt.edu/ejournals/JITE/v38n2/foster.html
Deming, W. E. (1986). *Out of the crisis*. Cambridge, MA: MIT Press.
Harel, G., Behr, M., Post, T., & Lesh, R. (1987). Qualitative differences among 7th grade children in solving a non-numerical proportional reasoning blocks

task. In J. C. Bergeron, N. Herscovics, & C. Kieran (Eds.), *Proceedings of the Eleventh International Conference, Psychology of Mathematics Education PME-XI* (Vol. II, pp. 282–288). Montreal, Canada: International Group for the Psychology of Mathematics Education.

Karplus, R., Pulos, S., & Stage, E. (1983). Proportional reasoning of early adolescents. In R. Lesh & M. Landau (Eds.), *Acquisition of mathematical concepts and processes* (pp. 45–90). New York, NY: Academic Press.

Katehi, L., Pearson, G., & Feder, M. (2009), The status and nature of K–12 engineering education in the United States. *The Bridge, 39*(3), 5–10. Retrieved from https://www.nae.edu/Publications/Bridge/16145/16161.aspx

Kaput, J. J., & West, M. M. (1994). Missing-value proportional reasoning problems: Factors affecting informal reasoning patterns. In G. Harel & J. Confrey (Eds.), *The development of multiplicative reasoning in the learning of mathematics* (Research in Mathematics Education Series, pp. 235–287). Albany, NY: State University of New York Press.

Lamon, S. J. (1993). Ratio and proportion: Connecting content and children's thinking. *Journal for Research in Mathematics Education, 24*(1), 41–61.

Langrall, C. W., & Swafford, J. (2000). Three balloons for two dollars: Developing proportional reasoning. *Mathematics Teaching in the Middle School, 6*(4), 254–261.

Martínez Ortiz, A. (2004). *Using the engineering design process to develop a framework & an approach for integrating engineering into the elementary classroom science curriculum.* Unpublished manuscript, Tufts University, Medford, MA.

Martínez Ortiz, A. (2005). *Fusing engineering-integrated engineering LEGO robotics and mathematics: An elementary classroom curriculum*. Unpublished manuscript, Tufts University, Medford, MA.

Martínez Ortiz, A. (2008). *The impact of engineering education at the kindergarten to high school levels: A review of research* (Qualifying paper). Tufts University, Medford, MA. Retrieved from http://dl.tufts.edu/catalog/tufts:UA071.001.001.00006.00002

Martínez Ortiz, A. (2011). *Fifth grade students' understanding of ratio and proportion in an engineering robotics program*. Paper presented at the 2011 American Society for Engineering Education Conference, Vancouver, British Columbia, Canada. Retrieved from http://www.asee.org/public/conferences/1/papers/2649/view

Massachusetts Department of Education. (2001). *Massachusetts science and technology/engineering curriculum framework*. Retrieved from http://www.doe.mass.edu/frameworks/scitech/2001/0501.pdf

Misailidou, C., & Williams, J. (2003). Diagnostic assessment of children's proportional reasoning. *The Journal of Mathematical Behavior, 22*(3), 335–368. doi:10.1016/S0732-3123(03)00025-7

Moundridou, M., & Kaniglonou, A. (2008). Using LEGO MINDSTORMS as an instructional aid in technical and vocational secondary education: Experiences from an empirical case study. In P. Dillenbourg & M. Specht (Eds.), *Times of Convergence. Technologies Across Learning Contexts* (pp. 312–321). Berlin, Germany: Springer-Verlag. doi:10.1007/978-3-540-87605-2_35

Museum of Science. (n.d.). The engineering design process. Retrieved from http://www.mos.org/eie/engineering_design.php

U.S. Department of Education, National Assessment Governing Board. (2014). *Technology and engineering literacy framework for the 2014 national assessment of educational progress.* Washington, DC: Author.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common core state standards for mathematics*. Washington, DC: Author. Retrieved from http://www.corestandards.org/assets/CCSSI_Math%20Standards.pdf

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books.

Puntambekar, S., & Kolodner, J. L. (2005). Toward implementing distributed scaffolding: Helping students learn science from design. *Journal of Research in Science Teaching*, *42*(2), 185–217. doi:10.1002/tea.20048

Resnick, M., Martin, F., Sargent, R., & Silverman, B. (1996). Programmable bricks: Toys to think with. *IBM Systems Journal, 35*(3–4), 443–452. doi:10.1147/sj.353.0443

Roden, C. (1995). Young children's learning strategies in design and technology. In J. S. Smith (Ed.), *IDATER 95: International Conference on Design and Technology Educational Research and Curriculum Development* (pp. 21–27). Loughborough, UK: Loughborough University of Technology. Retrieved from https://dspace.lboro.ac.uk/2134/1521

Shewhart, W. A. (1986). *Statistical method from the viewpoint of quality control*. W. E. Deming (Ed.). New York, NY: Dover.

Texas Education Agency. (2008). *Chapter 111. Texas essential knowledge and skills for mathematics*. Austin, TX: Author. Retrieved from http://ritter.tea.state.tx.us/rules/tac/chapter111/index.html

Tourniaire, F. (1986). Proportions in elementary school. *Educational Studies in Mathematics, 17*(4), 401–412. doi:10.1007/BF00311327

Vergnaud, G. (1983). Multiplicative structures. In R. Lesh & M. Landau (Eds.), *Acquisition of mathematics concepts and processes* (pp. 127–174). New York, NY: Academic Press.

Book Review

Roth, M. S. (2014). *Beyond the university: Why liberal education matters*. New Haven, CT: Yale University Press.
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Will there forever be a rift between workforce education (career and technical (CTE), technological, and vocational) and liberal arts education? Will American society ever reach consensus over the daunting question regarding education's purpose: "Does one attend college or university for the sake of learning in-and-of-itself, or in pragmatic preparation of a future career?" Will we ever reach a mending of what Rose (2008) dubbed "the hand/brain divide"? Dr. Michael S. Roth does not think so. Roth is a champion of "traditional" liberal arts education. That is not to say he totally discredits the value of vocational education. Yet, in *Beyond the University: Why Liberal Education Matters,* he not only relegates workforce education to second-class status, but misrepresents historical figureheads.

Organization

Roth assumes the role of historian and provides a poignant argument for his readers. All is informative, personal, elegant, witty, and non-academic; it is written to appeal to a mass audience of both scholars and lay persons alike. Roth captures the reader's attention by sharing his personal testimony and concern that stems from his experience as president of Wesleyan University, the institution he attended as an undergraduate. A chronological comparison of conflicting ideals from monumental figureheads follows.

Roth's Ideas

Beyond the University does not advocate an eradication of workforce education. For the most part, it is a celebration of the historical roots of the liberal arts and its offerings to students. Roth defends the virtues of liberal learning as both a developer of better people and useful in preparation for future success. That said, according to Roth, liberal education is "under siege."

Changes to the American social, cultural, and economic landscape have challenged the notion that venturing off to a four-year institution is something impractical. In an era of economic instability, liberal arts is once again being attacked for its elitism and irrelevance. Parents and students wonder if higher education is a worthy investment. Modern-day pupils' focuses include: return on investment, résumé building, employment opportunities, and employers' expectations.

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Roth champions the benefits of a liberal arts education. Liberal, humanistic learning promotes personal development and, therefore, is an integral component of optimal success. Its [liberal arts education] broad context with its emphasis on inquiry and critical thinking is needed now more than ever. Such undertakings enhance capacities for the shaping of the self by instilling the ability to think for oneself, the successive reinventing of the world, and the unleashing of creative potential. Finally, a liberal education benefits all regardless of occupation by developing intellectual capacities, which has been revealed through the ages.

Liberal Arts vs. Vocational Education: A Historical Debate

The debate over the usefulness of education has a long history in America. *Beyond the University* serves as a superficial survey and comparison of influential figureheads from our collective past at odds with the purpose of education. Roth begins with the educational ideals of Thomas Jefferson, contrasting them with the practical approaches promoted by Benjamin Franklin. After an analysis of Emerson's views on education and the self, Booker T. Washington's opinion of education as a means of economic inclusion are compared with that of W.E.B. Du Bois. Jane Addams', William James', Richard Rorty's, Martha Nussbaum's, and John Dewey's educational philosophies follow.

John Dewey and a Shared Vision

Roth's understanding of Dewey mandates possible correction. Dewey argued vehemently against Snedded's philosophy of a narrow focused vocationalism, which transformed itself into industrial arts. At the opening of the 20th Century, Prosser and Snedden argued for the development of targeted skills for specific occupations, while Dewey advocated for a broader approach and application of career education to satisfy basic human fulfillment, which included vocational-adaptability and self-sufficiency, to best prepare students for life (Petrina, 1996; Rojewski, 2002). John Dewey desired education of the whole person through occupation, emphasizing the experience, active learning, and a connection to the learner's interests and activities. Dewey is one of the fathers of modern-day workforce education.

Differentiations need to be made regarding career education and respect for multiple options, pathways, and choice championed. Dewey's philosophy of learning through career, created an ever-widening schism in vocational education and the establishment of current occupational and technical studies. The aims of modern-day career education, career and technical education (CTE), and technology and engineering literacy are not far removed from that of liberal arts. Some individuals desire specific careers that require said vocational preparation. Beyond that, all parties concerned in specific subgroups within workforce education argue against "narrow, technical forms of teaching intended to give quick, utilitarian results" (Roth, 2014, p. 10) for curricula that requires learners to develop literacy and thinking skills, soft skills, and the like. American liberal education is not the only path to life-long learning. Different options exist, as diversity is the norm. Truthfully, a skeptical and cynical spotlight has been cast by Americans on our education system in totality (Johnson & Duffett, 2003).

All educational institutions, regardless of focus and offerings, face the same student recruitment and retention issues. Malaise, pessimism, and general apathy are the zeitgeist of the current era. The majority of Americans focus on return on investment, and rightfully so. Rising tuition costs and stories of college graduates either unable to find employment or being underemployed are routinely in the media. So too is information about high-wage, in-demand occupations that require education and training below the baccalaureate level. Many of my peers have informed me of their choice to attend community college to obtain a certification and start a career to become financially stable and independent, with the goal of ultimately returning to college at night and further their education. Does this not speak to independent and problem-solution thinking? Is this not an exemplification of Maslow's hierarchy of needs, where safety and security are a natural priority?

Final Analysis

Though there are ample reasons why the material in *Beyond the University* would not be agreeable to those in career and technical education, technology and engineering education, career development, and those that cannot afford the luxury of higher education, many vehemently agree with Roth. In short, though I reviewed this work because I felt it needed a critique, all was well written. Dr. Roth should be commended for his ideas and bringing them back into the social consciousness, opening up all for debate and hopefully moving education out of its current quagmire, to a new era of inspiration.

References

Johnson, J., & Duffett, A. (2003). *Where we are now: 12 things you need to know about public opinion and public schools. A digest of a decade of survey research.* New York, NY: Public Agenda. Retrieved from http://www.publicagendaarchives.org/citizen/researchstudies/education/national-education-reports

Petrina, S., & Volk, K. (1996). Industrial arts movement's history, vision, and ideals: Relevant, contemporary, used but unrecognized—Part 2. *Journal of Technological Studies, 21*(2), 28-35.

Rojewski, J. W. (2002). Preparing the workforce of tomorrow: A conceptual framework for career and technical education. *Journal of Vocational Education Research, 27*(1), 7-35.

Rose, M. (2008). Intelligence, knowledge, and the hand/ brain divide. *Phi Delta Kappan, 89*(9), 632-639.

Roth, M. S. (2014). *Beyond the university: Why liberal education matters*. New Haven, CT: Yale University Press.

Book Review

Crawley, E., Malmqvist, J., Östlund, S., Brodeur, D., & Eström, K. (2014). *Rethinking engineering education: The CDIO approach* (2nd ed.). New York: Springer.
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Undergraduate engineering students and industry hiring managers spent years awaiting a revolution in engineering education. That revolution seemingly arrived in 2007 with the first edition release of *Rethinking Engineering Education: The CDIO Approach*. In the second edition, Crawley, Malmqvist, Östlund, Brodeur, and Eström provide the engineering education community with an updated syllabus, standards, and an additional chapter to their original text. The authors attempt to address two main questions in their work: (a) "What is the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and at what level of proficiency?" (p. 17) and (b) "How can we do better at ensuring that students learn these skills?" (p. 20).

Motivation and Overview

The authors write primarily to engineering educators, administrators, and curriculum developers to discuss the Conceive-Design-Implement-Operate (CDIO) approach as it has now been implemented in classrooms across the globe. In looking at the gap between engineering education expectations and form, Crawley et al. (2014) "identified an underlying critical need—to educate students who are able to Conceive-Design-Implement-Operate complex, value-added engineering products, processes and systems in a modern, team-based environment" (p. 1). Their message seems to be aimed at a wider audience that includes all engineering and technology educators. "It is not a matter of fixing something that is broken, but of improving something that is vital to our future, namely technological education" (p. 183). Education that is focused on preparing students with elements of practical knowledge must employ applied instruction. This theme is consistent throughout the text and the authors provide valuable insight on how to bring the applied element to classroom instruction.

Crawley et al. (2014) make the case for their method by describing the role of engineers as conceiving devices and systems, designing "products, processes and systems that incorporate technology," (p. 2) and implementing designs. They also suggest that engineers need to ensure devices and systems can be operated without issue. The authors describe the traditional education approach as not meeting the needs of students and industry employers to prepare graduates who are able to accomplish these aforementioned tasks.

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Over the years, many graduates have found themselves working in environments bearing little, if any, resemblance to their educational experiences. The authors describe contextual learning and the importance of outside world examples to which students can relate new ideas. They explain how projects help students develop confidence to apply knowledge once they begin working. Their message has certainly been heard as they boast over one hundred institutions of higher learning around the world using these methods (Crawley et al., 2014). This text is required reading for engineering and technology educators or administrators.

After establishing the motivation for the approach, the authors clearly define CDIO and present its syllabus and desired learning outcomes. They then discuss the role of integrated curriculum and the importance of design-implement experiences. Here, the authors also offer ideas related to adaptable workspaces that promote hands-on learning and collaboration. Next, they cover teaching, learning, and assessment in the CDIO format and provide direction on implementation. Crawley et al. cover program evaluation before providing a brief history of the development of engineering education. They conclude the text with a new chapter on the future of the CDIO approach. The twelve CDIO standards (Table 1) are presented in order throughout the book's eleven chapters, and are supplemented with vignettes that include examples of functional elements. The text includes the updated CDIO syllabus, which incorporates the new topics of leadership and entrepreneurship, and the standards and rubrics in appendices.

CDIO as a Context

Crawley et al. indicate their tasks have been chosen because they apply to all types of engineering disciplines and activities and have been consistently used throughout the past five decades. The context of engineering has involved a focus on society's problems, the products, processes, and systems to address those problems, invention and technology, collaboration with other disciplines, the need for effective communication, and dealing with resource constraints. The authors explain the system lifecycle as providing the appropriate context in which to teach engineering curriculum.

They make it clear this approach provides the context, not the content, of teaching engineering. There is no "dumbing down" of the engineering disciplines. Crawley et al. (2014) posit engineering content should be taught in this framework because "(a) it is what engineers do; (b) it is the basis for the desirable skills that industry proposes to university educators; (c) it is the natural context in which to teach these skills; and, (d) it better supports the learning of the technical fundamentals" (p. 32). Engineering students are often disappointed that these facets of the discipline are not covered in their educational experiences. These situations often shape student persistence in engineering programs, so administrators and educators concerned with this area should take note.

Important components in the approach are design-implement experiences. Students need to be able to design and implement ideas because these activities are central to what engineers do. Crawley et al. recommend students be given opportunities early on and throughout their programs to develop these skills. They argue content should be learned in the context of design-implement experience involving active learning. The authors also discuss the importance of reflection on the part of students. Students must be given the time to think about their designs, how they have implemented them, and pose questions about potential improvements. Engineering students who have developed strong habits of continuous improvement will be the most successful.

Meeting Challenges to Implementation

Those convinced of the potential of the CDIO approach will most certainly face significant challenges in implementing these methodologies. Crawley et al. (2014) explain that implementation "implies a shift in the nature of engineering education to a more integrated curriculum" (p. 37). The past two decades have been replete with research focused on integrated approaches in engineering classrooms (Craft & Mack, 2001; Grigg et al., 2004; Jenkins, Pocock, Meade, Mitchell, & Farrington, 2002). There has been emphasis on implementing an increased practical element to what had previously been centered on science and theory. Those hoping to redefine engineering education have been focused on the challenges that present themselves, and how best to deal with them. In *Redefining Engineering Education*, the authors prepare their readers and provide answers.

The authors dedicate a chapter to the topic of effecting change and dealing with how to properly get started in this endeavor through implementing the core activities and institutionalizing change. They give their readers numerous recommendations on how to go about the process of change. First, they recommend teams be comprised of established leaders and newer faculty members; this approach is necessary to avoid the "us and them" mentality. Second, the writers state change agents must work outside of traditional assumptions; curriculum designers don't change because of long standing usage. They encourage the field to move past this thinking and involve all stakeholders, including students, in the process.

The authors point out the importance of recognizing faculty who are instrumental in executing the new approach and providing incentives. They stress creating a "culture of faculty learning" (p. 194) and recommend providing opportunities for development, specifically involving both professional activities and scholarly work; this emphasis on both facets is important for those looking to include both in their classrooms. Finally, Crawley et al. explain both students' formal academic requirements and informal expectations, and thus provide a clear message to students about their academic goals and how they will be actively involved in their own learning. There are important suggestions throughout this section for educators of all engineering disciplines and even those outside engineering education.

Version Updates

For those readers familiar with the original release of the CDIO syllabus, the authors explain the reason for this updated version arising from new knowledge and missing information identified by users. This update clarifies the organization of the approach by better outlining its structure. The authors made a concerted effort to revise content based on international accreditation and curriculum evaluation texts. They discuss the internationalization of engineering education and this inclusive list of accrediting bodies ensures the adaptability of the syllabus to this trend. Crawley et al. have also included missing items identified by users of the previous syllabus and clarified terminology. The updated release is more complete since the authors have incorporated feedback from a vast number of users from all over the globe. We are reminded the syllabus is not meant to dictate every facet of curriculum design, but serves as a tool that can be adapted as necessary.

Concluding Remarks

Crawley et al. (2014) have developed an important resource for engineering educators and curriculum developers. There are elements that are important for all engineering and technology educators, and also teachers in any discipline looking to incorporate increased practical elements into their classrooms. This review has focused on specific topics including the motivation to transform engineering curriculum and overcoming the barriers to implementing that change. It is hoped readers are compelled to think about the need for changing engineering education and realize they can overcome the obstacles by becoming change agents and heed the call for improvement. We owe it to our stakeholders to provide an education that prepares students for their world of work and meets the needs of industry and society. The authors of *Rethinking Engineering Education* compel us to change and provide us with the resources we need to get there.

Table 1
The CDIO Standards v2.0

Standard	
1 – The Content	Adoption of the principle that product, process, and system lifecycle development and deployment—Conceiving, Designing, Implementing and Operating—are the context for engineering education
2 – Learning Outcomes	Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders
3 – Integrated Curriculum	A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills
4 – Introduction to Engineering	An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills
5 – Design-Implement Experiences	A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level
6 – Engineering Workspaces	Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning
7 – Integrated Learning Experiences	Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills
8 – Active Learning	Teaching and learning based on active experiential learning methods
9 – Enhancement of Faculty Competence	Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills

10 – Enhancement of Faculty Teaching Competence	Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning
11 – Learning Assessment	Assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge
12 – Program Evaluation	A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement

References

Craft, E., & Mack, L. (2001). Developing and implementing an integrated, problem-based engineering technology curriculum in an American technical college system. *Community College Journal of Research & Practice*, *25*(5-6), 425-439.

Grigg, N., Criswell, M., Fontane, D., Saito, L., Siller, T., & Sunada, D. (2013). Integrated civil engineering curriculum: Five-year review. *Journal of Professional Issues in Engineering Education & Practice*, *130*(3), 160-165.

Jenkins, S., Pocock, J., Meade, R., Mitchell, Z., & Farrington, J. (2002). Capstone course in an integrated engineering curriculum. *Journal of Professional Issues in Engineering Education & Practice*, *128*(2), 75-82.

Book Review

Evans-Andris, M. (1996). *An apple for the teacher: Computers and work in elementary schools*. Corwin Press.
ISBN: 978-0-803-96348-1
$10.00 (paperback) 208 pages

If you have teaching experience or have been part of technology implementation in education in recent years, *An Apple for the Teacher* is still relevant to today's schools and remains a must read. The book was the product of a longitudinal study using ethnographic methods where the author was immersed in elementary schools with new computers. Thick descriptions of the teachers, teachers' attitudes, computer-use time and activities, and how computers had an effect on the culture of teaching and the school are provided throughout. Evans-Andris captured the essence of how teachers dealt with the new and unfamiliar world of computers in schools. Readers can expect to learn how teachers incorporated computers into their work patterns, how computers disrupted the traditional skills of teachers, and the consequences of technological change for the occupational culture of teachers. *An Apple for the Teacher* identifies real issues occurring 'in the trenches' of our schools.

Although computer technology is the centerpiece of Evans-Andris' study, readers will discover the importance of a strategic plan of implementation, the need for administrative support of technology use, and a need for appropriate professional development for teachers once technology is in place. This book acted as a guide through many of the obstacles standing in the way of effective implementation of computers and shared personal insights from teachers finding their place in a changing environment. The organization of the book created an easy to follow flow of major topics of importance. Evans-Andris wrote about the introduction of computers, motivating teachers for change, the effects of technology on education, the role of the computer coordinator, and occupational rewards for teachers. Each chapter included a literature review specific for each main topic, interpretations of the data, and highlighted what readers should take away.

The completion of this research led to a number of important findings related to structural and occupational dimensions of technical change in elementary schools, and the implications for education at the elementary level. Evans-Andris identified the various computing styles among teachers, ideas toward a theory of technical change and teaching, the value of an integrative computing style in schools, and the development of an effective computer implementation program as important points of discussion.

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The three styles of computing that emerged from this study were avoidance (the most common form), integration, and technical specialization. Evans-Andris defined each style and identified how each could impact teachers and their students. The acceptance or avoidance of technology in schools can have large impacts on student learning and teachers may experience an occupational shift, as computers are not going anywhere, anytime soon. Evans-Andris' research proposed the need for goals, clear expectations of computer use, professional development opportunities, and teachers to be open to altering their 'traditional' lesson plans. As schools work to integrate computers, administration must determine what will benefit students most, and then follow up by establishing guidelines for teachers. The policies put in place should not focus on the short-term and how we use technology to teach our students, but rather be long-term, and think about preparation for a future beyond education. Finally, Evans-Andris used the data to recommend a set of guidelines for schools wanting to bring technology into their schools. A few of these guidelines included: administration must lead the charge and be involved, there are equipment needs and demands that cannot be overlooked, and teachers must be trained appropriately to assist them in integration within their classrooms.

Upon final analysis of the data, Evans-Andris reported two outcomes: (a) the development of a comprehensive theoretical explanation of technological innovation and teaching that considers both organizational and occupational factors in the process of change, and (b) a practical guide for schools to use if they want to implement new computer technology. Although this book was written in 1996, more recent research by Professor Larry Cuban, in *Oversold & Underused: Computers in the Classroom*, supported similar findings at the lower elementary level and within high school and university settings (2001). In addition, a systematic investigation of technology integration within an urban high school in a large Midwestern city (2013) identified comparable results as Evans-Andris and Cuban. *An Apple for the Teacher* remains a useful resource because we continue to face related issues today, as we did when computers were first arriving in schools.

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