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Cognitive Mapping Techniques: Implications for Research in Engineering and Technology Education

The primary goal of this paper is to present the theoretical basis and application of two types of cognitive maps, concept map and mind map, and explain how they can be used by educational researchers in engineering design research. Students thrive when they are afforded problem solving opportunities in ill-structured domains that embrace inquiry and design. As the frequency of these types of problem increases in high school curricula so are growing concerns that the problem solving strategies required to adequately approach and solve them may not be supported by the techniques and pedagogy used in most classrooms (Crismond, 2011; Christian & Silk, 2011). One of the approaches to enhance problem solving in ill-structured domains is cognitive mapping. Cognitive mapping techniques can also be useful to researchers as they study students' problem solving strategies and cognitive processes.

The increased emphasis on engineering design in technology education can present several pedagogical challenges because of the limited understanding of the cognitive strategies used by K-12 students when they are solving engineering design problems (Lewis, 2005). Some even argue that current instructional approaches that are often used to teach subjects in ill-structured domains, such as engineering design and scientific inquiry, are not consistent with the cognitive architecture of novice learners (Kirschner, Sweller, & Clark, 2006). This lack of alignment might explain why students encounter difficulty connecting previously learned concepts to the solving of ill-structured problems. The literature shows that in general novice learners do not organize their knowledge in a way that facilitates understanding, efficient retrieval, and application - resulting in ineptness in transferring previous knowledge to situations that differ from those studied in classroom (Kirschner, Sweller, & Clark, 2006; Ellis, Rudnitsky & Silverstein, 2004). Nevertheless, research using cognitive mapping techniques can help educators understanding how students mentally represent design problems. They can also aid the teacher in the proper use of scaffolding techniques to guide students in the solution of complex designing problems.

Cognitive Mapping Explained

Cognitive mapping techniques have gained traction in business and education as tools to stimulate creative thinking and problem solving. Cognitive mapping techniques such as concept mapping and mind mapping can aid the teacher and the researcher by providing a "glimpse" into learners' cognitive

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structure. Both the teacher and researcher can leverage this knowledge to improve their understanding of learning and problem solving.

Cognitive maps are regarded as "internally represented schemas or mental models for particular problem-solving domains that are learned and encoded as a result of an individual's interaction with their environment" (Swan, 1997, p. 188). According to Semantic Theory, knowledge is stored in a network format where concepts are linked to each other (Katz & Fudor, 1963). The more interconnected the knowledge, the higher the probability that a person will recall information when required. From a constructivist's perspective, the learner attains new knowledge by integrating new information with existing knowledge structures. Therefore, the network mapping of concepts and their relationships externalizes how knowledge may be mentally integrated. These mental externalizations, or cognitive maps, are often termed concept maps, knowledge maps, and mind maps (Turns, Atman, & Adams, 2000; Wheeldon & Faubert, 2009; Wycoff, 1991).

Concept Maps

Concept maps are graphical representations that illustrate how people visualize relationship between various concepts (Plotnick, 1997). In its traditional form concept maps are graphical node-arc representations of concepts and their relationships with each other. The nodes of the map contain the concepts and the links between the nodes captures their interrelationships. Labeling the links provides information about the nature of the relationships (Turns, Atman, & Adams, 2000). The links between the concepts can be one-way, two-way, or non-directional. The concepts and the links may be categorized, and the concept map may show temporal or causal relationships between concepts (Plotnick, 1997).

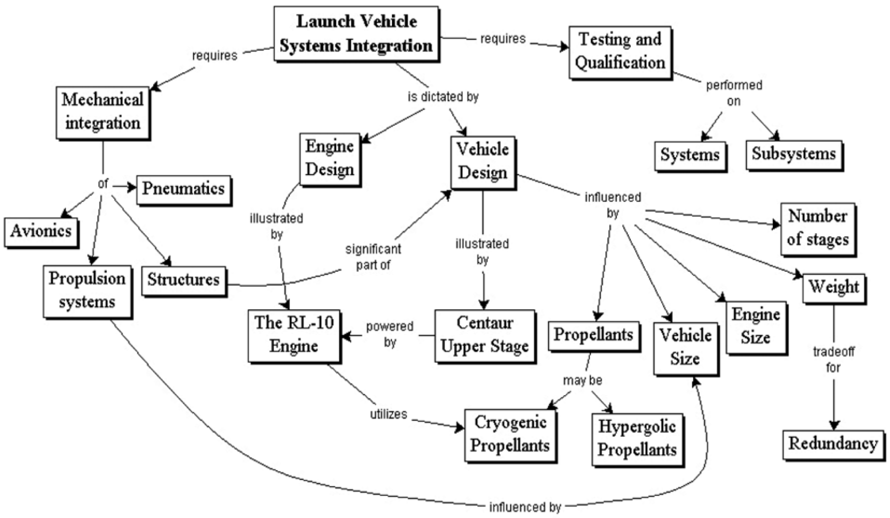


Figure 1. Concept map of vehicle system integration (emeraldinsight.com)

Concept maps have their roots in cognitive psychology and they attempt to illustrate a visual representation of the dynamic schemes of understanding within the human mind (Wheeldon & faubert, 2009). Ruiz-Primo and Shavelson (1996) and Ausubel's (1968) theories provide guidance as to what constitutes a concept map. They propose that concept maps should be hierarchical with superordinate concepts at the apex, labeled with appropriate linking words, and cross-linked so that relations between sub-branches of the hierarchy are identified. Novak and Gowin (1984) articulated that the hierarchical structure develops as new concepts are added, which are subsumed to more general inclusive concepts. The expansion of the hierarchy is govern by the principles of progressive differentiation, so that new concepts and links are added to the hierarchy either by creating new branches or by differentiating existing ones further. The external representations of cognitive structures, however, are not constrained by hierarchical concept mapping. Concept maps can also have a network, spider or chain structure.

The relationship between concepts can either be static or dynamic. A change in one concept can affect the state of the subsequent concept. A dynamic relationship between two concepts reflects and emphasizes the propagation of change in these concepts. It shows how a change in the quantity, quality, or state of one concept causes a change in the quantity, quality, or state of the other concept – signaling the functional interdependency of the two concepts involved. In engineering education, it is often necessary to illustrate the dynamic relationship between concepts. For example Ellis, Rudnitsky & Silverstein (2004) use dynamic concept maps to relate time varying forces to time varying motion, helping students to think beyond the equation of constant acceleration to generalized motion (see Figure 2).

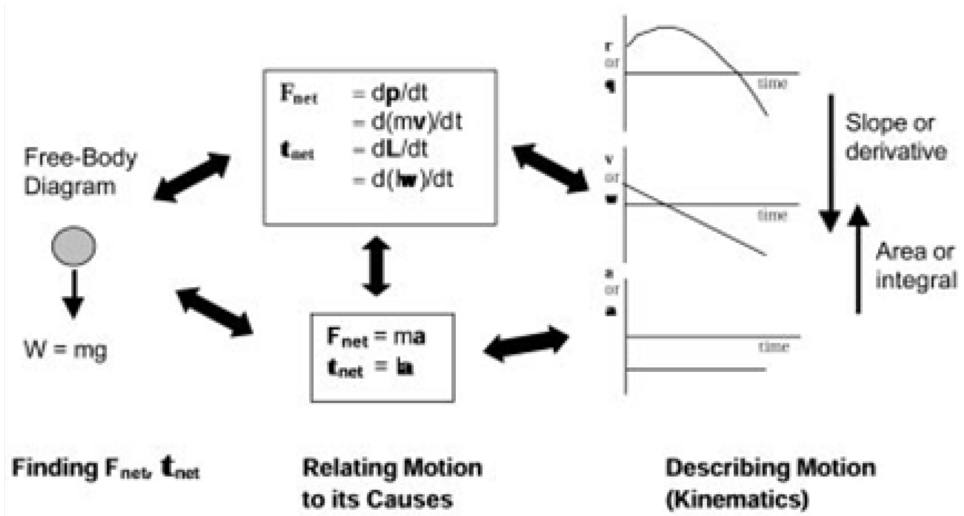


Figure 2. Dynamic concept map used in engineering (adapted from Ellis, Rudnitsky & Silverstein, 2004).

Mind Maps

Mind maps are primarily association maps. The aim of creating a mind map is to explore creative association between ideas. They are visual, non-linear representation of ideas and their relationship. Like concept maps they consist of a network of connected and related concepts. They differ from concept mapping in that the mind mapping process starts with a topic at the center of the graphic (Buzan & Buzan, 2000). They are usually freeform, less formal and structured, and do not have labels that show the nature of the relationship between the ideas. Minds maps often use line thickness, colors, pictures and diagrams to aid knowledge recollection.

Mind maps have several pedagogical and cognitive benefits. The visual images created enhance student learning (Budd, 2004). They also help students to make connections to material in meaningful ways. Nesbit and Adesope (2006) indicated that mind maps have been shown to lower extrinsic cognitive load because students are creating a two-dimensional space to tie in ideas and concepts that relate together. In addition, using mind maps also helps teachers vary their pedagogical methods in order to effectively reach diverse learners (Nesbit & Adesope, 2006). Mind maps have also been used as reflective tools that allowed for broader associations to be made to the material (Budd, 2004).

Buzan and Buzan (2000) recommended the following guideline when making a mind map:

- Place an image or topic in the center using at least three colors
- Use image, symbols and dimensions throughout your mind map
- Select key words using upper or lower case letters
- Each word image is alone and sits on its own line
- Connect the lines starting from the central image. Lines become thinner as they radiates from the center
- Make the lines the same length as the word image
- Use colors throughout the map
- Develop your own personal style of mind mapping
- Use emphasis and show associations in your mind map
- Use radial hierarchy, numerical order, or outlines to embrace your branches

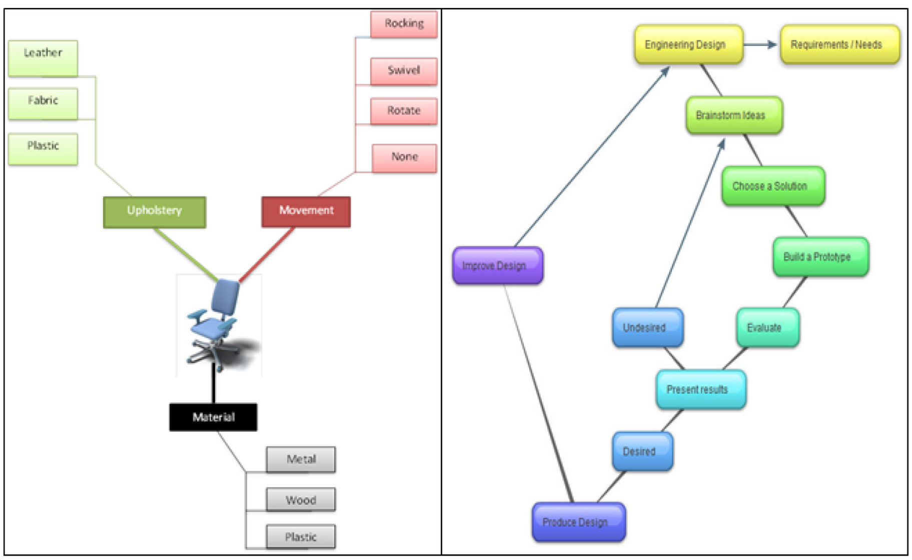


Figure 3. Examples of mind maps generated by pre-service teachers.

While the overall goal of using concept and mind mapping techniques are similar, Davis (2011, p. 280) asserts that mind mapping "allows students to imagine and explore association between concepts while concept mapping allows students to understand the relationship between concepts and hence understand those concepts themselves and the domain in which they belong." Concept mapping is the more flexible of the two and is researched and used more often in the classroom. Regardless of which type of mapping technique used, both can be useful techniques in aiding the researcher, teacher, and student learn and apply engineering and technology concepts and practices to solve problems.

Applying Cognitive Mapping in Research Methodologies

As engineering design becomes more prominent in technology education curricula, educational researchers should seek creative and constructive methods for studies in design cognition (Petrina, 2010; Lewis, 2005). Cognitive mapping has been used successfully as a tool for analysis in both qualitative and quantitative research. An examination of these methods may illuminate technology education researchers on how this technique can be employed in research.

Quantitative Analysis

In a mixed method study that examined students' conceptualization or mental representation of Information and Computer Technology (ICT), Pearson and Somekh (2003, see also Somekh & Mavers, 2003) used concept maps to quantitatively assess students' mental representations. Description of the maps generated by students more aligned with the definitions given for mind maps, however, the methods used can still inform engineering and technology educators researchers in their analysis.

The methods employed by Pearson and Somekh entailed the initial classification of maps into a predefined number of categories followed by the scoring of each map. The scoring was performed by counting the number of links and the number of nodes for each map. Furthermore, the representational richness of each map was scored by counting the occurrence of key objects. According to Pearson and Somekh (2003, p.12), "the final quantitative analysis of the maps was undertaken by adding the items in all of the content categories together to produce a numeric score for each map which gave an approximation of its richness." In another research study Turns, Atman, and Adams (2000) used concept maps to assess an introductory human factors engineering course at the course and program levels. The maps were scored on the comprehensiveness of the included concepts, the level of detail in the map – operationalized through the number of hierarchical levels – and the complexity of the links.

In general, the types of systems used to assign metrics to concept maps can be categorized into three general scoring strategies: scoring the components of the constructed map, comparing the constructed map with a criterion map, and using a combination of both strategies (Ruiz-Primo & Shavelson, 1996). When scoring the constructed map the researcher can focus on the propositions (i.e., the amount, accuracy, and crosslinks), the hierarchy levels, and the examples. The examples are specific events or objects that are valid instances of those designated by the concept level. The scoring system may range from those that only use propositions to those that use a combination of all three. Using a criterion map allows a constructed map to be compared to a map constructed by an expert, and the overlaps between the two are scored. A content area expert can generate the criterion map or it can be an average of maps constructed by several experts. Novak and Gowin (1984) suggested a system to score concept maps (see Table 1).

Table 1
Novak and Gowin's (1984) Scoring System

Component	Description	Score
Propositions	Is the meaning relation between two concepts indicated by connecting the link and linking word(s)? Is the relation valid?	1 point for each meaningful, valid proposition shown. 5 points for each valid level of the hierarchy
Hierarchy	Does the map show hierarchy? Is each subordinate concept more specific and less general than the concept shown above it (in the context of the material being mapped)	5 points for each valid level of the hierarchy
Crosslinks	Does the map show meaningful connections between one segment of the concept hierarchy and another segment	10 points for each valid and significant crosslink. 2 points for each crosslink that is valid but does not illustrate a synthesis between concepts and propositions
Examples	Specific events or objects that are valid instances of those designated by the concept level	1 point for each example.

Qualitative Analysis

It is likely that the use of cognitive mapping techniques finds more value in qualitative research. According to Miles and Huberman (1994) cognitive maps can be used in qualitative research for individual level analysis to display the complexity of a person's thinking. As cognitive processes are not typically organized linearly, the flexibility in the structure of cognitive maps allows researchers to make observations about participants' thought processes. As a technique, cognitive mapping can help researchers to understand the cognitive processes of students in engineering design and other types of technological problem solving. It offers engineering and technology researchers an additional approach for analyzing qualitative data obtained from interviews, focus groups, and observations. According to Hathaway and Atkinson (2003), these creative means of engagement produce maps to probe the "backstage" of participants' experiences and perceptions, and represent a new strategy that seeks to go beyond soliciting "a rehearsed form of narrative that precludes more spontaneous answers" (p. 162). Wheeldon and Faubert (2009) indicated that the front-end visual construction of a participant's experience captured in a map can enable researchers to more specifically design subsequent stages of data collection and use participant-generated themes to help guide more in-depth analysis. These researchers asserted that cognitive mapping offer a means of gathering further unsolicited reflections providing a visual snapshot of the data in which to ground theory. This can aid researchers in refining subsequent data collection strategies.

Representing and communicating data and themes. The benefits of using cognitive maps are also rooted in the need for credible and trustworthy methods of analyzing voluminous text data. According to Daley (2004, p.1),

> …often qualitative studies describe the data analyses as a process of reading and re-reading transcripts until themes emerge. This type of description makes it difficult for subsequent researchers to understand not only the analysis process, but to understand where and how the findings have emerged from the data.

There is also the potential to utilize cognitive maps in more creative ways to analyze qualitative data. For example, Wheeldon and Faubert (2009) opined that limiting oneself to the traditional definition of mind or concept map could deny researchers of creative means to identify themes in qualitative research. These definitions constrain concepts maps to include clear and unique concepts, lines suggesting hierarchical relationships, and linking words. For example, the cognitive map depicted in Figure 4 lacks a clear hierarchy, linking words, and directional arrows, yet it offers a view of the individual's understanding. It might not be appropriate to attempt to use this concept map alone to understand how an individual perceives the origin of his or her values, but the way in which the map is constructed might give way to more qualitative coding schemes or assist in the development of subsequent data collection approaches including interviews and focus groups (Wheeldon & Faubert 2009).

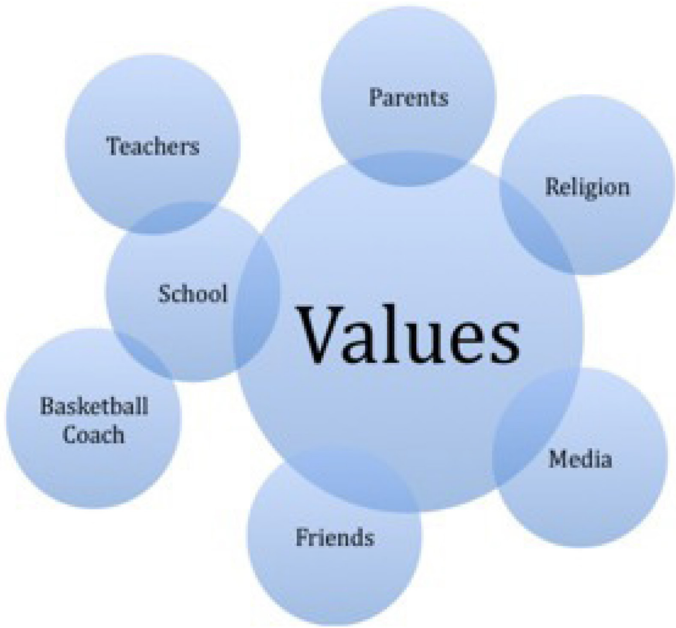


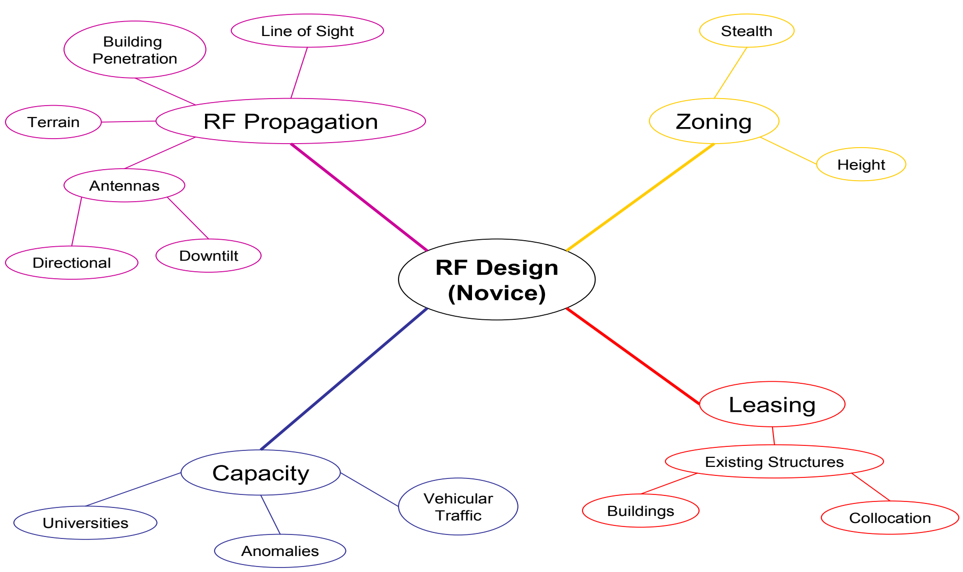
***Figure 4*.** Free form concept map: where do your values come from (Wheeldon & Faubert, 2009)

Cognitive maps can help qualitative researchers in the methodological challenge to reduce data to a manageable form without losing the embedded meaning. Cognitive mapping techniques such as concept maps allows the researcher to: reduce the data in a meaningful way by providing visual identification of themes and patterns on a limited number of pages, identify overarching themes and their interconnected concepts, and present the findings of a qualitative research study as a graphical display so that readers can understand the findings and see how actual data quotes are connected to larger parts of the study.

As a technique to illustrate the complexity of students thinking in engineering design problem solving, cognitive maps can be used to depict how students categorized concepts in system design problems and capture patterns and themes in the cognitive strategy used by both novice, advance beginners, and expert problem solvers. Maps produced from these studies often reveal significant differences in the maps constructed by experts and those constructed by novices, differences that can inform curricula content and instructional strategies to improve students' proficiency in problem solving (Markham & Mintzes, 1994; Williams, 1998).

Categorizing concepts. Design problems are highly variable and complex, requiring a higher level of thinking. When solving system design problems students must meet desired needs within realistic economic, environmental, social, political, ethical, health and safety manufacturability, and sustainability (ABET, 2011). In research, transcripts from students' think aloud protocols can be analyzed using hierarchical concept maps to help researchers understand how students organize and categorize concepts, constraints, and strategies to reach acceptable solutions. Rich insight into students' complex thinking processes can be gathered as their maps are compared with those of experts or more proficient problem solvers.

Patterns and themes. Both cognitive mapping techniques can be used by engineering and technology researchers to understand the pattern and identify the themes reflected in the cognitive process of expert problem solvers. For example, in one study that used think aloud protocols, Lammi and Thornton (2013) asked a novice and an expert engineer to design a new wireless network. Constraints were placed in the design challenge to create a realistic ill-defined scenario. The designers had limited capital, variable cellular traffic venues, and were up against strict zoning laws. A three dimensional aerial map overlaid with major and minor transportation thoroughfares was given to the engineers to aid in their design.



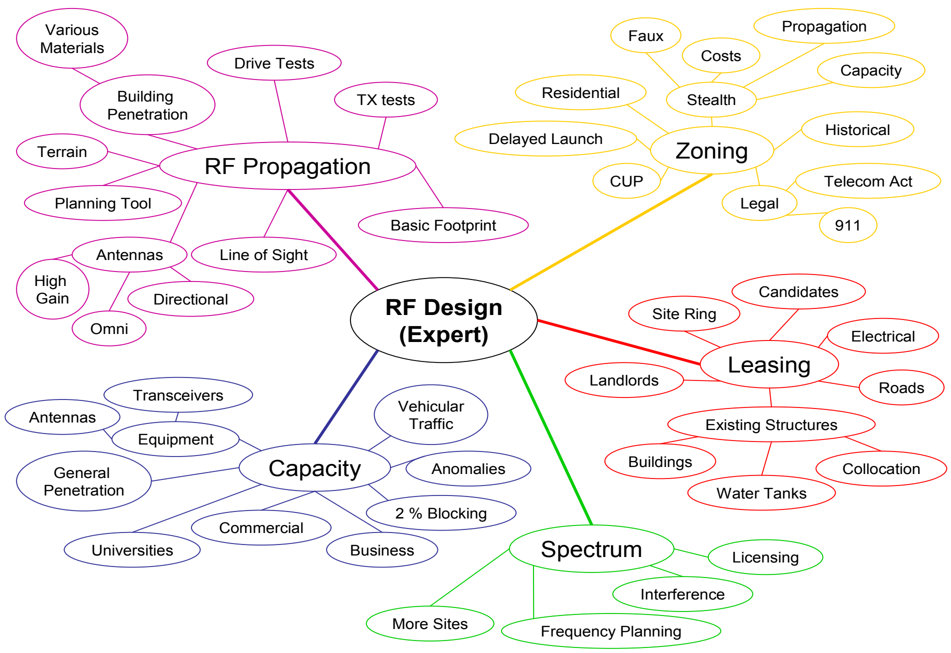


Figure 5. Novice and expert's RF design mind maps of a design problem

This study used verbal or "think aloud" protocol to gather the participants' thoughts as they were performing their tasks. The audio data was broken into units or segments. The segments were then coded into distinct mental processes used in engineering design. The findings indicated certain patterns. For example the both novice and expert used a top-down approach to solve the problem and to evaluate and visualize their design against the various constraints. The cognitive maps captured disparities in the knowledge of the novice revealing that he displayed less breadth and depth of the problem knowledge and unlike the expert, failed to allude to or mention spectrum considerations (see Figure 5).

Revisiting the mixed method research mentioned previously, Pearson and Somekh (2003) asked children who were participants in the study to use concept maps to communicate their ideas about information and communications technology (ICT). A qualitative analysis of the maps drawn by each students indicated that ten year old children have well-developed representations of ICT, suggesting that they are in an ideal position to acquire a range of skills in the use of ICT provided they have access to tools and would be capable of using these tools to support their own learning.

Dixon (2010) used think aloud protocol to examine ten mechanical engineers solving of a design problem. Six were students and four were professional mechanical engineers with many years of practice.

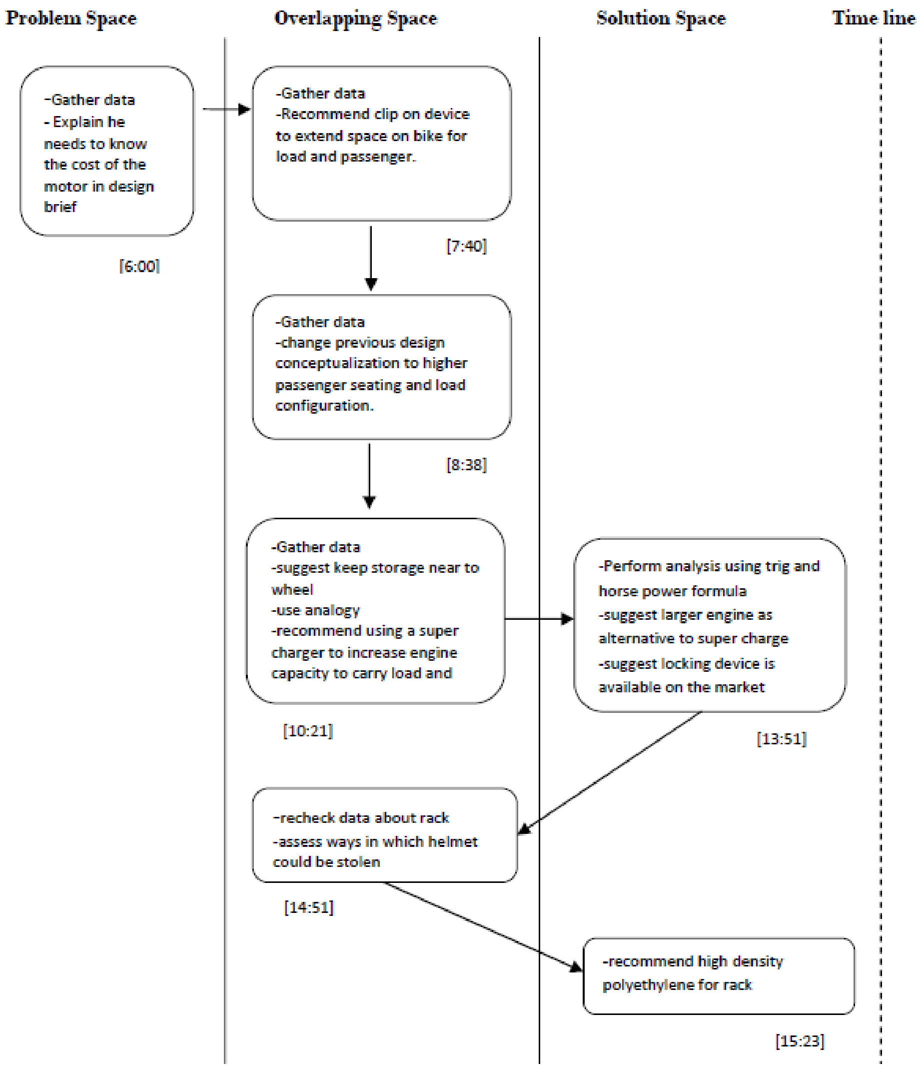


Figure 6. Cognitive map depicting how and when a professional engineer navigates the problem solution and overlapping spaces during the solution of a design problem.

Their think aloud protocols were recorded, transcribed, and coded. One of the goals of the research was to determine how the expert and novice navigated the problem space, solution space, and the overlapping space (the space where information is interchanged between the problem and solutions spaces as they co-evolve). Cognitive maps were used at individual level analysis to explore how and at what stage of the design solution the novice and experts navigated the problem, solution, and overlapping spaces (see Figure 6). These cognitive maps supplemented other qualitative data analysis methods to established patterns in the novice and experts problem solving strategy. For example, the study showed that one pattern common between both groups was the iterative process that was reflected by going back and forth between the problem space and solution space. They both checked with the design brief or asked questions to verify or increase their understanding of the problem. This often led to the emergence of a different or modified conceptualization of the problem.

The maps also illustrate there were some difference in the pattern of exchange between the problem and solution spaces of the engineering student and professional engineer that took the shortest time to solve conceptual design problem. The patterns however, for the engineering student and professional engineer who took the longest time were more similar. Overall, the cognitive maps patterns showed that the engineering students spent less time than the professional engineers gathering and rechecking data regarding constraints, criteria, and other information that they considered relevant from the problem space.

Cognitive mapping allows the qualitative researcher to represent and communicate complex concepts and cognition, structure and adapt methodology, categorize salient concepts, and enhance thematic analysis. However, a disadvantage of concept maps in qualitative work is that analysis can become time consuming and the maps can be difficult to read by persons who are not acquainted with the format and as the maps becomes denser the linkages are harder to see (Miles & Huberman, 1994). Despites these disadvantages, cognitive maps can be used in conjunction with other methods of data analysis to provide a more complete picture of the cognitive process and strategies, especially those in engineering design cognition.

Conclusion

As engineering design receive more attention in technology education curricula, the strategies used by technology educators to teach will improve as the number of research that examine the cognitive strategies used by students increases. Using cognitive mapping techniques to supplement other types of data analysis technique is one way technology education researchers can apply creative and constructive methods for studies in design cognition. Not only do cognitive mapping techniques help qualitative researchers in the methodological challenge to reduce data to a manageable form without losing the embedded meaning, if used creatively they can allow researchers to see unique themes or patterns used in design problem solving.

With the appropriate application of metrics, cognitive maps can also be used in quantitative data analysis. The examples highlighted in this paper illustrate how cognitive mapping techniques can be used effectively for quantitative data analysis. Its strength, however, exists in how it is able to aid the researcher to qualitatively analyze voluminous transcribed text data from expert and novices designers. While analyzing cognitive maps can be time consuming, properly constructed maps can illustrate how students categorize design concepts, display patterns in their cognitive strategy, and identify themes that emerge from the solving of design problems.

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Mathematics in Technology & Engineering Education: Judgments of Grade-Level Appropriateness

Introduction

Persistent calls to eliminate the fragmentation of science, technology, engineering, and mathematics (STEM) education advocate for the realignment of the U. S. educational structure toward one that is standards-based and nationally coordinated (Presidents' Council of Advisors on Science and Technology, 2012; National Science Board, 2007). Such coordination presupposes the capacity to vertically align STEM standards across grade levels and to horizontally connect these standards into integrated learning experiences at a single educational level. To achieve these horizontal and vertical connections, knowledgeable and inspired educators will be needed who both understand the essential concepts and standards of multiple disciplines and who can create symbiotic pathways that mutually enable students to meet standards of two of more disciplines.

Loepp (2004) judged that of the standards in science, technology and mathematics, "the mathematics standards have been the most useful for those who develop curricula" (p. 7). Furthermore, mathematics standards provide technology and engineering (TE) teachers and teacher educators with a framework to gauge alignment and promote coherence in school curriculum. However, it is not clear to what extent TE professionals—teachers, teacher educators, and curriculum developers—are able to use mathematics standards to infuse mathematics at a known grade level into TE curriculum. This study attempts to characterize the ability of TE professionals to identify the grade level of mathematics standards and of mathematics integrated into technology learning activities.

Background

Technology and engineering educators have long championed the infusion of mathematics into technology curriculum (e.g., Maley, 1987), especially to enhance TE learning goals and demonstrate "connections between technology and other fields of study" as specified in Standard 3 from the *Standards for Technological Literacy* from the International Technology Education Association (ITEA, 2007, renamed the International Technology & Engineering Educators Association, ITEEA). Notably, LaPorte and Sanders (1993) employed technological problem solving activities as a practical and motivating context for integrating mathematics (e.g., graphing, proportion, volume calculation, and unit

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conversion). Even difficult mathematical constructs, such as predictive analysis, have reportedly been, "better understood" by students when they were "connected to solving a problem or building an artifact" (Merrill, Custer, Daugherty, Westrick, and Zeng, 2008, p. 61). More recently, scholars have argued that engineering design is the appropriate context for integrating mathematics into technology curriculum (Daugherty, Reese, & Merrill, 2010).

Merrill and Comerford (2004) and Litowitz (2009) urged TE educators to directly address mathematics standards from the National Council of Teachers of Mathematics (NCTM, 2000) as they develop and implement curriculum. NCTM standards are divided into five mathematical content areas (number and operations, algebra, geometry, measurement, and data analysis and probability) and five process areas (problem solving, reasoning and proof, connections, communications, and representation). Similar to the Standards for Technological Literacy (ITEA, 2007), each standard is further defined by sets of NCTM benchmarks, referred to as expectations. These 223 NCTM expectations indicate the achievement expectations for one of four grade levels, including P-2, 3-5, 6-8, and 9-12.

Several obstacles may hinder the horizontal and vertical infusion of mathematics in TE curriculum, such as the historical professional preparation of TE teachers, teachers' knowledge of mathematics and standards, and numerous examples of below-grade mathematics in TE. McAlister's (2005) examination of technology teacher preparation programs in the U.S. indicated the level of mathematics required in 24 (of 44) programs. He noted that "Project Lead The Way requires Teacher Education programs to require at least one course beyond College Algebra. Using that standard, 58% of the participating programs offer a level of mathematics to prepare them to effectively introduce pre-engineering concepts under the PLTW model" (p. 4). Only four of the 24 programs in McAlister's study required undergraduates to study calculus. Furthermore, Gattie and Wicklein's (2007) survey of inservice TE teachers suggests that that practicing TE teachers perceive both their "knowledge of mathematics" and their ability "to integrate appropriate levels of mathematics into instruction" as a professional development need (p. 13). This suggests that some practicing TE teachers may not be well-prepared to identify grade-appropriate mathematics.

Another obstacle may be that examples of TE literature and curriculum overemphasize below grade-level mathematics. For example, when taking work measurements, high school manufacturing students calculated the arithmetic average of work measurements to inform decisions about tool purchases, workstation design and production flow (Rose, 2007a, p.10). Rather than high school level mathematics, calculating a mean fits the Grade 6-8 mathematics expectation: "find, use, and interpret measures of center and spread, including mean and interquartile range" (NCTM, 2000, p. 248). Including below-grade level mathematics in TE may promote transfer of knowledge and skills learned in mathematics lessons in previous years to technical contexts. But synergistic gains of grade-level integration are not realized if the mathematics is only or predominantly below grade level. Michael (1990) looked at junior high school students in physical science, concluding that "the most important variable for Physical Science success, aside from ability, is the LEVEL of mathematics studied" (Abstract).

Thus, there is a need for curriculum development and professional development initiatives to purposefully pursue strategies to infuse mathematics content at grade level within TE curriculum. Burghardt, Hecht, Russo, Lauckhardt, and Hacker (2010) did this when they examined the use of mathematical Knowledge and Skill Builders (KSB)—a series of short, focused tasks that reinforced middle school students' conceptual knowledge of mathematics at their grade level—as part of a Bedroom Design challenge. Using a pre/posttest control group design, the KSB groups showed statistically significant higher mathematics knowledge scores than those who did not participate in the infused curriculum. Furthermore, Bottge, Grant, Stephens, & Rueda (2010) looked at fractional computation and procedural fluency for fractions with middle school students. They found that purposefully integrating grade-appropriate mathematics using *enhanced anchored instruction* into TE allowed "technology education teachers [to] make important contributions in helping students develop their computation and problem-solving skills" (p. 81). Both of these studies involved strong professional development for teachers prior to these teachers delivering mathematics-infused TE instruction.

Unanswered in the literature is the question of how accurately TE professionals identify the grade level of mathematics, either by identifying the grade level for an expectation in mathematics or by identifying the grade level of mathematics when it is contextualized in a TE student activity. Furthermore, how much of the mathematics in TE do these teachers recommend be below, at, or above grade level?

Methods

The purpose of this exploratory study was to characterize the accuracy of TE professionals─curriculum developers, teacher educators, state supervisors, and teachers─ in judging the grade-level of mathematics. An online survey was employed to address the following research questions:

1. To what extent do TE professionals report being familiar with NCTM standards?
2. Given an NCTM expectation, how accurately do TE professionals classify it by grade level?
3. Given examples of mathematics in TE education, how accurately do TE professionals identify the mathematics grade level (per NCTM expectations)?
4. Are there differences among TE professionals by role in terms of their ability to correctly classify NCTM expectations and mathematics in TE education?

This study was supported in part by a Research Incentive Grant from the Council on Technology Teacher Education. Professionals who develop TE curriculum or deliver either teacher education or professional development opportunities for preservice and practicing teachers may find this information valuable for informing programmatic decisions.

Instrument

A researcher-produced questionnaire included sections on demographics, familiarity with math standards and the teaching of mathematics in TE, NCTM expectations, and examples of mathematics integrated within TE activities. Fifteen expectations were randomly selected from the 3-5, 6-8, and 9-12 grade levels, three for each of the five NCTM content areas (process areas were omitted to provide a narrower focus). Respondents were asked to judge whether each item best fits in the Pre-Kindergarten-2, 3-5, 6-8, 9-12, or College level, thus allowing over- or under-estimation for any item by respondents. Preliminary examples of mathematics integrated into TE activities were adapted from the TE literature (the last five years of *The Technology Teacher* and *Tech Directions* magazines) and published curriculum (*Engineering byDesign*™). Working individually and with reference to NCTM (2000), three practicing, licensed mathematics teachers read 30 examples of mathematics in TE activities and selected the NCTM expectation from across all grade levels best-matching the item. Fifteen items that received 100% agreement on the grade level were included on the final questionnaire, which served to validate this section. A readability test of the entire instrument with two TE educators informed revision.

Sampling

After Institutional Review Board approval, a snowball sampling strategy was used to recruit TE professionals. Initial calls for participation were distributed to the Council on Technology Teacher Education listserv, ITEEA Council of Supervisors, state TE associations, and *Stem Connections*, a digital newsletter for ITEEA members. The initial email asked recipients both to take the online survey and to distribute the call for participation through their own email distribution lists. The survey was open for three months in fall 2011.

Limitations

Being self-selected, this sample is likely to differ from the population of TE professionals regarding knowledge and opinions related to mathematics. No generalizations to this population are intended for what should be seen as an exploratory study.

In recent years, a newer set of secondary school standards referred to as Common Core standards was released in June of 2010 and has been adopted by 45 states (Common Core Standards Initiative, n.d.). Because teachers would not be expected to have much familiarity with these new standards at the time of the present study, a decision was made to use the NCTM standards.

Results

There were 168 usable surveys received from respondents who were located in 37 U. S. states. By professional role (Table 1), respondents were mostly high school teachers (38%), middle or junior high school teachers (23%), and teacher educators (19%.) The typical respondent was male (83.3%) with 15 years of teaching experience, and reported teaching one K-12 engineering course. Fifty-three percent of respondents reported having had four years of high school mathematics with an additional 13% having taken advanced placement (AP) mathematics in high school. During college, 67% had completed college algebra and 48% had completed calculus (Table 2).

Table 1

Characteristics of Respondents

	Respondents		Female		Years Teaching Experience		K-12 Engineering Courses Taught	
Role	*n*	%	*n*	%	Median	IQR	Median	IQR
Elementary	2	1.2%	2	100%	3	2	0.5	1
Middle/JH	38	22.6%	7	18.4%	14.5	15.75	1	3
High School	64	38.1%	10	15.6%	14	15	2	3
CTE	13	7.7%	3	23.1%	10	13.5	2	3.25
Teacher Educator	32	19.0%	2	6.3%	19	20	0.5	2
Supervisor	15	8.9%	2	13.3%	14	11	2	4
Curr. Developer	2	1.2%	1	50.0%	27	4	2.5	5
Other	2	1.2%	1	50.0%	9.5	3	2	0
TOTAL	168	100%	28	16.7%	15	16	1.5	3

Table 2
Type of Math Course Completed in College by Role of Participant (Multiple Responses were Possible)

		None		General		College Algebra		Calculus		Statistics	
Role	*N*	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Elementary	2			1	50	2	100				
Middle/JH	38	1	3	15	39	25	66	15	39	19	50
High School	64	1	2	23	36	43	67	40	63	27	42
CTE	13			5	38	11	85	5	38	7	54
Teacher Ed.	32	1	3	8	25	20	63	12	38	23	72
Supervisor	15			5	33	10	67	7	47	8	53
Curr. Developer	2			1	50	1	50			2	100
Other	2			1	50	1	50	1	50		
TOTAL	168	3	2	59	35	113	67	80	48	86	51

As shown in Table 3, respondents reported being “somewhat unfamiliar” (median=2) with the *Principles and Standards for School Mathematics* (NCTM, 2008). With the exception of elementary teachers who had low participation, teacher educators reported greater familiarity with the NCTM standards than other roles. Overall, respondents reported that approximately 30.7% (mean) of the lessons they give in TE contain instruction in math with higher average reported by high school teachers (34.5%) than by other teachers.

Table 3
Respondents' Reported Familiarity with NCTM Standards, Instruction Containing Math, and Recommended Grade Level of Math in TE

	Reported NCTM Familiarity[a]			Instruction in T&E Lessons Contains Math[b]			Recommended Grade Level of Mathematics in TE[c]		
Role	*n*	Median	IQR	*n*	Mean %	SD	*n*	Mean %	SD
Elementary	2	4	2	2	22.5	3.5	2	-12.5	10.6
Middle/JH	38	2	2	38	27.1	24.7	32	-12.6	29.9
High School	64	2	1.75	63	34.5	28.0	59	-7.0	22.6
CTE	13	2	1.5	13	28.1	24.7	13	-12.7	32.8
Teacher Ed.	31	3	3	31	26.9	24.7	32	-12.7	6.5
Supervisor	15	2	2	15	35	24.7	13	-4.6	17.7
Curr. Dev.	2	2.5	3	2	47.5	38.9	2	25.0	21.2
Other	2	2	0	2	15.0	14.1	2	5.5	6.4
TOTAL	167	2	2	166	30.7	25.9	155	-9.1	26.6

Note. [a] Likert Scale of Reported Familiarity with 1=No Familiarity and 5=Extremely Familiar. [b] Percentage of the courses taught by the respondent that reportedly contain instruction on math. [c] The mean difference between the percentages of mathematics in TE recommended above grade level and below grade level.

Respondents were asked, "What percentage of the mathematics in technology education should be below, at, or above the student's current grade level?" Overall mean percentages were 25% recommended below-grade, 59% recommended at-grade, and 16% recommended above-grade. Subtracting the recommended percent below-grade from the recommended percent above-grade provides a variable for the net difference. The overall net difference was -9.1%, interpreted to mean that on average respondents suggested about 9% more math content should be below grade level than above grade level in TE. This indicates an approach that favors using TE to reinforce grade-level math, to a lesser extent to address below-grade level math, and to an even lesser extent to introduce higher level math.

A broad range of responses was received from the item asking: "What are the most complex mathematical concepts you teach in your technology and engineering classes?" Researchers coded all responses into the following mathematics topics: algebra (59.5%), general mathematics (49.4%), trigonometry (31.6%), geometry (28.5%), statistics (10.1%) and calculus (6.3%). Among these examples, 27.8% of the respondents offered examples that may be described as physical science principles without reference to the mathematics involved, including references to fluid dynamics, drag, Ohm's Law, mechanics, and Boyle's Law. This suggested a possible misunderstanding about the distinction between physics and mathematics.

Classifying Expectations

Respondents were asked to classify each of 15 NCTM expectations according to grade level (Table 4, continued on next page). The average accuracy of respondents for all items was 40.1% correct, with underestimates by one (21.7%), two (5.5%) and three grade levels (0.4%) nearly mirroring the overestimates by one (22.2%), two (9.0%), and three (1.2%) grade levels. Across the fifteen expectations, the average respondent had 1.47 more instances of overestimation by a grade level than underestimation.

Table 4

Respondents' Grade Level Assignment of NCTM Expectations

		Grade Level				
NCTM Expectations	Correct	P-2 *f*	3-5 *f*	6-8 *f*	9-12 *f*	13+ *f*
Develop fluency in adding, subtracting, multiplying, and dividing whole numbers	73.9% ↓ n=165	30	**122**[a]	10	3	0
Understand and represent translations, reflections, rotations, and dilations of objects in the plane by using sketches, coordinates, vectors, function notation, and matrices	62% ↓ n=166	0	7	30	**103**[a]	26
Model and solve contextualized problems using various representations, such as graphs, tables, and equations	53.6% ↑ n=166	2	25	**89**[a]	47	3
Use factors, multiples, prime factorization, and relatively prime numbers to solve problems	51.8% ↓ n=166	3	55	**86**[a]	20	2
Solve simple problems involving rates and derived measurements for such attributes as velocity and density	49.4% ↑ n=166	0	11	**82**[a]	72	1
Compute and interpret the expected value of random variables in simple cases	44.6% ↓ n=166	1	20	58	**74**[a]	13

Understand such attributes as length, area, weight, volume and size of angle and select the appropriate type of unit for measuring each attribute	43.1% ↑ n=167	9	**72**[a]	79	7	0
Develop fluency in operations with real numbers, vectors, and matrices, using mental computation or paper-and-pencil calculations for simple cases and technology for more complicated cases	41.9% ↓ n=167	3	20	67	**70**[a]	7
Recognize and apply geometric ideas and relationships in areas outside the mathematics classroom, such as art, science, and everyday life	36.4% ↓ n=165	26	52	**60**[a]	27	0
Discuss and understand the correspondence between data sets and their graphical representations, especially histograms, stem-and-leaf plots, box plots, and scatterplots	34.1% ↑ n=167	1	14	**57**[a]	75	20
Use symbolic algebra to represent and explain mathematical relationships	32.3% ↓ n=167	3	16	88	**54**[a]	6
Explore congruence and similarity	31.1% ↑ n=167	25	**52**[a]	62	27	1
Analyze precision, accuracy, and approximate error in measurement situations	30.4% ↓ n=168	3	42	71	**51**[a]	1
Propose and justify conclusions and predictions that are based on data and design studies to further investigate the conclusions or predictions	10.8% ↑ n=166	3	**18**[a]	47	77	21
Identify and describe situations with constant or varying rates of change and compare them	6.6% ↑ n=167	3	**11**[a]	61	84	8

Note. [a] Grade level for each NCTM expectation. ↓ Net underestimation. ↑ Net overestimation.

There were five 9-12 expectations, all of which had net underestimation, as shown by the negative values in Table 5; four of the five 3-5 expectations were overestimated. All three expectations taken from the Numbers & Operations standard were underestimated. The Grade 3-5 expectations for Data Analysis and Probability and for Algebra were overestimated more than one grade range (i.e., as 9-12).

Table 5
Number of Grade Ranges Under- and Overestimated for Selected NCTM Expectations

	Grade Level		
	3-5	6-8	9-12
Standards Area	Mean	Mean	Mean
Numbers & Operations	-.103	-.213	-.665
Algebra	+1.516	+.142	-.729
Geometry	+.561	-.465	-.077
Measurement	+.477	+.387	-.961
Data Anal. & Probability	+1.581	+.619	-.523

As noted in Table 4, four expectations had over 50% correct classification by respondents. The highest accuracy for any item occurred for a Grade 3-5 expectation; 73.9% of respondents accurately classified "Develop fluency in adding, subtracting, multiplying, and dividing whole numbers." The lowest accuracy occurred for a Grade 3-5 expectations; only 6.6% (n=11) of respondents accurately classified "Identify and describe situations with constant or varying rates of change and compare them across this same range" with most respondents overestimating by one (36.5%), two (50.3%) or three (4.8%) grade levels. The most commonly underestimated item was a Grade 9-12 expectation: "Analyze precision, accuracy, and approximate error in measurement situations." This was accurately classified by 34% of respondents, but 69% underestimated grade level (by one (42.3%), two (25.0%), and three (1.8%) levels.

Level of Math in Technology & Engineering Activities

In the last portion of the survey, respondents were asked to classify 12 learning activities according to the highest grade level of math that would be used to complete the activity (Table 6). Each of these had been independently coded by three licensed mathematics teachers who consulted NCTM standards. Only items with unanimous agreement among coders were used, and the coders' results are referred to as "correct."

Table 6
Estimates of Mathematics Grade Level Within TE Activities

Activity (many had illustrations)	Correct	Grade Level P-2	3-5	6-8	9-12	Col.
Find the impedance Z of a circuit with 20W of reactance X_L represented by the vector diagram.	74.3%↑ *n* = 167	0	1	18	**124**[a]	24
A twin-engine airplane has a speed of 300 mi/h in still air. Suppose the airplane heads south and encounters a wind blowing 50 mi/h due east. What is the resultant speed of the airplane? To solve, find the sum of the vectors that represent the speed of the airplane and the speed of the wind.	69.0%↓ *n* = 168	0	2	30	**116**[a]	20
Now that you know your vehicle's time-trial speed, determine how far your vehicle would travel at that speed if it ran for one minute.	62.5%↑ *n* = 168	1	30	**105**[a]	30	2
Using a line graph, "students will determine the class of mathematical functions (linear, quadratic, or exponential) representing an aspect of technological change.	55.1%↓ *n* = 167	1	13	52	**92**[a]	9
As indicated in this bar chart, "how did the number of computer tomography (CT) scanners in the United States compare to the median number in the world in 2002? State as an approximate ratio.	52.4%↑ *n* = 168	1	17	**88**[a]	56	6
Working in teams, students produce a working radio-controlled watercraft….During the testing phase, students find the total mass of the boat (in grams), the density of the hull (D=M/V in g/ml), and the mass of the hull (calculate area and then displacement of the water).	51.2%↑ *n* = 168	0	9	**86**[a]	69	4
Multiple Choice: Americans recycle increasing amounts of waste through municipal waste collection. The table shows waste collection data for 2007. What is the probability that a sample of recycled waste is paper? A. 16%; B. 28%; C. 33%; D. 57%.	44.9%↑ n = 167	0	16	**75**[a]	68	8

To construct your tower, roll rectangular sheets of paper into cylinders to create structural members.	42.8%↑ n = 166	28	**71**[a]	54	12	1
A carpenter builds three boxes. One box uses 12 nails. The second box uses 6 nails and 6 screws. The third box uses 8 screws and 2 hinges. Nails cost $.04 each, screws cost $.06 each, and hinges cost $.12 each. 1. Write a matrix to show the number of each type of hardware in each box. 2. Write a matrix to show the cost of each type of hardware. 3. Find the matrix showing the cost of hardware for each box.	33.3%↓ n = 168	1	27	80	**56**[a]	4
After using a Boyle's Law apparatus or computer simulation to collect pressure and volume readings, students "create a graph from the data collected, with the 'y' axis being Volume and the 'x' axis being Pressure.	8.9%↑ n = 168	0	**15**[a]	73	71	9
Numerically Controlled (NC) Mill Problem: Engraving your Name. Step 1. Plot the first letter of your name on an x/y coordinate grid and label the coordinates of the key points.	6.6%↑ n = 167	1	**11**[a]	83	68	4
One step in completing the flexural test of a panel is to plot your findings on a data table. "Plot the weight (W) on the abscissa (x coordinate) and the sag (S) on the ordinate (y coordinate).	6%↑ n = 168	0	**10**[a]	62	75	21

Note. [a] Grade level for the mathematics from coders using NCTM standards. ↓ Net underestimation. ↑ Net overestimation.

Overall, respondents classified 42.2% of the items correctly, i.e., at the same grade level as did the mathematics teachers (Figure 1). There was moderate net overestimation among respondents with an average of 4.6 more overestimates per person than underestimates. It should also be noted that less than 10% accuracy was shown for three items, all of which were coded at the Grade 3-5 level. As shown in Table 6, these three items required students to graph variables on a coordinate grid system. Furthermore, respondents overestimated the grade level of these three items by 1.4 to 1.6 grade levels on average.

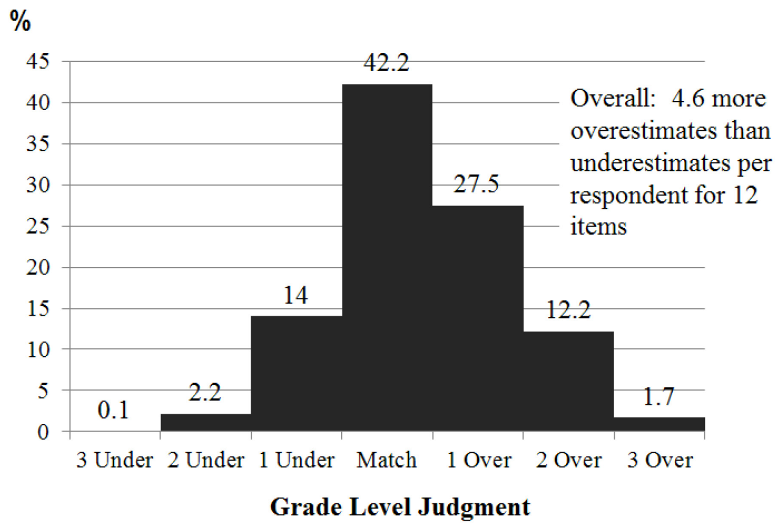

Figure 1. Accuracy of respondents' grade level judgment of mathematics within TE activities.

Conclusions and Discussion

Successfully integrating mathematics into TE curriculum and instruction is a complex endeavor. It requires skilled TE teachers and curriculum designers who can strategically infuse mathematics content into compelling technology-based learning experiences. Mathematics standards provide a ready framework to guide teachers in coordinating their efforts with other STEM educators.

This exploratory study sought to describe the familiarity of TE professionals with the grade level of NCTM standards and of mathematics integrated into student learning activities. An online survey of TE professionals was completed by a convenience sample. These 168 respondents likely had a greater preparation in high school and college mathematics than the broader population with almost 50% reporting they had taken calculus. Thus, generalizing these results to the TE education community is not warranted. Few differences were found among professional roles of respondents (e.g., high school teachers, teacher educators).

Reported familiarity with NCTM standards was moderately low. This was also confirmed by the selection of *College* as a possible category for an NCTM expectation in some instances, even though they are P-12 expectations, and suggests a need for professional development in this area, thus supporting Gattie and Wicklein's (2007) findings. Respondents accurately classified NCTM expectations by grade level about 40% of the time. Seven of fifteen expectations were consistently underestimated, and seven were consistently overestimated; there was slight, net overestimation. However, when mathematics was contextualized within TE student activities, the level of mathematics in the majority of items was overestimated compared to the grade level determined by coders using NCTM standards, which may have several explanations. First, in some instances, TE courses may have traditionally served non-college bound students, conditioning teachers to overestimate grade level. Second, there may be interference due to the more advanced level of the technical content. For example, a student activity involving a milling machine may not be classified as a 3-5 activity, and by association, any mathematics in that activity may also be deemed at the grade level of the technical content. Third, the vocabulary of mathematics may contribute to overestimation. For example, the term *abscissa* may be found in an activity that only calls for primary school mathematics, even though the word might not seem to be primary school level vocabulary. Respondents also indicated that an average of 9% more mathematics instruction within TE *should* be below grade level than above grade level (Table 3). This finding may exacerbate the problem of overestimating noted above.

Underlying the issue of integrating mathematics into TE is the teacher's uncertainty about the level of the mathematics to be integrated. It may be appropriate to integrate below-grade level math when encountering complex technical tasks because it relieves cognitive energies for the more complex tasks. Furthermore, situating mathematics within technical design and problem solving may improve a student's ability to apply what they are learning in a new setting. The integration of at-grade level mathematics offers several advantages. The coordinated timing of mathematics across courses may enhance students' retention, provide a less fragmented approach to schooling, and speed conceptual understanding. Above-grade level mathematics may by the trickiest as it can lead to frustrations and non-engagement by students. However, it can also serve to inspire, enrich, and motivate students to reach beyond their grade level.

This study looked at grade *ranges*. This obscures whether particular mathematics content has or has not yet been mastered by a particular student, which seems more pertinent in deciding whether the inclusion of mathematics in TE is and should be remedial, reinforcing, or enriching.

Recommendations

Much work remains to be done if TE professionals are to contribute consistently to students' mathematics achievement. Given that teachers' knowledge of mathematics and their knowledge of pedagogy have been shown to influence high-quality teaching and student learning (Baumert, et al., 2010), TE teacher preparation programs and professional development should provide more extensive opportunities for both preservice and inservice teachers to develop mathematics knowledge and learn how to use effective strategies to teach mathematics that is embedded within the TE curriculum. Increasing TE teachers' familiarity with mathematics standards at all grade levels may help to reduce the gap between their estimation of mathematics grade level and the actual grade level of that mathematics, and possibly increasing the coherence of the school curriculum and student achievement. As schools shift to Common Core or other standards, professional development initiatives should empower TE teachers to understand and use mathematics standards in designing, implementing, and evaluating their programs. For example, TE teachers may partner with math teachers to map the intersections of math concepts [and standards] within existing technical curriculum (Stone, Alfeld, & Pearson, 2008). Because TE and mathematics teachers can have different understandings of key concepts (Rose, 2007b), this collaboration may help in reaching shared understandings that allow teams of teachers to work together to best enhance student achievement.

Teacher educators, providers of professional development, curriculum developers and authors should help preservice and inservice teachers to become acutely aware of the level of mathematics that is integrated into their TE instruction, by increasing their understanding of mathematics standards. Curriculum developers should be aware of a possible tendency among TE professionals to overestimate the grade level of mathematics and are advised to overtly identify the grade level of mathematics in integrated curriculum.

Given this exploratory study, future research characterizing TE professionals' estimates of mathematics grade level are advised to use probabilistic sampling so that results could be generalized to the population. A future study could examine the conditions under which TE teachers learn how to select and integrate mathematics and other subject areas in their classrooms that is below, at, or above the grade of their students, perhaps by using the Common Core standards as an authority on grade level. While the present study looked at levels containing multiple grades (e.g., 9-12), an interesting issue for future research would be whether the mathematics represents something the student has learned, is learning, or has yet to learn in a mathematics course.

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Self-Report and Academic Factors in Relation to High School Students' Success in an Innovative Biotechnology Program

Biotechnology constitutes one of the most challenging, cutting-edge, and rapidly growing fields in science today (U.S. Department of Labor, 2008). Its products influence our daily lives on multiple levels and often improve our quality of life. Both the practical implications and the hands-on nature of this 'modern science' make the topic of biotechnology an attractive addition to the high school science curriculum (France, 2007). The interdisciplinary nature of biotechnology also makes it an ideal candidate for future curricular offerings that strive to incorporate the K-12 Framework for Science Education (National Research Council [NRC], 2012) and the Next Generation Science Standards (NGSS; http://www.nextgenscience.org/). Bybee (2011) noted that the shift from inquiry methods to the use of both science and engineering practices will likely be the greatest challenges related to the NGSS, and suggested that these practices should be thought of as both instructional strategies and learning outcomes. Indeed, the NGSS performance expectations place emphasis on combining practice and content in the assessment of student learning (Bybee, 2012). Sneider (2012) suggested the use of existing learning activities as a first step in integrating technology and engineering practice into science teaching.

The literature provides both a conceptual base for integrating biotechnology into curricular offerings, as well as practical examples implemented by early adopters. Wells (1994), for example, gathered biotechnology experts to compose a common taxonomic structure to guide the development of high school biotechnology curricula. Twenty panel members identified eight main areas, including topics that span both science (e.g., biochemistry, medicine, environmental science) and engineering (e.g., genetic engineering, food science, environmental safety). Similarly, an early survey of biology teachers captured recommendations for science and engineering content (the structure and function of DNA, understanding the genetic code, genetic engineering, cloning, and the biology of cancer), as well as the recommendation that this content be delivered through labs when possible (Zeller,1994). Harms (2002) noted that providing students with the opportunity to practice biotechnology provides specific examples of applied science that generalize to a differentiated understanding of concepts.

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A small number of studies have been published to describe the impact of biotechnology programs (Bigler & Hanegan, 2011; Gabric, Hovance, Comstock, & Harhisch, 2005; Marchaim, 2001; Powell & Stiller, 2005; Santucci, Mini, Ferro, Martelli, & Trabalzini, 2004). Initial results are positive, indicating an increase in student interest and a positive shift in motivation to learn (Powell & Stiller, 2005; Santucci et al., 2004). Knowledge gains have also been reported, though further investigation indicates that knowledge has been measured broadly. Dawson & Soames (2006), for example, asked students to list as many examples as possible in relation to biotechnology, genetic engineering, and cloning. Correct examples were scored as indicators of knowledge. Pre-post assessments have also been used, as well as post-only open-ended questions (Mueller, Knoblock, & Orvis, 2009). The latter method, in particular, indicated that students' ability to apply biotechnology knowledge was significantly improved if teachers used active rather than passive teaching techniques. Additional research with pre-post pencil-paper assessments suggests that hands-on classes that utilize professional equipment enhance student learning above and beyond the gains normally associated with these classes (Bigler & Hanegan, 2011).

Framed within the context of the NGSS, these descriptions indicate that many biotechnology programs are providing students with opportunities to engage in science and engineering practice and that these experiences result in positive outcomes. The measures used in the literature to date have been specific to biotechnology rather the broader science and engineering practices embedded within the activities. None measured skill and few measured applied knowledge within the context of practice as envisioned by the NGSS. Assessment of these experiences may be a challenge given that it is difficult to assess student understanding of the various topics introduced via hands-on activities (Steck, DiBase, Wang, & Boukhtiarov, 2012). As we move into the next generation of science standards, it will be critical to integrate the use of biotechnology techniques and equipment within the disciplinary core ideas of the NGSS, and to provide appropriate measures to document student learning within this context.

Background and Purpose

The need for a shift in science education that moves from the memorization of facts to learning by doing has been widely recognized for decades and now has the potential to be realized through the NGSS (National Science Teachers Association, 1982; National Science Board, 2007; [NRC], 2012). One innovative program poised to respond to this shift is the UCSD ScienceBridge Tech Sites. With funding from the Howard Hughes Medical Institute (#51006101) and the United States Department of Education (#R305A080692), ScienceBridge has pilot tested the use of high school-based biotechnology production sites. Within this context, biotechnology is defined in relation to specific tasks related to genetic engineering, protein structure and function, and enzyme reactions. There are eight departments in the Tech Site model: Solutions and Aliquots, Microbial Media, Inventory Management, Risk Management, Facilities Management, Order Fulfillment, Customer Service, and Quality Assurance. Working within and across departments students engage in tasks such as creating solutions, maintaining live cultures, managing inventory, and distributing materials. The balance between entry level jobs and management positions that require more extensive scientific and technical expertise also reflect the biotechnology industry. Students can move from team to team across multiple semesters to acquire a well-rounded skill set.

Tech Site courses were offered to students through a district-level Regional Occupational Program (ROP) designed to provide career skills to students through community partnerships (Mitchell, Adler, & Walker, 2011). Though implemented as a technology education course, the Tech Site's biotechnology focus is also appropriate for science and engineering courses. The NGSS Scientific and Engineering Practices embedded in the experiences include Asking Questions, Developing and Using Models, Planning and Carrying out Investigations, Analyzing and Interpreting Data, and Constructing Explanations and Designing Solutions. The science content largely focuses on Disciplinary Core Ideas within Life Sciences (LS1, LS2, LS3, and LS4) as well as Engineering, Technology, and Applications of Science (ETS2). Working collaboratively to manage kit production and delivery reiterates several additional NGSS ideas, including Connections to Engineering, Technology, and Applications of Science, the Nature of Science, and Science is a Human Endeavor.

Evaluation of the Tech Sites began in 2008 using a pre-post survey that was administered to students at the beginning and end of the course. In later years, student academic data were also gathered. The Tech Site evaluation is best categorized as a developmental evaluation, an approach that collects data to guide adaptation to the emergent and dynamic environments that occur during the development of projects, programs, and/or policy reforms (Patton, 2011). The Tech Site evaluation is considered developmental because the data were collected as the project evolved in response to changes in the overall ScienceBridge program. For example, ScienceBridge created new biotech labs each year, thereby expanding the skill set required of Tech Site students. The individual Tech Sites also developed in nuanced ways based on the culture of both the individual school and district. The evaluation was also conducted at the crossroads of a policy change ([NRC], 2012), and thus the data have the potential to serve as a developmental evaluation of indicators and methods that might prove useful to those interested in implementing biotechnology courses in response to the NGSS. This exploratory study investigates two questions:

1. What self-report measures can be used to document success in a high school biotechnology course?

2. What is the relation between self-report measures and more traditional forms of assessment, and can self-report measures be used to predict course success?

Method

Participants

Students from three high schools in two urban districts participated in the Tech Sites from 2010-2012. All students participated in the evaluation each year. In total, Tech Sites served 183 students over the course of this two year period; 178 participated in the evaluation (97%). Demographic characteristics are presented in Table 1. There were more females than males and over half of the students identified as Hispanic.

Table 1
Student Participant Demographics (n=178)

	n	%
Gender		
Male	76	42.7
Female	102	57.3
Missing	0	0
Grade		
10^{th}	49	27.5
11^{th}	55	30.9
12^{th}	68	38.2
Missing	6	3.4
Ethnicity		
African American	14	7.9
American Indian	2	1.1
Asian	51	28.7
Hispanic	99	55.6
Native Hawaiian/Pacific Islander	11	6.2
White	30	16.9
Missing	0	0

Measures

Pre- and post-surveys were administered to students online at the beginning and end of each term, respectively. One Tech Site allowed students to enroll for multiple terms; for these students, their initial pre data were used in comparison to post data from their final term of participation. Three survey constructs were of interest for the current study: students' attitudes toward science and both their self-reported awareness of and proficiency with biotechnology skills.

Attitude was measured via a battery of survey items that differed each year (see the Appendix for survey scales and items). In 2010-2011, the science items from the STEM Semantics Survey were used (modified from Tyler-Wood, Knezek & Christensen, 2010). The battery consisted of five adjective pairs. Each pair included one negative and one positive adjective and a series of six open boxes that connected the two terms. Students were asked to choose the option between the adjective pair that best reflected their opinion of science. In 2011-2012 the Math Science Interest Scale (Fouad & Smith, 1996) was used to measure students' interest in 20 specific science or math related activities by asking them to rate their interest on a five-point Likert scale: Strongly dislike, Dislike, Somewhat like, Like, Strongly like. To equate the different attitude ratings scales used, students' average scores on the five-point scale were multiplied by 6/5.

To measure students' awareness of biotechnology skills at the beginning of the Tech Site course, students rated a list of activities using three options: I had never heard of this skill before I started the Tech Site course; I had heard of this skill before starting the Tech Site course, but I had never used it myself; I had used this skill before I started the Tech Site course. Fifteen specific skills were rated in 2010-2011; six new items were added to the list in 2011-2012 to reflect new areas of focus within the program, bringing the total to 21 items. Using a different scale, students rated their proficiency with these skills at the beginning and end of each term: I cannot perform this skill; I can perform this skill but only with assistance; I can perform this skill well enough to do it on my own; I can perform this skill pretty well and could teach it to a friend if I had time to review; I can perform this skill very well and could teach it to a friend right now.

Three academic measures were used in the study. Students' scores on the California High School Exit Exam (CAHSEE) were used as a measure of baseline English/Language Arts (ELA) and Math ability (for reliability and validity information see California Department of Education, 2012). This state-based exam was created to ensure that students graduate with basic skills in each discipline. Students take the exam for the first time in 10^{th} grade and then again in subsequent years if they do not achieve a passing score. For the purposes of the current study, students' final scores in both ELA and Math were used.

The second academic measure was students' final course grade, which included classroom participation in biotech production activities as well as scores on written and practical exams. The third academic measure was the score on an articulation exam offered by San Diego Miramar College's biotechnology program. Two of the Tech Sites were part of a college program that allows students to earn college course credit for their high school biotechnology class. All students with a course grade of B or higher in an approved class were eligible to take the written exam and those who pass the exam receive four units of college credit. The exam measures general biology/biotechnology content knowledge, understanding of computational/data analysis content, and understanding of important biotechnology techniques.

Results

As shown in Table 2, internal consistency estimates of reliability were computed for each construct on the student survey. The values for Cronbach's alpha ranged from .84 to .96 across constructs, indicating satisfactory reliability for each variable of interest. Based on this consistency, students' average score across items was used for further analysis of each construct (i.e., Attitude, Awareness, and Skill).

Table 2
Cronbach's Alpha Statistics for Survey Scales

	n	# items	α
Attitude			
2010-2011 Pre	85	5	.84
2010-2011 Post	70	5	.91
2011-2012 Pre	99	20	.91
2011-2012 Post	71	20	.92
Awareness			
2010-2011 Pre	79	15	.91
2011-2012 Pre	90	21	.90
Skill			
2010-2011 Pre	74	15	.94
2010-2011 Post	73	15	.93
2011-2012 Pre	95	21	.93
2011-2012 Post	72	21	.96

Paired-samples *t* tests were conducted to evaluate whether students' science attitudes and biotechnology skills improved after the program. As shown in Table 3(next page), results indicate that attitudes remained constant before and after participating in the Tech Site. Students' biotechnology skills improved significantly after the program.

Table 3
Pre-Post Attitude and Skill

	M	*SD*	*df*	*t*	*p*
Science Attitude (out of 6)					
Pretest	4.43	.79	101	-.24	.81
Posttest	4.45	1.01			
Biotechnology Skill (out of					
Pretest	2.49	.86	93	-11.72	<.001
Posttest	3.69	.90			

Correlation coefficients were used to investigate the relation among key variables. Using the Bonferroni approach to control for Type I error across the 36 correlations, a *p*-value equal to or less than .001 (.05/36 = .0014) was required for significance. The results of the correlational analyses presented in Table 4 (next page) show that 13 out of 36 correlations were statistically significant. Moderate to high positive relations were found between all academic measures. There was no consistent pattern in how attitude related to the other variables. Skill at the end of the course was positively related to a number of variables, including a moderate relation to course grade and a high relation to exam score.

Two path analyses were also conducted, one for course grade and the other for exam score. Path model analyses were run using Mplus, Version 7. The following equations and Figure 1 describe the initial path model. Full information maximum likelihood estimators of parameters were used.

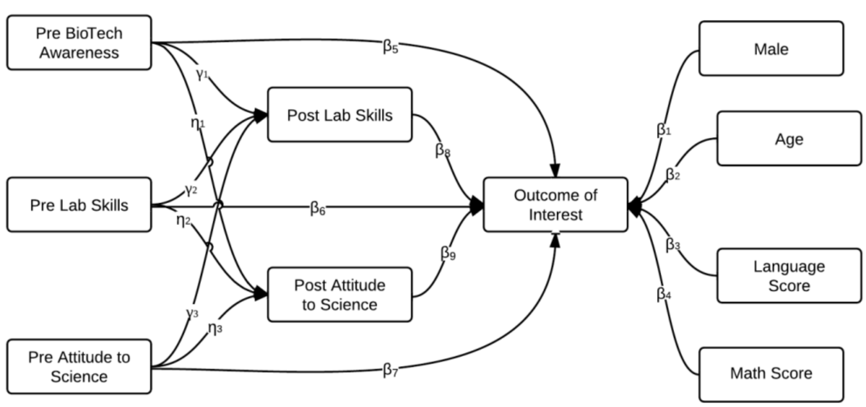

Figure 1. *Model Path Diagram*

Table 4
Correlation Matrix of Self-Report and Academic Outcome Variables

		1	2	3	4	5	6	7	8
1	ELA Score								
2	Math Score	.50							
3	Pre Attitude	-.06	-.02						
4	Pre Awareness	.24	.07	.17					
5	Pre Skill	.31	.06	.21	.49				
6	Post Attitude	-.11	-.08	.60	.14	.10			
7	Post Skill	.16	.20	.16	.38	.36	.31		
8	Course Grade	.35	.28	.08	.21	.18	.26	.31	
9	Exam Score	.46	.55	.21	.37	.30	.19	.50	.32

Note: Highlighted cells are those that achieved statistical significance with the Bonferroni correction for Type I error.

$$y_i = \beta_0 + \beta_1 Gender_i + \beta_2 Age_i + \beta_3 Language_i + \beta_4 Math_i + \beta_5 AwarePre_i + \beta_6 SkilPre_i + \beta_7 AttdPre_i + \beta_8 SkilPost_i + \beta_9 AttdPost_i + \varepsilon_i$$

$$SkilPost_i = \gamma_0 + \gamma_1 AwarePre_i + \gamma_2 SkilPre_i + \gamma_3 AttdPre_i + \xi_i$$

$$AttdPost_i = \eta_0 + \eta_1 AwarePre_i + \eta_2 SkilPre_i + \eta_3 AttdPre_i + \nu_i$$

Model fit statistics indicate a good fit of the model to the course grade data. RMSEA = 0.031, CFI = 0.986, and SRMR= 0.032. Direct effects are presented in Table 5 (next page) and indirect effects are presented in Table 6 (next page). Students' ELA and Math scores and post attitudes had a statistically significant association with their course grade ($\beta_3 = 0.091, p < .05$; $\beta_4 = 0.065, p < .05$; $\beta_9 = 3.536, p < .001$). Post skills were significantly predicted by students' pre awareness ($\gamma_1 = 0.386, p < .01$) and pre skills ($\gamma_2 = 0.244, p < .01$). Post attitude was significantly predicted by pre attitude ($\eta_3 = 0.648, p < .001$). Further, pre attitudes had a significant indirect effect on course grade through post attitudes ($\eta_3 \times \beta_9 = 2.291, p < .01$).

Table 5
Direct Effects on Course Grade

	Estimate	S.E.	Asymptotic Z test
Course Grade on			
Male(β_1)	-2.637	1.484	-1.777+
Age(β_2)	1.157	0.735	1.574
ELA Score(β_3)	0.091	0.037	2.445*
Math Score(β_4)	0.065	0.033	2.012*
Pre Awareness(β_5)	1.533	2.01	0.763
Pre Skill(β_6)	0.422	1.141	0.37
Pre Attitude(β_7)	-2.108	1.141	-1.848+
Post Skill(β_8)	1.252	1.077	1.162
Post Attitude(β_9)	3.536	0.999	3.539***
Post Skill on			
Pre Awareness(γ_1)	0.386	0.139	2.767**
Pre Skill(γ_2)	0.244	0.077	3.151**
Pre Attitude(γ_3)	0.066	0.063	1.046
Post Attitude on			
Pre Awareness(η_1)	0.063	0.136	0.462
Pre Skill(η_2)	-0.038	0.077	-0.495
Pre Attitude(η_3)	0.648	0.061	10.611***

+: $p < .1$; *: $p < .05$; **: $p < .01$; ***: $p < .001$

Table 6
Indirect Effects on Course Grade

	Estimate	S.E.	Asymptotic Z test
Course Grade on			
Pre Awareness through Post Skill ($\gamma_1 \times \beta_8$)	0.483	0.445	1.085
Pre Awareness through Post Attitude ($\eta_1 \times \beta_9$)	0.223	0.486	0.459
Pre Skill through Post Skill ($\gamma_2 \times \beta_8$)	0.306	0.283	1.08
Pre Skill through Post Attitude ($\eta_2 \times \beta_9$)	-0.135	0.276	-0.49
Pre Attitude through Post Skill ($\gamma_3 \times \beta_8$)	0.082	0.108	0.762
Pre Attitude through Post Attitude ($\eta_3 \times \beta_9$)	2.291	0.685	3.345**

+: $p < .1$; *: $p < .05$; **: $p < .01$; ***: $p < .001$

Model fit statistics also indicated a good fit of the model to the exam score outcome. RMSEA=0.021, CFI=0.993, and SRMR=0.033. Table 7 presents the direct effects and Table 8 (next page) presents the indirect effects. Students' Math score and post skills had statistically significant associations with their exam score ($\beta_4 = 0.263, p < .01;\ \beta_8 = 5.493, p < .05$). Post skills were significantly predicted by pre-awareness ($\gamma_1 = 0.415, p < .01$) and pre skills ($\gamma_2 = 0.236, p < .01$). Post attitude was significantly predicted by pre attitude ($\eta_3 = 0.647, p < .001$). None of the pre measures had a significant indirect effect on exam score through post attitude or skill.

Table 7
Direct Effects on Exam Score

	Estimate	S.E.	Asymptotic Z test
Exam Score on			
Male(β_1)	-3.78	3.424	-1.104
Age(β_2)	3.796	2.432	1.561
ELA Score(β_3)	0.044	0.091	0.481
Math Score(β_4)	0.263	0.078	3.365**
Pre Awareness(β_5)	7.526	4.404	1.709+
Pre Skill(β_6)	2.65	2.395	1.107
Pre Attitude(β_7)	4.372	3.31	-1.321
Post Skill(β_8)	5.493	2.289	2.399*
Post Attitude(β_9)	4.738	2.468	1.92+
Post Skill on			
Pre Awareness(γ_1)	0.415	0.138	3.016**
Pre Skill(γ_2)	0.236	0.077	3.066**
Pre Attitude(γ_3)	0.056	0.063	0.888
Post Attitude on			
Pre Awareness(η_1)	0.076	0.136	0.56
Pre Skill(η_2)	0.045	0.077	-0.586
Pre Attitude(η_3)	0.647	0.061	10.65***

+: $p < .1$; *: $p < .05$; **: $p < .01$; ***: $p < .001$

Table 8
Indirect Effects on Exam Score

	Estimate	S.E.	Asymptotic Z test
Exam Score on			
Pre Awareness through Post Skill ($\gamma_1 \times \beta_8$)	2.281	1.238	1.842+
Pre Awareness through Post Attitude ($\eta_1 \times \beta_9$)	0.361	0.671	0.538
Pre Skill through Post Skill ($\gamma_2 \times \beta_8$)	1.294	0.677	1.912+
Pre Skill through Post Attitude ($\eta_2 \times \beta_9$)	-0.213	0.385	-0.554
Pre Attitude through Post Skill ($\gamma_3 \times \beta_8$)	0.306	0.365	0.838
Pre Attitude through Post Attitude ($\eta_3 \times \beta_9$)	3.067	1.63	1.881+

+: $p < .1$; *: $p < .05$; **: $p < .01$; ***: $p < .001$

Conclusions

This study was part of a developmental evaluation of the UCSD ScienceBridge Tech Site program and explored the relationships among self-report and objective academic measures. As with any exploratory research, the purpose of the current study was to understand a phenomenon in greater detail with the hope of identifying hypotheses that can be explored in future research.

Documenting pre-post change on key variables of interest is a common method of measuring impact in program evaluation studies, and this method was used throughout the first years of the Tech Site evaluation. Course success in this context was defined as a statistically significant increase in students' scores after the program. The current analysis indicates that the UCSD Tech Sites were effective at improving the biotechnology skills of students, while science attitudes remained unchanged.

Initial studies of high school biotechnology courses have suggested that student motivation and knowledge are impacted positively and that impact is most pronounced within the context of active learning strategies (Bigler & Hanegan, 2011; Powell & Stiller, 2005; Santucci et al., 2004). The current study is the first of its kind to explore how student characteristics and biotechnology course outcomes relate to one another. Results indicated that students' general attitudes about science and their overall math skills predicted success across a number of measures, including both self-reported skill ratings as well as the more traditional measures of course grade and exam score. Further, the results demonstrate the association between skill, as measured through self-reported proficiency ratings, and achievement on an articulation exam. This link was particularly important for the program given that it was operated within the context of an ROP; it documented the relation between skills students learned in the course and the potential next steps in their educational and/or technical careers.

Implications

The results from the current study offer additional points of both intervention and evaluation for educators implementing biotechnology courses. The association between attitudes and knowledge in the literature includes a moderate correlation found among Israeli high school graduates (Pe'er, Goldman, & Yavetz, 2007), as well as a weak correlation found for secondary students from five European countries (Dijkstra & Goedhard, 2012). The results from the current study add to this literature by demonstrating that science attitudes may serve as a constant in relation to students' success in science courses. Science attitudes were predictive of academic outcomes despite the fact that there were not changes in attitude scores from pre to post. Ayendiz and Kaya (2012) concluded their study of Turkish high school students' science attitudes by stating that "classroom instruction has a significant impact on students' attitudes toward science (p. 44)." It is important to note that each of these international studies positioned their results within the context of either the educational and/or cultural system being studied. Future research should investigate the relation between attitude, attitude change, and academic outcomes among American students. Differences in how these variables interact in the context of biotechnology, engineering, and science courses should also be investigated. Should this research confirm that attitude plays a role in students' academic outcomes it would provide an additional leverage point for educators to utilize as they work to impact student learning.

The results from the current study also have implications for how student learning is measured. Norton (2004) suggested that teachers use formative assessment as a tool to allow students to collaborate with others and express ideas in their own unique and creative ways. The results from this study indicate that self-reported proficiency measures might serve as an accurate formative measure when data are being collected on specific skills. Students' proficiency ratings increased across the life of the Tech Site, were correlated from the beginning to the end of the course, and post proficiency ratings also correlated with both course grade and exam scores. The proficiency ratings conducted as part of this evaluation are also practical for today's biotechnology classroom; they were quick to administer and required no additional materials or resources.

It is somewhat surprising that students' self-assessments were also predictive of exam scores. As researchers begin to focus on ways to measure students' proficiency with science and engineering practice in relation to the NGSS, it may be useful to consider whether and how self-assessment of these skills provides a valuable measure of student learning across disciplines. Future research should validate the utility of this idea by comparing students' self-reported skills with those measured through objective performance-based assessments such as practical exams. Proficiency skill ratings may prove a valuable response to the challenges associated with assessing lab-based, problem-based, and hands-on learning experiences (Savin-Baden, 2004; Steck et al., 2012) at a time when these learning experiences are likely to become more rather than less common.

The topic of biotechnology has been a new source of study within recent years as educators and researchers grapple with ways to achieve and measure student learning in relation to this modern science. The thrust of the NGSS aligns nicely with the topic of biotechnology and provides a host of new challenges related to establishing integrated curricular materials and assessments that move beyond content to measure science and engineering practice. Whether biotechnology courses continue to be implemented within the context of technical programs such as ROP, as engineering programs, or by science educators trying to align with the NGSS, the results from this exploratory study document student characteristics to keep in mind as educators and policymakers consider whether and how to incorporate biotechnology into high school curricula. This study also highlights potential measurement strategies for educators and researchers to use to understand student learning in relation to this content.

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Appendix

Modified item from Tyler-Wood, Knezek & Christensen (2010)
In my opinion, science is:

Unpleasant	❒	❒	❒	❒	❒	❒	Pleasant
Fresh	❒	❒	❒	❒	❒	❒	Suffocating
Dull	❒	❒	❒	❒	❒	❒	Exciting
Likable	❒	❒	❒	❒	❒	❒	Unlikable
Uncomfortable	❒	❒	❒	❒	❒	❒	Comfortable

Math Science Interest Scale (Fouad & Smith, 1996; Strongly Dislike, Dislike, Somewhat Like, Like, Strongly Like)

Visiting a Science Museum
Listening to a famous scientist talk
Solving computer problems
Solving math puzzles
Touring a science lab
Joining a science club
Creating new technology
Using a calculator
Working with plants and animals
Taking classes in science
Working in a medical lab
Reading about science discoveries
Participating in a science fair
Working in a science laboratory
Learning about energy and electricity
Working as an astronomer
Taking classes in math
Working with a chemistry set
Inventing
Watching a science program on TV

Awareness and Proficiency Ratings of Biotechnology Skills
Awareness Scale: I had never heard of this skill before I started the Tech Site course, I had heard of this skill before starting the Tech Site course, but I had never used it myself, I had used this skill before I started the Tech Site course

Proficiency Scale: I cannot perform this skill, I can perform this skill but only with assistance, I can perform this skill well enough to do it on my own, I can perform this skill and could teach it to a friend if I had time to review, I can perform this skill very well and could teach it to a friend right now

Pipetting
Micropipetting
Making solutions
Diluting solutions
Making media (agar)
Pouring plates
Streaking plates
Performing transformations
Calculating concentrations
Performing sterile techniques
Quality assurance testing
Handling microorganisms
Using a microscope
Using SOPs (Standard Operating Procedures)
Measuring pH
Using the metric system
Making a graph
Interpreting a graph
Using a centrifuge
Protein purification
Observing enzymatic activity

Team Based Engineering Design Thinking

The objective of this research was to explore design thinking among teams of high school students. This objective was encompassed in the research question driving the inquiry: How do teams of high school students allocate time across stages of design? Design thinking on the professional level typically occurs in a team environment. Many individuals contribute in a variety of ways to facilitate the successful development of a solution to a problem. Teachers often require students to work in teams, but little is known about how the team functions in the context of design and the potential interaction between team performance and authentic design challenges. Few research results are available to guide high school teachers in developing successful design teams and how to encourage teams in their efforts.

Problem Statement

The National Center for Engineering and Technology Education has formalized a focus on infusing engineering design into secondary technology education (National Center for Engineering and Technology Education, 2013). Results of the Center's work have included engaging students in engineering design challenges using a problem based learning framework. While extensive efforts have be afforded to developing learning experiences and professional development activities for teachers, little attention has been given to how teams of high school students allocate their design time. The endeavor to model design problem solving satisfactorily has engaged scholars across domains (Hayes, 1989; Newell & Simon, 1972; Polya, 1945; Rubenzer, 1979). Understanding how students use their time provides educators with opportunities to improve areas where students spend little effort. This study investigates how teams of students allocate time in the design process and draws comparisons between two different design problems administered. Comparisons are provided between teams in this study and previous studies on individual experts and individual students.

The discrepancy between our society's dependence upon technology and our ability to understand various technological issues has emerged as a serious concern for educators. "Technology is the outcome of engineering; it is rare that science translates directly into technology, just as it is not true that engineering is just applied science" (National Academy of Engineering, 2004, p. 7). Specifically, "Americans are poorly equipped to recognize, let alone ponder or address, the challenges technology poses or the problems it could solve"

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(Pearson & Young, 2002, pp. 1-2). The relationship between understanding engineering and technological literacy is of special urgency during the high school years, since “technologically literate people should also know something about the engineering design process” (Pearson & Young, 2002, p. 18).

Design thinking is fundamental to understanding the technologically dependent nature of our society. A need for a technologically literate populace, therefore, includes an understanding of the engineering design process. The design process links technology and engineering, two elements of STEM education. “Design is the central component of the practice of engineering and a key element in technology education” (Pearson & Young, 2002, p. 58). While design thinking is an elusive and difficult construct to define, measurements for this study included a pertinent subset of measurements consistent with previous literature, much of which was generated through work of the Center for Engineering Learning and Teaching (Atman, Chimka, Bursic, & Nachtmann, 1999; Atman, Kilgore, & McKenna, 2008; Morozov, Yasuhara, Kilgore, & Atman, 2008; Mosborg et al., 2005; Mosborg et al., 2006). This paper reports on measurements including time allocated across essential elements of the design process and disaggregates the data by problem type and team gender composition.

Methodology

A descriptive study was conducted spanning multiple high schools in urban, rural and suburban environments. This study identified quality high school technology and engineering learning and teaching environments in a criterion based sampling strategy. Criterion for selective schools was aligned with the vision of Pearson and Young, where “technology teachers with a good understanding of science and the interactions between technology, science, and society will be well prepared to work with other teachers to integrate technology with other subjects” (p. 108). Teachers at the target schools permitted advertising to recruit their students for participation in the study. Students in this study were considered to be representative of experienced students who had taken most or all engineering related courses at their high school. Students were recruited who were actively engaged in the study of engineering design through a criterion sampling strategy (Creswell, 1998) using the following criteria:

- The high schools had an established program of study which employs a focus on engineering in a sequence of courses developed in association with an engineering outreach effort as part of a university program.
- In these courses, students participated in design activities which engage their critical thinking and problem solving skills within the framework of the engineering design process.

Sample. The quantitative research method design leveraged the use of data from 17 design teams comprised of 2-4 students each for a total of 47 students. The 17 teams were composed of eight male only teams, four female only teams, and five mixed gender teams. The teachers grouped the students into teams according to their personal schedules, and the teams were assigned the design challenge. Some team members were friends while other teams were comprised of students who did not know each other well. All members of a team were from the same school, but the 17 teams spanned four schools in two states. Each of the schools selected to participate had a recognized engineering program associated with an outreach effort by a university engineering program. Curricular offerings at the high schools included Project Lead the Way (PLTW), Engineering Projects in Community Service (EPICS) High, First Robotics, and locally developed engineering and/or technology courses supported by their regional University.

Demographics. Students were selected who represent diverse backgrounds and have chosen to enroll in this sequence of courses. Most students in this study were seniors who had taken multiple engineering courses during their high school experience. Typically participants were enrolled in a senior level capstone design course such as the Project Lead the Way, Engineering Design and Development course. Approximately one-third of the students were female and most reported their ethnicity as White or Asian. About one-half of the students responded to a question about their future career choice and nearly three-quarters of those indicated engineering. Refer to table 1 for demographics.

Table 1
Student Demographics

	Student Response
Mean Number of Engineering Courses	3.6 courses
Expressed interest in Engineering	68%
Females	34%
Seniors	74%
Underrepresented in Engineering	17%

Engineering Design Problems. According to the National Center for Engineering and Technology Education Caucus Report of 2012, “There is a need for more definitive guidance about what makes quality design challenges and how they can be implemented well in existing courses” (p. 2). Two different design problems were administered in this study which were open-ended, realistic, accessible, and complex (Mosborg, et al., 2006). The “playground problem” was provided to permit comparisons between team and individual performance while the “street crossing problem” variation facilitated comparisons among types of problem structures. The “playground problem” was comparable to the design problem used in previous studies with individual high school students (Mentzer, Becker, & Park, 2011) and previous work with college students, and experts (Atman, et al., 1999; Mosborg, et al., 2005;

Mosborg, et al., 2006). The street crossing problem was less structured, could be readily adapted in order to be locally relevant, and was potentially more authentic for the participants because it was situated in a local context experienced daily by the students. In addition, students engaged in the pedestrian flow problem had an opportunity to specify constraints and criteria as none were presented. The "pedestrian flow problem", administered to approximately half of the teams, was a variation of the "street crossing problem" adapted from previous literature (Cardella, Atman, Turns, & Adams, 2008; Carie Mullins, Atman, & Shuman, 1999).

Administration of the Design Challenges. Eight of the teams received a playground design problem and nine received a locally relevant school hallway traffic flow problem. Teams were expected to develop a solution in 2 hours. The interactions of group members were video and audio recorded while they were developing the design solution. Data included video and audio recordings of the design sessions. Video cameras were small, mounted on miniature tripods to minimize their intrusion. All students were wired with a lavaliere microphone to ensure high quality audio feeds. Wires were run under the team workspace to prevent tangling, however, the wires limited student mobility. Students generated documents and other artifacts with traditional office supplies provided. Artifacts typically included sketches, notes, and formal drawings.

The Playground Problem has been used in multiple studies and can be traced to Dally and Zang (1993). The original need for project driven approaches in the freshman engineering design course was to increase student performance and retention and to situate student learning of abstract concepts through real world applications in an experiential activity. In the original activity, students designed a swing set with slides and seesaw. Atman et al. (1999) revised the foundational work of Dally and Zang to create a playground design problem. In their challenge, engineering students were presented with a brief playground design task and access to background information upon request. Participants were provided with a maximum of three hours to develop a solution to the problem while thinking aloud. Mosborg et al. (2005) applied the playground design challenge using the "think aloud" research protocol with 19 practicing engineers who were identified as experts in the field. Mosborg et al. (2006) compared groups of freshman and senior engineering students with practicing engineers using data their research team previously collected on the playground design challenge. Atman et al. (2008) analyzed data from previous studies with a focus on the language of design, its relationship to design thinking as a mediator, and relationships between the internalization of design thinking and language acquisition.

Consistent with previous studies on college and high students, participants were given a one page design brief of the playground problem. The participating teams, acting as engineers, were assigned to design a playground on a donated city block. The constraints included limited budget, child safety, and compliance with zoning regulations and applicable laws. Participants were able to query the research administrator for additional specific information on the lot layout, cost of materials, neighborhood demographics, or other information. There was a two-hour time limit for completion of the design proposal, which was a modification of the original three hour limit in previous studies (Becker, Mentzer, & Park, 2012). This modification was made because the average design time in the previous study of high school students was about 90 minutes. The two-hour limit provided more time than the average individual needed, yet it reduced the resources needed for data collection. The participants presented a written proposal describing their design. This activity engaged the participants in problem framing and the development of an initial solution. Limitations of this design task included the lack of opportunity for participants to investigate the need for a solution, since the problem was simply assigned to them. Students did not have an opportunity to construct physical models or prototypes. Participants were aware that implementation of the design project would not occur and that their designs would not be realized.

The Street Crossing Design Problem was adapted from previous research (Cardella, et al., 2008; Carie Mullins, et al., 1999). The National Center for Engineering and Technology Education assembled a Caucus in August 2011 to identify characteristics of engineering design challenges (Householder, 2011). Results of the discussions by this group of experts indicated that excellent design challenges should incorporate the following characteristics:

- Authenticity
- Have personal and social relevance
- Require analytical thinking
- Involve group efforts
- Require hands-on participation
- Are clearly structured but open-ended
- Foster creative solutions
- Consider ethical issues
- Meet applicable constraints
- Provide opportunities for modeling with replication
- Consider systems implications
- Are well documented
- Are self-assessed and independently evaluated
- Enable communication among team members

The Street Crossing Design Problem was potentially more authentic and more closely aligned with the National Center's Caucus suggestions than the playground problem. "Authentic problems currently affect real-life situations encountered by the learners, their families, and their communities – and they do not have a generally recognized "right answer." (National Center for Engineering and Technology Education, 2012, p. 22). The problem was modified slightly from its original administration to more closely exemplify these characteristics. The street crossing problem was discussed with teachers at the schools involved. Teachers were asked to think about an intersection fitting characteristics of the original problem but located at or near the school where students would immediately recognize the problem as they personally experienced it daily. After negotiating with the teachers, it was discovered that car/pedestrian traffic flow was an issue, but a more relevant and pervasive similar issue was pedestrian (student) flow in school hallways. Each school had one or more significant blockages that caused congestion, frustration, and delay at passing times between classes. The design problem was modified to focus on student hallway flow rather than car traffic flow, making the problem more relevant and personal, as most students experience the congestion several times per day.

Each pedestrian flow problem was presented in a similar format: the school floor plan ("map") was provided to participants along with a very brief narrative stating that the student team was a team of engineers contacted by the school district. The narrative introduced an area that the students immediately recognized as a congested area and requested that the team present a proposal for resolving the issue. The constraints and criteria were not specified; leaving student design teams the opportunity to discuss and negotiate their specific problem definition and determine the most appropriate solution proposal. An example pedestrian flow problem looked like this, though details varied across schools to situate the problem in the local context:

> You are a team of engineer's contacted by [your school name here] School District. Often hallways are congested at passing time between classes. Hallway one, which is between the new and old portions of the school, is difficult to navigate. [your school name here] School District would like your team to develop and propose a solution.

This less structured problem is consistent with the National Center's suggestion that "Engineering design challenges are ill-structured problems that may be approached and resolved using strategies and approaches commonly considered to be engineering practices" (2012, p. 2). Typical office supplies were provided for the participants, a condition similar to those in the playground problem. However, participants were given access to the Internet in lieu of printed sheets of relevant data. The decision to provide Internet access was made to increase the sense of authenticity and relevance as students are familiar with and accustomed to having Internet access. The notion of having predetermined what information is needed for their solutions may unintentionally guide student design decisions to those based upon a finite resource pool.

Data Analysis. Time is a limited resource and the ways designers allocate their time among the areas of the design process has been a focus of previous work. The coding scheme was congruent with the approach used in earlier studies (Atman, et al., 1999; Bursic & Atman, 1997; Mosborg, et al., 2005; Mosborg, et al., 2006). Two measurements of time were made while the designers were at work: time allocated to elements of the design process; and total time engaged in design. The unit of analysis was the team. The data were coded into the nine categories presented by Mosborg et al. (2006, p. 15): (1) Problem Definition, defining what the problem really is; (2) Gather Information, searching for and collecting information needed to solve the problem; (3) Generating Ideas, thinking up potential solutions (or parts of potential solution) to the problem; (4) Modeling, detailing how to build the solution (or parts of the solution) to the problem; (5) Feasibility Analysis, assessing and passing judgment on a possible or planned solution to the problem; (6) Evaluation, comparing and contrasting two (or more) solutions to the problem on a particular dimension (or set of dimensions) such as strength or cost; (7) Decision, selecting one idea or solution to the problem (or parts of the problem) from among those considered; (8) Communication, the participants' communicating elements of the design in writing, or with oral reports, to parties such as contractors and the community; and (9) Other, none of the above codes apply. Statements coded as other included administrative questions such as "should we draw this on paper?" and "can I use a calculator?". Statements coded as "other" also were statements that were vague and ambiguous. Statements were only coded with one of the eight codes if reasonable evidence existed to justify the claim and therefor a statement that was made but not understood by the coders was assigned as "other".

Data analysis began with segmenting the data sets. A team of three researchers was tasked with the responsibility of segmenting. A segment was defined as a pause bound utterance, as suggested by Atman et al. (1999). Researchers were instructed to create a new segment in the video timeline for each instance when any student on the team began a new thought, which was typically indicated by beginning to speak after a pause. In previous literature (Becker, et al., 2012; Mentzer & Becker, 2010; Mentzer, et al., 2011), this segmenting procedure was applied to individuals. For the current study of teams, researchers created these segments each time any member of the team made a transition. The resulting segmented data represented the composite of all team member segments. At some points in the videos, all team members were functioning as one cohesive unit and segmenting was simple and monolithic. In other times, a team of four students might naturally divide into two teams of two and the segments represent start/stop times for each sub-team. By segmenting in this fashion, a divergence in design activities could be coded with two separate codes in two different, but overlapping episodes.

Quantitative measures of inter rater reliability on the segmenting process were not made. The research leadership determined the segmenting would be of reasonable quality if the inter-rater reliability measures for coding were high. If segmenting were done successfully, coding could potentially result in high inter rater reliability. Coding served as a proxy for quality control of the segmenting process. As a preliminary quality control mechanism, the lead researcher reviewed segmented work and provided feedback and guidance as the research assistants progressed.

Two undergraduate students coded the data in three phases. The first phase was to establish calibration of the research assistant's coding work. The second phase served to document the calibration using Kappa values as a measure of inter-rater reliability. The team of two research assistants coded 25% of each video and compared. The Kappa values averaged 0.71; details are presented in Table 2 (next page) along with the number of references used to generate the values. In the third phase, all videos were fully coded, approximately one-half by one research assistant and one-half by the other.

In the calibration phase, research assistants were provided with a conceptual overview of the coding process, structure, technique and rationale. They were presented with examples from previous work and practiced coding these data. Research assistants then coded a portion of a video and compared with each other. They met with a senior research team member and discussed the individual interpretations and differences to establish clarification on coding. A "Dynamic" Code Book was adopted and maintained. This was a document with very specific examples of the different codes developed by creating a description of the code and compilation of examples in context. This included adding detail and clarifying the meaning of segmenting and coding procedures and providing examples as coders did their work. The document was updated regularly and shared via network real time. As understanding and interpretation was negotiated by the coders and research team leaders, the codebook documents evolved into increasingly specific definitions.

The calibration process was iterative. Each coding session was followed by a debriefing session and the cycle started over. Kappa values began relatively low and rose gradually as the research assistants became more closely aligned in their designations. When average Kappa values for each code approached 0.70, the research team transitioned into the next phase which was documentation. Some effort was focused on calibration, but most effort was allocated toward coding a random 25% of each video and documenting the comparison.

Table 2
Cohen's Kappa For Each Design Activity

Design Activity	Cohen's Kappa	References Compared
Problem Definition	0.76	152
Gathering Information	0.72	630
Generating Ideas	0.66	65
Modeling	0.68	1412
Feasibility	0.46	294
Evaluation	0.75	26
Decision	0.80	15
Communication	0.88	732
Average Inter-Rater Reliability	0.71	

In the final phase of coding, the 17 videos were divided among the two research assistants. Earlier work resulted in 25% of each video being coded already; the remaining 75% was coded. The entire video was reviewed and changes were made as needed to the coding structure in context of the newly coded 75%.

Results

The video data were coded by time allocated to: Problem Definition, Gathering Information, Generating Ideas, Modeling, Feasibility, Evaluation, Decision Making and Communication efforts. Activities that the team engaged in were coded. Key differences are discussed in terms of comparisons between individuals and teams, problem types and team gender. At times in the process, team members were all simultaneously engaged in one activity, but, at other times, individual students would engage in different activities. When team members provided reasonable evidence that they were doing two different activities, two or more codes were applied. The total coded data exceeded 100% in all teams because, at times, the team was receiving credit for two or more codes simultaneously. With this study's small sample size (n=17) statistical analysis was not conducted. However, trends emergent in the time allocation between individuals and teams may provide a foundation for future study.

Individuals vs Teams. Teams averaged 102 minutes in the design process as compared to individuals from previous work who finished, on average, at 92 minutes (Becker, et al., 2012). Table 3 shows the average time invested by the teams in each design activity in this study and the average time invested by individuals in the previous Becker and Mentzer study.

Information Gathering. Teams spent nearly twice the percentage of time engaged in gathering information. Information gathering was coded when students were actively requesting, reading, and reviewing information related to the problem or solution. Information requests could be made of the administrator. Teams working on the hallway traffic design challenge were provided with a laptop and Internet access. Student use of the Internet was generally coded as information gathering and represents a difference from the data collection protocol used with individuals and playground design teams as they did not have access to the computer.

Table 3
Mean and Standard Deviation Summary Statistics for High School Student Teams and Individuals

Design Process Measures	Individual (n=59) (Becker, et al., 2012)		Teams (n=17)	
	Minutes (SD)	Percent of time	Minutes (SD)	Percent of time
Total Time	91.7 (47.4)		101.7 (18.43)	
Problem Scope	15.5	18.0	27.2	26.3
Problem Def.	5.6 (3.1)	7.7	6.8 (5.49)	6.7
Info. Gath.	9.9 (13.3)	10.3	20.4 (12.19)	19.7
Solutions	63.2	70.5	55.6	55.1
Generating	2.9 (6.6)	3.9	2.8 (1.62)	2.9
Modeling	54.4 (35.4)	60.2	44.2 (13.29)	43.4
Feasibility	4.4 (4.1)	5.4	8.0 (4.41)	8.3
Evaluation	1.1 (3.5)	1.0	0.5 (0.78)	0.5
Realization	8.2	7.6	24.2	23.6
Decision	0.4 (0.7)	0.4	0.2 (0.32)	0.2
Comm.	7.8 (13.0)	7.2	24.0 (12.87)	23.4
Other	3.1	3.8	9.1	9.0

Modeling and Communication. Time allocated to modeling and communication show differences between teams and individuals. The teams tended to spend less time modeling and more time communicating. Modeling was defined as detailing how to build something, including calculations, estimations, determining locations, and description of how something will be assembled or fabricated. Communicating was defined as the efforts involved in telling someone how to build the playground. Communication efforts focused on sharing the team's plan with others and could be directed toward a contractor or a board of directors considering the team's proposal.

Playground vs. Pedestrian Flow problems. The playground problem had been used extensively in previous studies described above, but was potentially less relevant and authentic to high school aged students who are generally too old to use playgrounds and too young to have children of their own playing on playgrounds. The pedestrian flow problem was experienced daily by students and differences in design process times were evident in this study. Table 4 summarizes time allocations as a comparison between problems.

Problem Definition. Time spent on problem definition differed between the pedestrian flow and playground problems. Teams spent more than twice the amount of time reading, reflecting on and considering the problem for the playground compared to the pedestrian flow challenge. The playground problem presentation was longer and more specific. Constraints and criteria were specified as compared to the pedestrian flow in which constraints and criteria were not specified. The research team had anticipated that the lack of definition would permit students to develop their own constraints and criteria relative to their local problem, but, time in the problem definition phase was actually less when constraints and criteria were not provided.

Information Gathering. Teams working on the pedestrian flow problem spent about twice the percentage of time searching for and digesting information relative to the problem than did the teams working on the less familiar playground problem. Examples of information gathered in the playground problem focused on identifying typical components on playgrounds such as swings, slides, monkey bars, and material characteristics such as strength, durability, and cost. Information across both problems included benchmarking, but on different conceptual levels. Searching for playground components was a concrete task resulting in a list of typical play things while the hallway problem yielded much more complex transfer from other schools or public places where traffic congestion was a problem. Students looked at airports as examples of moving people in short periods of time as a potential method of benchmarking and gathered these examples to spawn ideas in their scenario. The transfer from an airport or mall hallway to a school hallway was challenging for students perhaps because the population of users was different (i.e. adults in airports vs. students; adults may be motivated to run to their next flight vs. students who may not be interested in getting to the next class).

Students in the hallway problem appeared to spend more time searching, perhaps motivated by their personal interest. In each administration of the problem, students were obviously bothered by the problem and were quick to engage as compared to the playground problem where students engaged at our request but seemed less intrinsically motivated. The hallway challenge included Internet access, which could have related to the additional search time. Our informal observations seemed to indicate that students not only accessed the computer, they also gathered information from memories of direct observations. They recalled their experiences in airports and malls with pedestrian congestion. They recalled traffic flow rates and locker placements in the school and considered the impacts of this information on their design process.

Feasibility. Teams on the pedestrian flow problem spent more than twice the percentage of time considering feasibility of their solutions as compared to the teams on the playground problem. Feasibility was defined as considering the practicality or viability of a solution or element of the solution. This was differentiated from evaluation in that evaluation included comparing two or more options while feasibility was passing judgment on one potential idea. In the playground problem, feasibility typically centered around cost in addressing the question: "Would an item/component cost too much?" Also, playground design teams considered the extent to which they met the constraints. This differed in the hallway problem because students were not provided with constraints or criteria nor did teams spend time to specify either constraints or criteria for the solution of the problem. Feasibility, however, consumed a much greater percentage of time as students attempted to determine if their solutions would work. Students implicitly must have identified some constraints and criteria as they talked about feasibility but not directly. Typical examples included students discussing the financial cost of a solution or the impact that the proposed solution might have on the problem without explicitly identifying a budget or rationale that costs should be limited or minimal. Some solutions were structural while others were behavioral and students considered their potential solutions and students' behavioral responses. This led to discussions of teachers' roles, administrators' media campaigns for pedestrian traffic patterns and the feasibility consideration: "would it work?"

Table 4
Mean and Standard Deviation Summary Statistics for High School Student Teams in the Playground Problem and Pedestrian Flow Problem

Design Process Measures	Playground Teams (n=8)		Pedestrian Flow Teams (n=9)	
	Minutes (SD)	Percent of time	Minutes (SD)	Percent of time
Total Time	108 (10.9)		95.8 (21.5)	
Problem Scope	25.3	23.0	28.9	29.4
Problem Def.	9.9 (3.7)	9.2	4.1 (5.4)	4.4
Info. Gath.	15.4 (9.0)	13.7	24.8 (12.9)	25.0
Solutions	62.4	57.8	49.5	52.6
Generating	2.7 (1.9)	2.5	2.9 (1.4)	3.2
Modeling	53.2 (10.0)	49.4	36.1 (10.3)	38.1
Feasibility	5.4 (1.7)	4.9	10.4 (4.7)	11.3
Evaluation	1.1 (0.8)	1.0	<0.1 (<0.1)	<0.1
Realization	29.6	27.9	19.4	19.8
Decision	0.5 (0.3)	0.5	<0.1 (<0.1)	<0.1
Comm.	29.2 (11.4)	27.4	19.4 (12.4)	19.8
Other	9.7	9.1	8.5	9.2

Feasibility seemed more relevant for students to consider in the hallway challenge as compared to the playground problem. Students were familiar with the hallway issues and the solutions had direct impact on their lives. They seemed to have capacity for understanding the complexities of hallway traffic more than complexities in the playground problem. Student design teams seldom considered the issues of safety in the playground, overlooking such facts as the difficulties that 2 year olds, have in negotiating ladders. If the students had been parents of children for whom the playground were being designed, they might have considered safety and functionality with greater understanding, but as 17 and 18 year olds, they seemed to lack a sense of understanding about the functionality and dangers surrounding playground equipment design.

Team Gender Composition. Teams were comprised of single gender and mixed gender. Four all-female teams, seven all-male teams and five mixed gender teams displayed differences in design processes. The gendered nature of the teams was difficult for the research team to control and, as a result, did not split equally across design problems. Three of the four all-female teams were provided with the pedestrian flow problem while only one was provided the playground problem. Five of the seven male only teams received the playground problem while two teams received the pedestrian flow problem. Two of the five mixed gender teams engaged in the playground problem while three attempted the pedestrian flow problem. Results of teamwork disaggregated by gender are presented in Table 5. Total design time varied across groups with female only teams finishing their work nearly 22 minutes before their all male counterparts. Mixed groups of males and females averaged about eight minutes less than all male teams.

Problem Definition. While female only teams spent less time engaged in design, they spent more time on problem definition (8.4 minutes) than did the all-male (7.0 minutes) and mixed gender groups (5.2 minutes). This finding is particularly noteworthy, as most of the female teams engaged in the pedestrian flow problem which, according to data presented in Table 3, drew relatively little attention to problem definition (4.1 minutes).

Table 5
Mean and Standard Deviation Summary Statistics for High School Student Teams by Gender Composition

Design Process Measures	Female Only (n=4)		Male Only (n=8)		Mixed Gender (n=5)	
	Minutes (SD)	Percent of time	Minutes (SD)	Percent of time	Minutes (SD)	Percent of time
Total Time	87.1 (13.3)		108.8 (7.9)		101.9 (25.8)	
Problem Scope	26.6	29.9	27.1	24.6	27.9	26.3
Problem Def.	8.4 (6.4)	9.0	7.0 (5.4)	6.4	5.2 (4.2)	5.3
Info. Gath.	18.2 (14.9)	20.9	20.0 (9.7)	18.2	22.7 (12.9)	21.1
Solutions	44.5	50.8	58.4	54.0	59.9	60.2
Generating	2.4 (0.6)	2.7	2.9 (1.7)	2.6	3.1 (2.0)	3.4
Modeling	35.6 (13.8)	40.6	47.2 (11.4)	43.7	46.2 (12.8)	45.3
Feasibility	6.3 (1.8)	7.4	7.8 (4.4)	7.2	9.8 (5.2)	10.7
Evaluation	0.2 (0.3)	0.2	0.6 (0.8)	0.5	0.8 (0.9)	0.8
Realization	16.5	19.6	29.6	27.3	21.9	20.9
Decision	0.2 (0.3)	0.2	0.2 (0.3)	0.2	0.3 (0.4)	0.3
Comm.	16.3 (3.8)	19.4	29.4 (12.7)	27.1	21.5 (14.0)	20.6
Other	9.8	11.3	10.2	9.4	6.7	7.0

Modeling and Communication. Most of the differences in overall design time were related to modeling and communication. Females spent about 25% less time modeling than did males and mixed gender groups. The average female modeling time was 36 minutes while males and mixed groups spent 47 and 46 minutes respectively. Male student teams spent nearly twice the amount of time communicating (29 minutes) as did female student teams (16 minutes).

Discussion and Implications

Discussion focuses on four topics: inter-rater reliability, problem definition, evaluation and decision making, and modeling and communication. The development of this study was based on a series of studies situated on the college level (Atman et al., 2007). In these studies, experts were provided with a design problem as a comparison group to college students. These experts provided a verbal protocol individually and were provided with a very comparable experience engaging with the playground problem as were participants in the current study. Overall, experts spent more time engaged in the problem with nearly 132 minutes being their average as compared to teams of high school students whom spent nearly 102 minutes. This difference in time was primarily in modeling and communication. Experts spent more than 55% of their time (about 73 minutes) modeling while teams of high school students spent less time modeling (about 43% or 44 minutes). However, high school students spent more time communicating (about 23% or 24 minutes) than did experts who allocated about 5 minutes or 4% of their time.

Inter-Rater Reliability. Reliability of modeling and feasibility coding was low despite extensive efforts to calibrate by the research team. Some of the lack of agreement could be related to researcher calibration, but the research team suspected that the lack of agreement is also related to lack of clarity by the student teams about the nature of these activities. The students were vague about how modeling was related to other aspects of the design process, particularly communication. What initially appeared to be graphical sketching as a method of developing ideas and laying out a potential solution for discussion evolved into a document for the final proposed solution. Differentiating between modeling and communication in the abstract was simple for the undergraduate research assistants as the difference centered on purpose. If the purpose of the sketching, for example, was to understand and improve appearance, functionality or fabrication techniques and the team used this information to think through challenges and determine specifications, it was coded as modeling. If, on the other hand, team effort was directed at documenting their plans for fabrication for the purpose of telling someone how to build from the plans, it was coded as communicating. Student teams often started modeling and the work evolved into communication. This evolution made precise determination difficult. In cases where the transition was gradual and vague, the coders generally defaulted to modeling until there was evidence that the purpose was an attempt to communicate team intentions/plans. In some cases, teams were very deliberate about this transition. In other cases, the transitions occurred gradually but were clarified later. For example, what might have appeared to be modeling was later determined to be communication and codes were changed appropriately as the coding process progressed through the team’s work.

The boundaries between thinking on paper via sketching and making notes, and communicating with external stakeholders blurred and presented the research team with difficulty identifying student intentions. At the end of the design challenge, students frequently presented rough sketches and messy notes, resulting in poor quality technical communication. If this situation is to be improved, teachers should make clear to their students how to communicate technical information in a persuasive way to external stakeholders. Classroom experiences might be focused on presentation skills where students present their work to other classes or an invited audience of people who are not familiar with the daily student design experiences. This external audience would challenge students to provide details and rationale for decisions made in context which was generally absent from student work in this research.

Problem Definition. Students engaged in dialog about the feasibility of their potential solutions or elements of solutions in the hallway problem more than in the playground problem, but problem definition was considered more in the playground problem. These two activities may be inversely correlated such that a general lack of problem definition would lead to a tendency for students to be quick to question whether a potential solution would work. In the hallway problem, student teams seldom made explicit the constraints and criteria which made determining the feasibility of an idea more difficult and time consuming. The National Center for Engineering and Technology Education suggested, "As designs are considered for viability, optimization is essential. Students should make their value structures and goals for design success explicit early in the decision process. This sense of clarity provides opportunities to select and promote designs that make the most successful balance of trade-offs" (2012, p. 26). In the less structured hallway problem, students would consider an idea and then ask if it would work or be too expensive without having specified the definition of success or budget.

Teachers should encourage students to identify the constraints and criteria as well as how success should be measured early in the design process. Feasibility considerations were slightly higher for team based design problems than individual design problems. Further research might test for a causal relationship, which if present, would indicate that teamwork might facilitate experience and exposure to critical thinking about solutions in the feasibility phase of the design experience. The National Center for Engineering and Technology Education caucus of 2012 suggested that "In collective team efforts, students may hold each other accountable for meeting criteria" (p. 18). The sense of accountability may have manifested in feasibility as students questioned each other's ideas prompting consideration of flaws and opening the door for improvements. Stakeholder interests were included in student discussions of feasibility in the hallway problem much more frequently than the playground problem. In the hallway problem, they mentioned considerations such as how students would interact with their solution, how teachers would be involved and react to students in a redesigned hallway. They considered impacts of hallway reconstruction on the neighboring rooms and how the changes impact roles of librarians, cafeteria staff, and classroom teachers. Occasionally, parents and shopkeepers were mentioned in the playground problem as stakeholders but with far less emphasis. This may be related to the sense of relevance provided by the hallway problem, because students cared in a very personal way about the success of their design and considered a larger system of stakeholders.

Evaluation and Decision Making. In both design problems, evaluation and decision making activities were rarely observed. Student teams spent very little time comparing alternatives on a criterion, which was our working definition of evaluation. Students also spent very little time choosing among the alternatives. Decision making was defined in this study as a deliberate choice between two or more alternatives. A typical decision and evaluation activity in the playground problem included material selection. Student teams would ponder using wood or metal as a construction material, discuss costs, strength and durability, then make a selection. In the hallway problem, even fewer evaluations or decisions were observed. This lack of evaluation and decision making may be directly related to the fact that students developed few alternative solutions during the brainstorming phase. While they did brainstorm and develop ideas, selection decisions tended to be related to the feasibility of individual components of the solution rather than a comparison of alternative solutions. Students would frequently say, "Let's put in a slide, it's cheap" with no externalized comparison of the alternatives.

The general lack of evaluation and decision making may relate to a lack of alternatives for consideration. Students tended to think about new ideas until they had a few viable options and developed those into their final design. The lack of alternatives generally reduced the need to evaluate differences between them and reduced the number of decisions (choices between alternatives) to make. Teachers should encourage students to develop a significant list of alternative ideas before evaluation and decision making. Decisions regarding materials were made on the playground problem, but in both design problems, students did not develop many alternative designs. They considered the advantages of different materials but seldom considered holistically different solutions.

Future Research

Findings from this study suggest potential trends and correlations between individual design activities and group design work as well as suggesting differences between teamwork on two different kinds of problems. This study had a sample size of 17 teams in total. Eight teams were challenged with the playgroup problem and nine teams engaged in the hallway problem. With only eight or nine teams in comparison, statistical analysis was not conducted. This work is potentially foundational to larger studies as it may allude to trends and correlations that could be tested in experimental or quasi-experimental research conditions on a larger scale.

This work may have implications for methods of group based verbal protocol studies. Future research efforts using student observations might increase their inter-rater reliability measures with teams by being able to identify what papers students are using when they are writing or sketching. In work with individuals, reviewing the digitized artifacts and video observation data typically provided ample evidence to determine what students were writing. However, with teams of students and multiple artifacts, researchers were less able to identify which paper was being used during a particular phase of the design process. Cameras positioned from an angle overhead might allow association between papers and content of the writing. However, in this research effort, a wide angle video of four students made identifying what was written and when difficult. In addition, the research team noticed that they were able to code feasibility, for example, consistently, but they had difficulty determining exact start and stop times. One research assistant might include a background statement as a lead in to feasibility while another might code a narrower band of feasibility leading to general agreement between researchers but low Kappa values.

From a methodological perspective, the inverse relationship between time spent in problem definition and time spent in feasibility might provide insight into student thinking about problem definition. Though problem definition in the hallway design task was seldom coded, future researchers could use feasibility as a method of extracting student definitions of the problem. Feasibility considerations have inherent value statements that could provide a proxy for problem definition. Therefore, by analyzing student conversation about the feasibility of an idea, a future research team may be able to identify the implicit constraints and criteria that students do not mention explicitly. For example, if a student judges a potential solution to be too expensive, we can infer that cost is a criterion even though it was not mentioned as one. Students mentioned concerns such as slide or platform height or soccer field location in the playground problem, which relate to the constraint presented that the playground must be "safe". In this example, the students silently operationalized safety by considering a minimum distance from a nearby road to the soccer field. In addition, students' brainstorming activities may provide insight to the problem definition in that they tend to think of potential solutions and the commonalities across those solutions may be hints into their problem definitions. As an example, students who list different ways of controlling student hallway traffic such as traffic lights, teachers, or mirrors, may suggest implicitly that widening the hallway is not practical or that they feel constrained by the lack of resources to make major structural changes in the school architecture.

Further research might investigate qualitative differences in the ways and methods in which all female teams engaged in problem definition as compared to males and mixed groups. Female groups spent more time and a much higher percentage of time on problem definition than their peer groups. It might prove beneficial to practitioners to understand the impact of this additional time on the design thinking. Does this additional effort represent a deeper understanding, and does a deeper understand cause improved design performance and more effective solution development?

Additional investigation may clarify differences between gender and modeling and communication activities. All female groups spent dramatically less time modeling and communicating which accounted for most of the differences in overall design problem time. Are females modeling and communicating less or differently than their male only and mixed gender team counterparts? Teachers should consider and make explicit modeling and communication expectations so that group efforts are comparable. If the teacher is expecting significant modeling and communication activity, the teacher should be sensitive to the possibility that team gender composition may impact these behaviors. Teachers need to monitor these activities and clearly articulate the importance and purpose of these elements of design so that teams allocate time where the teacher is expecting.

The National Center for Engineering and Technology Education suggested characteristics appropriate for engineering design challenges for high school students (National Center for Engineering and Technology Education, 2012). This study used the characteristics to adopt an instrument used in previous work. However, relevant design problems might not only improve design challenges as measurement instruments but might also fundamentally change the learning and teaching process. Data were not gathered in this study about the typical classroom design problems that were the foundation of student experience. Future research could investigate impacts on student learning related to authenticity and its impact on motivation and engagement. Students who are actively engaged in learning may interact with the design problem very differently and therefore their learning and experiences may be different from student less engaged. In addition, while most students in this research were seniors and each had taken numerous design related courses, the number of design problems and their duration were not studied but could impact student performance. Further study might investigate classrooms that conduct design problems regularly as a pedagogical approach as compared to classrooms which situate design problems only as a capstone experience.

Summary

This study provided seventeen teams, each comprised of 2-4 high school students, with a team based engineering design challenge. Observational protocol analysis was conducted based on a foundation of previous work, including the adoption of previous coding schemes. Differences between groups and individuals were compared. Teams of students were split in two groups; one set of teams received a playground design problem while the other received a hallway design problem. Teams worked up to two hours after school on the design problems and provided the recommendations resulting from their work at the conclusion of the session.

This material is based upon work supported by the National Science Foundation under Grant No. 0426421. Any opinions, findings, and conclusions of recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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A Curricular Analysis of Undergraduate Technology & Engineering Teacher Preparation Programs in the United States

Introduction

Technology & engineering teacher preparation programs at colleges and universities in the United States have been in a state of decline since the 1970's. In an editorial published in the Spring 1997 *Journal of Technology Education* Volk indicated that the number of undergraduate students graduating in technology teacher preparation declined by nearly two-thirds between the period of 1970 and 1990. Plotting the downward trend in graduates, Volk estimated the demise of technology education teacher preparation in the United States around the year 2005. While Volk's prediction has not been proven to be entirely accurate, the downward trend in technology teacher preparation has continued. An analysis of the 2002/2003 *Industrial Teacher Education Directory* (Bell, 2002) indicated that there were more than forty programs nationwide with estimated undergraduate teacher preparation enrollments of more than 20 students. Just one decade later the *2012/2013 Technology & Engineering Teacher Education Directory* (Rogers, 2012) indicated that only 24 programs had an estimated undergraduate enrollment of 20 students or more. Of those programs that remain, another concern is that there is still considerable diversity with regard to the curricula that comprise the various technology & engineering teacher preparation programs. For instance, at one end of the spectrum some programs have retained a traditional approach to technology & engineering education that is deeply rooted in hands-on experiences, often through traditional projects that involve material processing with wood or metal along with courses in graphics, electricity and power technology. On the other end of the spectrum are programs that have evolved through schools of engineering. Some of these programs require teacher preparation students to complete the same course work as any typical engineering major along with additional coursework in pedagogy in order to earn teacher licensure.

In the fall of 2013 a study was conducted to compare the required curricula of those 24 undergraduate programs that maintain enrollment of 20 students or more in order to determine what a composite or composite curriculum might look like. A list of those institutions included in the study is provided in Appendix A.

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Such a composite curriculum could be useful in the process of updating accreditation guidelines used by the *Council on Technology & Engineering Teacher Education* that have now been in place for more than a decade (NCATE/ITEA/CTTE, 2003).

Methodology

This study utilized a multi-part methodology in order to create a composite curriculum undergraduate curriculum for technology & engineering teacher preparation in the United States. First, technology or technology & engineering teacher preparation programs having an undergraduate population of 20 students or more were identified using the *2012/2013 Technology & Engineering Teacher Education Directory* (Rogers, 2012). Next, basic information about critical aspects of each program were determined. Those critical aspects included the following:

a. Number of credits required to complete the program
b. Number of professional credits required
c. Number of technical credits required
d. Number of general education credits required
e. Highest level of math & science required
f. Technical course work most frequently required
g. Professional course work most frequently required

The composite curriculum that was created addresses several key aspects of all technology & engineering teacher preparation programs in the United States including *professional studies* requirements, *technical studies* requirements and some components of *general education* (sometimes referred to as *liberal studies*) such as mathematics and science that are most closely associated with technology & engineering content.

Limitations of the Study

1. The study was limited to those 24 technology & engineering teacher preparation programs maintaining undergraduate enrollments of 20 students or more and may not be indicative of all technology & engineering teacher preparation programs throughout the United States.
2. Information about the size of programs was acquired from self-reported institutional data in the 2012-2013 *Engineering & Technology Teacher Education Directory (2012, Rogers)* that is presumed to be reasonably accurate but not guaranteed to be accurate.
3. The composite curriculum created as a result of this study was based upon existing curriculum requirements for those programs included in the study. As such, it is simply a composite curriculum of what exists now, and may not be reflective of the most contemporary or progressive curriculum from a philosophical standpoint.

Findings

Table 1 shows the findings regarding credit distribution for a composite curriculum that was determined by reviewing the program requirements for the 24 technology & engineering education programs included in the study.

Table 1
Credit Distribution for a Composite Curriculum for Technology & Engineering Teacher Preparation in the United States

	Mean	Range
Total Credits Required	126	120 - 139
Total General Education Credits Required	45	30 - 60
Total Professional Credits Required (includes student teaching)	33	24 - 49
Total Technical Credits Required	44	27 - 57

n = 24

The data indicate that a composite curriculum would be reasonably evenly distributed among the three core areas of *general education*, *professional studies* and *technical studies* that comprise all teacher preparation degree programs in the United States. Table 2 addresses mathematics and science requirements for Technology & Engineering Teacher Preparation programs in the United States.

Table 2
Highest Level Math & Science Requirements for Technology & Engineering Teacher Preparation Programs in the United States

Highest Level Math Required	Frequency	Percentage of Total
Calculus II	1	4%
Calculus I	5	21%
Pre-Calc Algebra	3	12.5%
Algebra & Trig	3	12.5%
Algebra OR Trig	1	4%
College Algebra	4	17%
Statistics	3	12.5%
Funds of Math	4	17%
Highest Level Science Required	Frequency	Percentage of Total
Physics II	1	4%
Physics	10	42%
Physics or Bio	2	8%
Physics, Bio or Chem	8	34%
Physics, Earth Science, Chem	2	8%
Undetermined	1	4%

n = 24

The data indicate a wide range of mathematics requirements with regard to programs. Almost 30% of the programs that were reviewed required no greater math than Statistics, but 25% of the programs required at least one Calculus course. Some form of Algebra was the most frequent type of math required by the greatest number of programs. The data indicated greater consistency with regard to science requirements. At least one Physics course was required more than any other type of science, but many institutions allowed for the selection of any natural science course to fulfill general education and/or major requirements.

Table 3 (continued on next page) addresses technical course work required within the curriculum. For the purposes of the study only required course work was considered. Many curricula that were reviewed included optional and/or elective course offerings but these electives were not considered for the purposes of this study since accreditation guidelines typically focus on required coursework.

Table 3
Most Frequently Required Technical Coursework Identified

Technical Content Required	Frequency
Energy & Power	46
Energy	
Power Systems	
Energy, Power & Trans	
Electronics (analog & digital)	
Robotics	
Automation/System Control	
Fluid Power	
Manufacturing	29
Industrial Organization	
Technological Enterprise	
Wood Manufacturing	
Metal Manufacturing	
Production Systems	
Communication	25
Multimedia	
Desktop Publishing	
Graphics	
Printing	
Design	24
Product Design	
Innovation	

Problem Solving	
Industrial Design	
Engineering Design	
Material Processing	23
Material Testing & Statics	
Construction	19
Introductory Drafting/CAD	16
Advanced CAD	10
Architecture	
CAD/CAM	
3-D Solid Modeling	
Civil Engineering/Arch	
Transportation	6
Technology & Society	6
Senior Design Project/ R&D	5
Medical/Agricultural/Bio-related	4
Engineering Principles	3
Other	
Computer Networking	3
Technological Systems	3
Computer Integrated Mfg.	3
Gateway to Technology	2
Technological Decision Making	1
Applications in STEM	1
Exploring Technology	1
Technology Systems II	1
Dynamics	1
Solids	1
Thermal	1
Machine Design	1

n = 24

With regard to technical content, many institutions have designed their curriculum to reflect the *Standards for Technological Literacy (SfTL)* (Dugger, 2000) and more specifically the portion of the *SfTL* referred to as the *Designed World*. The *Designed World* specifically identifies sectors of technology and the economy as communication, transportation, manufacturing, construction, energy & power, and biological, agricultural and medical technologies that are worthy of study toward the goal of technological literacy. Other aspects of the *SfTL* are reflective of the required course offerings indicated in Table 3 as well. For instance, the *SfTL* recognizes Design abilities as essential to becoming technologically literate and as a result many institutions require some type of course dedicated to design in addition to teaching about aspects of design through other technical courses as well. The information provided in table 3 also indicates that sometimes traditional courses continue to be required in most programs, but often for good reason. For instance, material processing courses are still very prevalent in various curricula reviewed, but in the current era they are often used as prerequisites to courses such as manufacturing or construction or product design. Also worthy of note is the lack of extensive acceptance within the field to aspects of technology such as agricultural, biological or medical technologies that do not have a longstanding history within the field like manufacturing or communication or construction. Similarly, more references to courses with *engineering* in the title might have been anticipated given the profession's recent turn toward engineering in the United States. Lastly, it is worth noting that the data collection method used may have done a bit of an injustice to subjects like electronics and transportation. These subjects were not separated out from the Energy & Power category the way that Drafting was reported separately from courses in the Communication category. Many of the programs reviewed did require courses in electricity/electronics, and many others taught aspects of transportation in conjunction with energy & power courses, creating a judgment call as to where to record these courses in Table 3. Disappointingly, few schools required specific coursework in robotics or automation even though these subjects are very popular in the middle schools and high schools throughout the United States.

The final area of curriculum that was reviewed was the professional course sequence. This area yielded more diversity in the required courses across institutions than would have been anticipated, given the fact that many of the requirements for teacher preparation like teaching methods courses are similar for all teacher preparation subject areas. Some of the variation can be explained by the fact that in the United States, education is a state's right. Therefore, there are no nationally mandated requirements, so teacher licensure requirements can and do vary from state to state. Analysis of the various professional requirements is provided in Table 4 (next page).

Table 4
Most Frequently Required Professional Coursework Identified

Professional Coursework Required	Frequency
Teaching Methods (General)	45
Instructional Techniques	
Curriculum Development	
Assessment	
Student Teaching Practicum	24
Foundations of Technology & Engineering Education	24
Methods of Teaching TE	16
Educational Psychology	16
Teaching Exceptional Students	14
Students of Special Needs	
Inclusion	
English Language Learners	
Professional/Clinical Field Experiences	10
Student Teaching Seminar	9
Multicultural Education	9
Literacy Through Content	8
Early Field Experiences	7
Observation and Participation	
Practicum	
Exploring Teaching Careers	6
Foundations of Education	5
Technology Lab Design/Management	4
Classroom Management	3
Elementary Technology Education	3
Technology for the Elementary	
Integrative STEM for Young Learners	
Design, Tech & Engineering for Children	
Issues in Secondary Education	2
Philosophy of Education	2
Other	
CTE Student Organizations	1
Standards for Technological Literacy	1
Resources for Technology	1
Integrative Engineering Concepts K-12	1
Learning & Motivation	1
Portfolio Assessment	1
Key Concepts for Middle Level Ed.	1

n =24

Not surprisingly, teaching methods courses were the most frequently identified required professional courses followed by the student teaching experience that is a requirement for all teacher preparation majors at all 24 institutions. More interestingly, it was apparent that virtually all of the institutions in the study maintained at least one departmental foundations level professional course and most maintained and required two professional courses from within the department. The data clearly indicate that courses addressing topics such as Exceptional Children in the Classroom and Multiculturalism are becoming more popular along with increased teaching exploration courses and early field experiences well prior to student teaching.

Conclusions

Technology & engineering teacher preparation programs across the United States have been in a state of decline for more than four decades. There are currently only 24 undergraduate technology & engineering teacher preparation programs in the United States with an enrollment of 20 students or more. Among those programs there exists much diversity about what constitutes a required sequence of courses or curriculum to complete a bachelor's degree and earn teacher licensure. Comparing the required curriculum for those 24 programs with undergraduate majors of 20 or more resulted in the design of the following composite curriculum:

Table 5
Courses that comprise a composite curriculum for technology & engineering teacher preparation in the United States based upon requirements in existing programs

General Education (45 Credits) Including:	Professional Studies (33 Credits) Including:	Technical Studies (44 Credits) Including:
College Algebra and 1additional College Mathematics course	At least 2 teaching methods courses addressing topics such as instructional techniques, curriculum, and assessment	2 courses in Energy & Power including Electricity/Electronics and Transportation
1 Physics course	At least 1 methods course specifically in technology & engineering education (most programs required 2 such courses)	1 course in Manufacturing
	1 course in Educational Psychology	1 course in Communication
	1 course in Special Needs children in the classroom	1 course in Construction
	Full semester student teaching experience	1 course in Design
		1 course in Material Processing
		1 course in Drafting/CAD

Only courses that were required by at least half of the 24 programs in the study were included in the composite curriculum provided in Table 5 above. Most of the courses would align quite well with the *Standards for Technological Literacy* (Dugger, 2000). Yet, notably absent are courses like biological, medical and agricultural technologies that are also referenced in the *SfTL.* This data would indicate that more than 12 years after the *SfTL* were published this content has failed to gain widespread acceptance in technology & engineering teacher preparation programs throughout the United States. Similarly, the study identified few courses that specifically embrace the engineering movement by title, although course titles do not speak to the types of activities delivered in existing courses that may help to address engineering content. Lastly, it is important to acknowledge that one significant limitation of this study was that the composite curriculum was derived from existing curricula. As such, it is not necessarily representative of a more progressive curriculum that an accrediting body might wish to foster.

Recommendations

1. As a follow-up to this study program coordinators or department chairpersons should be surveyed to determine factors influencing the design of their required curriculum for technology and engineering teacher preparation, along with factors influencing the recruitment of qualified teacher candidates. Such a survey has been tentatively developed and is provided in Appendix B.
2. The ITEEA's Council on Technology & Engineering Teacher Education (CTETE) should consider updating their accreditation guidelines for teacher preparation programs given recent changes in the field. These guidelines have been in place for more than a decade and were developed in conjunction with the NCATE accrediting agency. ITEEA and CTETE no longer maintain an affiliation with NCATE.

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Appendix A - Institutions Included in the Study

1. Central Connecticut State University
2. Colorado State University
3. Illinois State University
4. Ball State University (Indiana)
5. Indiana State University
6. Purdue University (Indiana)
7. University of Northern Iowa
8. Fort Hays State University (Kansas)
9. Pittsburg State University (Kansas)
10. Montana State University
11. Wayne State University (Nebraska)
12. The College of New Jersey
13. State University of New York at Oswego
14. Buffalo State University (New York)
15. Appalachian State University (North Carolina)
16. North Carolina State University
17. California University of Pennsylvania
18. Millersville University of Pennsylvania
19. Valley City State University (South Dakota)
20. Brigham Young University (Utah)
21. Utah State University
22. Old Dominion University (Virginia)
23. University of Wisconsin – Stout
24. University of Wisconsin – Platteville

Appendix B - SURVEY

Factors Affecting the Design of Technology & Engineering Curriculum at Your Institution

Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree
1	2	3	4	5

1. The *Standards for Technological Literacy* have a major influence on the design of our curriculum.
2. The engineering movement has influenced changes in our required curriculum.
3. Increased math and science requirements would be beneficial but could cost us enrollment.
4. Our curriculum is moving toward an integrative STEM approach for Technology &Engineering education majors.
5. Our curriculum has increased field experience requirements in recent years.
6. The loss of our NCATE SPA affiliation has negatively impacted the perception of our program with administration.
7. ITEEA/CTETE should work on developing a revised set of accreditation guidelines to more accurately reflect current trends in the field.

Directions:
Please provide a limited response to the question provided below.

8. Please identify the single greatest factor shaping the nature of your curriculum at present.

Book Review

Carr, N. (2011). *The shallows: What the internet is doing to our brains.* W.W. Norton & Company. $15.95 (paperback), 228 pp. (ISBN: 978-0-393-33975-8).

Reflecting upon my own life, personally and professionally, with my phone synced to my iPad Mini, which is also synced to my personal iPad, has numerous different audio alerts for emails, texts, iMessages, tweets, and Facebook status updates. My PlayStation3 syncs to my Netflix and Amazon Instant Video, which additionally not only syncs to my iPad, but to my ASUS. My Dropbox alerts me when it has updated files from my work computer.

Technology is not new in its perceived effects on our lives. In 1964, Marshall McLuhan published *Understanding Media: The Extensions of Man*. Within his writing, a popular phrase found its way into our lexicon, "the medium is the message." Carr explains that McLuhan was trying to express "that in the long run a medium's content matters less than the medium itself in influencing how we think and act" (p. 3). Carr takes the premise of McLuhan as a given, and launches a philosophical, historical, and neurological argument that the Internet is changing our ability to think and analyze critically—that our brains are literally changing to crave the instantly gratifying, often trivial, digital world.

From a personal struggle, Carr began to realize that the Net had a strong influence over him more than the disconnected computer ever had. Carr, even when away from the Net, desired to be connected—checking emails, googling, clicking links. He was troubled that he intensely struggled to pay attention to one task for more than a few minutes—it was if his brain was actually changing. Was it?

Carr begins *The Shallows* by relating to the readers. In using Stanley Kubrick's *2001: A Space Odyssey* as a cycling metaphor, Carr begins with the quote, "Dave, my mind is going," to which Hal responds, "I can feel it. I can feel it." Carr hasn't been the only one to feel that his brain was changing—pathologists, doctoral students, authors—well-educated men and women expressing to Carr that they can no longer read long written works, or pay attention to one task for more than a few minutes, or read critically, only skimming for important pieces of information. They yearned for him to understand that they physically could not do those tasks that they used to do so easily. Understanding that he was not alone in what was occurring to him, Carr begins his search to determine what the internet is doing to our brains.

Technology is any piece that makes a task easier for us. Carr looked historically at different technologies throughout history to see if people changed in response to the technology. He found that they had. For example, Friedrich Nietzsche, a German philosopher from the 19th Century, due to physical ailments, had to give up his pen-and-paper writings. Falling into depression, he ordered a typewriter—a new technological advance in his time. He resumed his writing, but, his audience discovered, his writing had begun to change. His "prose became…tighter, more telegraphic" (p. 18), and when questioned, Nietzsche replied, "Our writing equipment takes part in the forming of our thoughts" (p. 19). Even the ideas of the alphabet, reading, and writing, are technologies. Before the invention of the alphabet, we were oral societies—"knowledge is what you can recall, and what you recall is limited to what you can hold in your mind" (p. 56). With the invention of the alphabet, and subsequently reading and writing, we no longer had to train our brains and commit all to memory; we could write down what we wanted or needed to remember and we no longer had to tax our brains for all vital information. However, we must be cautious because "once technologized, the word cannot be de-technologized" (p. 77). As new technologies appear, our brains will continue to route and re-route new pathways to conform to new technologies.

Carr maintains that the Internet as a medium for information has changed the way we process information. The Net is changing at an alarming rate—as is our use of it. For example, "American children between the ages of 2 and 11 were using the Net about 11 hours a week in 2009, an increase of more than 60% since 2004" (p. 86). "The typical American teen has jumped from 2,300 to 3,300" (p. 228) texts per month in only a couple of years. Facebook, if it was a country, would be the third largest country in the world. These statistics are often used to prove that we, as a society and as students, are reading more than we did 20 years ago—and that's true. However, we are "devoting much less time to reading words printed on paper" (p. 88) and that those are two different types of reading. Reading in the cognitive sense not only relies on our sense of sight, but our sense of touch. When we transfer our reading from paper to a screen, we navigate the text differently as well as "the degree of attention we devote to it and the depth of our immersion into it" (p. 90). When we choose to read the majority of our words on a screen, rather than paper, "we don't see the forest…we don't even see the trees. We see twigs and leaves" (p. 91).

Scientifically, dozens of studies have found that when "we go online, we enter an environment that promotes cursory reading, hurried and distracted thinking, and superficial learning" (p. 116). The more we become connected to the Net, the more we push to do more on the Net, the more we find that our brains are becoming "different" (p. 120). We are becoming scattered in the information superhighway, and we are not gaining knowledge from the Net. David Brooks writes, "I had thought that the magic of the information age was that it allowed us to know more, but then I realized the magic of the information age is that it allows us to know less" (p. 180). Our brains are unparalleled in their ability to create new synapses when needed, but the flipside is also true—when we no longer use synapses, they cease to fire; "we become, neurologically, what we think" (p. 33). What we are becoming are simply "hunters and gatherers in the electronic data forest" (p. 138).

Advances in technology are fun, exciting, and often pose easier ways to do things. They are alluring, bright, and feed into an addiction we don't even realize we have. However, we must be cautious to the degree we are allowing ourselves, our human elements, to become digitized, or worse, dispensable. Are we going to become so machine-like that we, in essence become a machine? "That's the essence of Kubrick's dark prophecy: as we come to rely on computers to mediate our understanding of the world, it is our own intelligence that flattens into artificial intelligence" (p. 224).

Full of scientific and scholarly discussion weaved through prose that speaks to the readers, this book is intended for most everyone. High school students through senior citizens would benefit from the reading of this book. Carr's intention is to start the discussion that the Net is changing our brains physically and physiologically. There is scientific evidence that this is occurring and we must, as a society, begin talking about what we are doing to ourselves and our constant need to be connected. Carr feels that there are changes to be made, but without a starting conversation, things will never change.

The anecdotes and examples Carr lists could have been written about me or any number of my friends and colleagues. On a philosophical level, I am drawn to what he explains has occurred throughout history as new technologies have entered our world. As a scientist, I want studies, conclusions, and facts to prove to me what is occurring in my brain. Carr delivers on both levels. Historically, Carr frames technologies and their intended and unintended consequences against the framework of time, while at the same time, offers multiple scientific studies that support what we have seen throughout history—technology changes us. In the case of the Net, not all changes are positive and some can have drastic consequences. At the same time, I do not feel that Carr is condescending to us as a society, but instead comes to us, the readers, on our level, offering a hand of support upon this possibly dangerous journey we have embarked upon.

There is no question that we rely on the Net. For personal and professional purposes, many of us are connected 24/7. We answer the dings of new email messages, the chirps of new Tweets, the 'woosh' sound of a sent text. We are drawn to the digitized society we have created for ourselves in the cool, crisp cases of phones, tablets, and laptops. However, it is imperative that we understand what this constant connectivity is doing to us on a physical and physiological level. If nothing else, this book opens the door for this understanding.

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The *Journal of Technology Education* provides a forum for scholarly discussion on topics relating to technology and engineering-related education. Manuscripts should focus on technology and engineering-related education research, philosophy, and theory. In addition, the *Journal* publishes book reviews, editorials, guest articles, comprehensive literature reviews, and reactions to previously published articles.

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