AC 2011-1452: SPECIAL SESSION: MOVING TOWARDS THE INTENDED, EXPLICIT, AND AUTHENTIC: ADDRESSING MISALIGNMENTS IN ENGINEERING LEARNING WITHIN SECONDARY AND UNIVERSITY EDUCATION

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Special Session: Moving towards the Intended, Explicit, and Authentic: Addressing Misalignments in Engineering Learning within Secondary and University Education

Abstract

Our four-year NSF-funded study has identified two important misalignments in the curricula of engineering students at the 9-16 level—one related to explicit connections between mathematics and precollege engineering coursework, the other between professional practice and college engineering programs. Our study of grades 9-12 intended and enacted curricula in *Project Lead the Way* (PLTW) reveals that early on, even though connections to other subjects are intended, explicit connections are infrequent, and math standards are only weakly incorporated. As part of the study of high school level engineering coursework, we analyzed intended, assessed and enacted curricula from the PLTW foundations courses. Findings include insight into the level of explicit integration of math and engineering, and how PLTW experiences influence teacher's views about preparing students for engineering careers. Implications for practice include the importance of creating awareness surrounding the need for instructors to make explicit connections at an early stage in precollege engineering so that students can improve their academic preparation as well as career readiness. Our studies of engineering practice indicate that curricula in high school and college give students an incomplete picture of engineering work and what engineers do and often do not develop the full skill set needed to successfully execute increasingly complex, interdisciplinary, and international projects in the engineering workplace. Research methods in studying engineering practice included mixed quantitative and qualitative online surveys, interviews with practicing engineers, and case studies of engineering firms. We found that effective engineers value communication, problem-solving, teamwork, ethics, life-long learning, and business skills. Many of them note that their undergraduate education did not always prepare them well in these areas. Because of these two misalignments, we hypothesize that potential engineering talent goes underdeveloped at important stages of educational pathways as students move from high school to college. We believe that incorporating these findings into an interactive special session would be of great value to the ERM community as well as our partners at the secondary school levels.

Keywords: engineering practice, engineering education, secondary level, explicit transfer

Background

As engineering practice constantly evolves through innovation and changing contexts, educational practice arguably needs to keep pace. According to *The Engineer of 2020*, the U.S. will not sustain its leadership and share of jobs in high-tech professions unless engineering education content and methods adjust to meet the demands of the workplace (NAE, 2004). Statistics from the American Society for Engineering Education indicate that U.S. engineering programs already fall short of supplying the country's demand for engineering talent (Grose, 2006).

There are many possible approaches to generating increased engineering talent within the United States and in countries around the world. In this study, we have worked to address this problem using two approaches. First, we have studied the *Project Lead the Way* (PLTW) foundations courses, including the content of the curriculum and instruction of these courses within U.S. secondary schools. As a complimentary study, we surveyed high school teachers about their beliefs about precollege engineering. Second, we have studied the work of professional engineers with the goal of suggesting means to improve the alignment of undergraduate engineering education with professional practice. In this proposed special session, we will use the findings generated from these two areas to detail means for improving engineering education at both the secondary and undergraduate level.

Secondary Engineering Education

Methodology

Our curriculum content analysis examined the intended and assessed curricula (Porter et al., 1988) of the PLTW foundations courses (Introduction to Engineering Design™ (IED), Principles of Engineering ™ (POE) and Digital Electronics ™ (DE)). The initial questions we posed regarding these curricula were predicated on the NRC report *Rising Above the Gathering Storm* (2007) – how can we better prepare students to meet the demands of a highly technological, global workforce in order to keep the United States competitive amongst developed nations? We performed content analysis using the framework suggested by the National Research Council 2004 Report, *On Evaluating Curricular Effectiveness: Judging the Quality of K-12 Mathematics Evaluations* (Confrey & Stohl, 2004) and using the National Council of Teachers of Mathematics (NCTM) content and process standards for grades 9-12. In addition to the PLTW courses, we also reviewed 12 high school math textbooks used in algebra, geometry and trigonometry courses to understand differences in the mathematics standards covered in PLTW versus academic mathematics courses (Nathan et al., 2008). We also studied all three PLTW foundations courses for explicit connections between mathematics and engineering concepts and skills. We identified four areas of analysis for each of the three curricula. From the student materials, we analyzed the planning materials, activities and assessments. From the teacher training materials, we looked at what teachers were presented with at the official summer training institutes (Table 1). Our content analysis focused on examining the content of the materials. We recorded the number of NCTM mathematics standards specifically connected to the engineering curriculum for each unit (Prevost et al., 2009).

Table 1: Materials for Analysis within each PLTW Curriculum

Intended Curriculum		**Assessed Curriculum**	**Enacted Curriculum**
Student Materials			*Teacher Training Materials*
Planning (Anticipatory Set; Concepts; Daily Lesson Plan; Performance Objectives; Presentations)	Activities (Worksheets; Hands-on work)	Assessments (Projects; Presentations given by students; and Written examinations)	Training Materials (Training documents; Activities; Projects; and Self-Assessment and Self-Reflection Items)
In the set up to the lesson or within the materials presented during the lesson, are math and science concepts explicitly connected to engineering concepts or activities?	Are students directed to actively connect math and science concepts to engineering concepts in their class work or homework?	Are the students assessed in a way that allows them to demonstrate connections of math and science concepts to engineering concepts?	Is the teacher presented with materials in training that would explicitly connect science and math concepts to engineering concepts?

Lastly, we analyzed each of the PLTW foundations courses as they were enacted. We videotaped a number of classes in each of the foundations courses. Our analysis consisted of studying the number and nature of the connections of mathematics and engineering skills and concepts using standards in both areas (Nathan et al., 2009; Prevost et al., 2010). First, the videotapes were digitized and entered into Transana (see www.transana.org), a computer application for discourse analysis that integrates the video, transcript text and codes. Classroom sessions were segmented into clips, and clips were coded to reflect the points of interest noted in our research questions, in a manner similar to Nathan et al., 2009. Our coding framework delineated two dimensions that are especially relevant here:

A. *Concepts* mark engagement with “big ideas” from STEM, such as: modeling in engineering; force and work in science; and algebra in mathematics. We separately note whether math concepts are explicitly integrated for students during instruction.

B. *Skills* address process-oriented tasks that are important for doing practical engineering work, such as problem solving and project management. We separately note whether math skills are explicitly integrated for students during instruction.

Concepts and Skills

The individual codes in this group were taken from mathematics standards recommended by the National Council Teachers of Mathematics (NCTM) for grades 9-12 as well as elements of the engineering design process. Additionally, in some cases we included codes that reflect important concepts identified in the literature (Nathan et al., 2009). Lastly, some of the codes were derived from classroom observation itself.

Table 2: Concept Codes

Code	**Description**
Mathematics: Algebra	Understand patterns, relations, and functions; Represent and analyze mathematical situations and structures using algebraic symbols
Mathematics: Geometry	Analyze characteristics and properties of two- and three-dimensional geometric shapes and development of mathematical arguments about geometric relationships; Specify locations and descriptions of spatial relationships using coordinate geometry and other representational systems; Apply transformations and use symmetry to analyze mathematical situations
Mathematics: Measurement	Map out the measurable attributes of objects and the units, systems, and processes of measurement and application of appropriate techniques, tools, and formulas to determine measurements
Mathematics: Number	Understand numbers, ways of representing numbers, relationships among numbers, and number systems; Understand meanings of operations and how they relate to one another; Compute performed fluently and reasonable estimates made
Engineering: Design Basis	Emphasis on the importance of creating a pre-specified "statement of the problem" or system requirements.
Engineering: Feedback	The incorporation of real-time control systems for measuring and responding to changes in state. Not to be confused with feedback on how the product works (either from users or during the testing and evaluation design stage).
Engineering: Functional Analysis	Determine how a system works, and what the purpose of each element of the engineered system is.
Engineering: Modeling	A representation of a design or system. Can be "literal" (as in a physical or electronic one-, two-, or three-dimensional model of the design itself) or symbolic (as in when equations, graphs, or schematics represent interesting aspect of the design). Sometimes the model is explicitly coupled to an analysis or testing/evaluation task.
Engineering: Re-Engineering	Improvement upon an existing design. This may require "reverse-engineering" if design artifacts like drawings and models are not available.

Engineering: Structural Analysis	Determine the strength of materials in a structure based on empirical testing or calculation of forces/stresses and understand the conditions necessary to conduct this analysis.

Skills codes are distinct from concept codes in that they focus on process-based procedures which allow the student to perform actions or apply learned concepts. Often, a student must understand an underlying concept in order to be proficient in a certain skill – for instance, in order to skillfully hit a target using a ballistic device, a student must understand some of the interrelated concepts from geometry, physics and measurement, among other things. The math skills are captured in the NCTM's *process* standards.

Table 3: Skill Codes

Code	**Description**
Mathematics: Communication	Organize and consolidate mathematical thinking through coherent and clear communication to peers, teachers, and others; Analyze and evaluate the mathematical thinking and strategies of others; Use the language of mathematics to express mathematical ideas precisely.
Mathematics: Connections	Recognize and use connections among mathematical ideas; Understand how mathematical ideas build on one another to produce a coherent whole; Recognize and apply mathematics in contexts outside of mathematics.
Mathematics: Problem Solving	Solve problems that arise in mathematics and in other contexts, using appropriate strategies.
Mathematics: Reasoning	Develop, select and evaluate mathematical arguments and proofs.
Mathematics: Representation	Create and use representations to organize, record, and communicate mathematical ideas; Use representations to model and interpret physical, social, and mathematical phenomena.
Engineering: Understanding Constraints	Ability to keep in mind parameters of the project while creating a solution.
Engineering: Creating Hypotheses	Generate an idea for testing based on knowledge of what might work (from math or physics, for example, or even other things that exist - a bridge in your neighborhood, something found in nature or even experience).
Engineering: Project Management	Figure out what must be done at certain time points in order to meet a deadline.
Engineering: Use of Software for Design	Use of computer aided tools for creating and modeling the project.

We added additional coding to indicate whether the mathematics and engineering were explicitly connected in a given clip. *Explicit integration* is defined as any instance wherein the materials specifically point to a mathematics principle, law, or formula, and depict how it is used to carry out or understand an engineering concept, task or skill (Prevost et al., 2009). Learning skills and new concepts requires a conceptual basis that is specifically pointed out to the student for it to be impactful (Bransford and Schwartz, 1999). Implicitly embedded concepts and skills are those in which the conceptual basis for understanding how mathematics is used for engineering is folded into the lesson, but not specifically pointed out by the instructor. Occasionally, but rarely, students will discover these connections on their own, even though they may be readily apparent to teachers, curriculum designers, and other content experts. Examples of explicit and implicit math integration in a PLTW course follow.

<u>Example 1</u>: Excerpt illustrating explicit integration of math with engineering

In this example two students are discussing the design of their project, a ballistic device, with their instructor:

S: ((At the same time)) Different, different angles.

S: A protractor sitting here. With a string with a weight on it. So as you tip it it'll that'll tell you what degree you're tipping it.

T: I like that. That's nice.

S: So that tells you what degree so we can figure that out.

In this example, the students chose a catapult as their ballistic device, and are explaining how they will measure the angle of trajectory. The mathematics concept central to this discussion is how to measure angles from the vertical. The explicit integration of this concept is how the students hang a weighted string off of the arm of the catapult in order to measure this angle directly (Lines 2-3). These explicit connections indicate that the students understand the mathematics within the context of the engineering, using mathematical terms.

<u>Example 2</u>: Excerpt illustrating implicit integration of math with engineering

In this example, the instructor is getting ready to test the balsa wood bridges that the students constructed using weights in an effort to break the bridge. The students will determine which bridge performed the best by comparing the weight of the bridge to the amount of weight it held. The students must record the weight of the equipment being used as well as their bridge and the variable weights being added in order to perform this calculation.

T: The cup, cup is sixty-three grams or two point two ounces. The hook, the hook is four ounces, if you're writing this down, or a hundred and fourteen grams.

S: Are we doing this in grams or ounces?

T: Your choice.

S: Grams.

T: You're gonna find grams are gonna be a little more accurate.

S: Grams (indecipherable).

T: Right, the unit's not important, we don't care if it's ton, pounds, grams, ounces, it's a comparison of one bridge to the others. So I would go grams cuz it's gonna be more accurate.

In this excerpt, the instructor has at least two opportunities to explicitly connect mathematics to the lesson. While they are using math to compute the strength of their bridge, and the instructor does say that they are going to compare one bridge to another (Lines 8-9), this is not an explicit explanation as to why when making ratios the unit is not important for this comparison. Secondly, the instructor mentions that grams are going to be "more accurate" for this comparison than ounces (Lines 6, 8-9), but he does not take the time to explain that grams are smaller units and therefore more resolute, or to explain how one unit of mass can be converted to the other.

In addition to studying the PLTW curricula, we also surveyed teachers both of academic subjects (math and science) and PLTW. Our goal in this particular aspect of the broader study was to develop a statistically reliable instrument to document what beliefs teachers hold as they pertain to precollege engineering and to explore the role these beliefs play in promoting technical education and engineering careers (Nathan et al., 2010). The survey was administered online and analyzed using t-tests comparing the PLTW teachers' responses to the responses of those who strictly taught mathematics and science subjects.

Findings

One major finding from these studies is a misalignment in precollege engineering education between intended and assessed curricula with regards to explicit integration of the mathematics and engineering. PLTW should be grounding students' conceptual knowledge of math and science to real world applications and allowing students to generalize their knowledge and apply it to new problems and applications. However, similar to the NAE (2009) report *Engineering in K-12 Education*, we find areas where STEM integration can be improved. In Introduction to Engineering Design (IED), for example, very little mathematics is included. When math is present it tends to be implicitly integrated. Explicit integration was expected to be shown by students in the assessed materials but not presented in an explicit way when considering the intended materials. Principles of Engineering (POE) showed an increase in the amount of explicit integration of math in all areas, however, we did notice that there was still disconnect in the intended versus assessed curricula, but in the reverse of IED. That is, the planning materials and activities were more explicitly integrated than in IED, but the assessments were not explicitly integrated. The final foundations course, Digital Electronics (DE), was the most integrated overall. The addition of math lessons is one reason for this. DE uses math that is beyond the 9-12 NCTM math standards. The use of logic and Boolean Algebra are not typically covered in the high school curriculum (Prevost et al., 2009). The enacted curriculum, analyzed and presented in separate studies, mirrored these findings (Nathan et al., 2009; Prevost et al, 2010). To summarize our major findings, when reviewing several hours of videotaped classes, we observed explicit integration of math and engineering 30% of the time in IED, 52% of the time in POE and 78% of the time in DE, showing a continued trend of improvement over the three PLTW foundations courses overall with regards to explicit connections. Thus, while PLTW does allow students to explore precollege engineering using interesting projects, it could be improved with more attention paid to explicit integration. With regards to teacher beliefs, we found that, in general, teachers' decisions were influenced both by academic and social factors (Nathan et al., 2010). When we compared PLTW teachers' opinions to academic subject teachers' opinions, one major difference was how they viewed the importance of academic achievement as an indicator of future success in engineering. Essentially, the math and science subject teachers were more likely to think that academic achievement in high school was more important if a student wants to pursue a career in engineering than PLTW teachers. We also saw that PLTW teachers were more likely to see their instruction as effectively integrating science and math concepts with engineering activities, even though we saw evidence that this alignment could be improved.

Implications

The need to integrate academic subject matter with career preparation has been mandated by policies such as the Carl Perkins act (reauthorized in 2007), Race to the Top funding, and the America COMPETES act. However, we saw that there was a difference in teacher opinions about the extent of integration of math and science with precollege engineering. PLTW teachers were more likely to think that there was integration in these areas than those who taught the academic subjects, suggesting differences in their classroom practices related to integration (Nathan et al., 2010). This is a concern given the evidence in our PLTW curriculum studies, where we found the amount of explicit integration to be noticeably lacking in the earliest of the foundations courses (Nathan et al., 2009; Prevost et al., 2009). Since the Learning Science community has shown that explicit integration is essential for students to be able to effectively transfer knowledge to novel settings (Bransford and Schwartz, 1999), we emphasize the need for continued analysis of teacher beliefs compared to what is observed in the intended and enacted curriculum in order to continuously improve student experiences.

In addition, to create meaningful, sustained change in engineering education practices, studies of teacher beliefs and expectations will need to continue to be conducted so that policies and programs are aligned with teacher views. We know from other work that teacher beliefs have an impact on curriculum reform efforts (Nathan, 2010). When we consider the views of academic subject teachers and PLTW teachers, we see that academic subject teachers place more emphasis on the need for academic achievement than PLTW teachers. This leads us to consider the broader issue of the purpose of precollege engineering. Will we pursue efforts to make engineering appealing to all students or just the academic elite? Certainly, knowledge of mathematics and scientific principles are essential to success in an engineering career, but there may be benefits to also emphasizing additional skills and knowledge such as communication, the ability to work with others and to understand the broader context for engineering (Nathan et al., 2010). Many who see precollege engineering as entry to a career in engineering view this pathway as appropriate for academic elite – designed to maximize the science and math. Others see precollege engineering curricula as an opportunity to expose and attract more students from diverse backgrounds to the field (Lewis, 2007). Findings from the field of Engineering Practice contribute nicely to this discussion.

Engineering Practice

Extending the findings from precollege engineering classrooms, not only are there questions about the purposes of precollege engineering, there are also questions about how undergraduate engineering coursework should be designed. Our research group studied the work of practicing engineers to understand how undergraduate engineering can better reflect the actual work of engineers. We hypothesize that improving the alignment of undergraduate programs with professional practice will better attract and retain engineering students. After reviewing literature on engineering work and discussing our methods, we review some of our findings on the nature of engineering practice and how engineers perceive misalignments between their work and typical undergraduate coursework.

Literature review

With a goal of better aligning engineering education with the constantly advancing work of engineering, it is first necessary to have a clear picture of that work (Trevelyan, 2007). Currently, that understanding is limited (Collin, 2005); expanding it could help educators better explain to students the relevance of coursework and motivate their learning (Trevelyan, 2007).

A few studies have begun to improve this understanding of engineering work and suggest means to improve education. Trevelyan (2007), for example, found that a great deal of an engineer's time involves coordinating the work of other people. He suggests that engineering education should involve more complex tasks requiring multi-faceted and interdisciplinary connections among groups of students. Jonassen, Strobel, and Lee (2006) describe workplace problems of engineers as being much more complex than those typically found in engineering coursework, particularly as they involve both technical and non-technical constraints, including budgets, time pressure from clients, and clearly communicating with co-workers. They also see most engineering programs as falling short of providing such rich problem solving experiences. Korte, Sheppard, and Jordan (2008) describe the early work experiences of engineers and how well their education prepared them for this transition to a work environment. In so doing they describe the work environment. Like Jonassen, et al., (2006), Korte et al. point out that educators should improve engineering education by working on more real-world problems that also require navigating social and organizational contexts involving more complexity, ambiguity, and subjectivity than classic problems and activities within courses. Korte et al. also note that while employers often rate new graduates highly in areas of technical preparation, they are much more likely to rate new graduates' communication and business understanding as inadequate. These skill areas could also find greater emphasis in undergraduate education.

In order to frame our study of the engineering workplace, we drew upon the work of David Shaffer (2007) as he describes epistemologies of work practice. He describes each profession as having a unique set of skills, knowledge, values, and ways of thinking that creates their unique epistemic frame. As they approach problems and interact with other professionals, they do so through that unique framework. As individuals participate in a professional community, they come to develop an identity within that community that resonates with this epistemic frame. In our four-year study, we have been working towards a better understanding of this epistemic frame of engineers and considering better means to help students develop this frame.

Methods

In our study of engineering practice we used a mixed methods approach of surveys, interviews, and observations to understand engineering learning. A total of 353 engineers or engineering managers were involved in our study to date.

The initial online survey contained 60 questions. Thirty-two questions had a likert-scale format, such as asking about where they learned a certain skill or how well their education prepared them for their work. Remaining questions were open response, such as asking engineers to describe how their education could have better prepared them for their work. We sent surveys to a sample of engineering alumni of a large, public research university for whom email addresses were available. We used responses from alumni who identified themselves as currently being either engineering managers or practicing engineers (N = 204). Arguably, there will be a selection bias within the survey as respondents all chose to attend one particular institution, and statistically they do not represent all engineers or disciplines. However, the variety of engineering disciplines represented and individuals' differing backgrounds do provide a useful cross-section of engineering practice. Our research group is currently administering a larger quantitative survey of engineers to produce more generalizable results—expected N of 1200 with a wide variety of backgrounds.

Engineering students conducted a portion of the interviews as part of their first-year, basic communication course. After going through IRB training, students each interviewed a practicing engineer using a protocol consisting of 15 open ended questions (N=99). These questions asked engineers about their background, their reasons for becoming engineers, and their continuing education. Students either interviewed engineers they knew, engineers on campus for professional development courses, or engineers assigned to them online through the MentorNet program. These engineers came from a wide variety of disciplines and backgrounds; while most lived in the Midwest, many lived throughout the United States and four lived in other countries.

Interviews and observations were also conducted within six case-study engineering firms. Three researchers were the leads on two sites each, visiting these firms multiple times over a series of three to six months, interviewing more than 50 engineers total and conducting more than 30 hours of observations across the sites. Observations included asking the engineers how they learned to do what they were doing. Only a small fraction of individuals who were interviewed by the researchers or students attended the same university as the survey participants, adding more generalizability to the perspectives shared in our study.

Engineers involved in the surveys and interviews had similar demographics. In the surveys, 84% were male and 16% female, and in the interviews 85% were male and 15% female. With self-reported ethnicity, in the survey, 87% were white, 3% Latino, 1% black, and 4% Asian. In the interviews, 89% were white, 3% black, 7% Asian, 1% Latino.

We used *The Engineer of 2020*, the American Society of Civil Engineers' *Body of Knowledge* and Hatfield and Shaffer's epistemology research (2006) to develop the survey questions. The interview protocol originally focused on gaining further elaboration and open-ended responses to survey questions, but evolved to also elicit deeper reflection on engineering thinking and learning. Observations served to validate survey and interview data in seeing how engineers' education factored into their job practice.

To analyze the data, we first coded survey and interview data based on the themes within the questions (e.g., personal background, job description, values, skills used, qualities of effective engineers, and learning). Based on emergent themes, we broke this coding down into more nuanced categories, such as where engineers learned, why certain skills were engineering skills, and what it meant to think like an engineer—using a thematic analysis approach (Boyatzis, 1998). Researchers initially coded multiple interviews together and continually discussed proper use of various codes in order to ensure consistency and reliability. One lead researcher supervised and coached others in data analysis process and coding, which further increased reliability. To aid in this data collection and analysis we used NVivo, a powerful software program especially designed to code qualitative data.

Findings

Unsurprisingly, the key element of engineering repeatedly brought up by engineers is problem solving. They define themselves as "problem solvers." Some engineers emphasize the technical nature of this problem solving: "[An engineer is] someone who can look at a situation objectively and use their knowledge and skills to brainstorm solutions." But, most engineers mention that there are many nuances to what they do to solve these engineering problems, particularly when many of them are not typical technical tasks. We observed engineers testing new equipment, designing new circuit boards, building a model of a specialized product, and researching how to redesign a particular device. However, we were more likely to observe these engineers discussing a problem with a new product in a meeting, learning from a company knowledge sharing event, coordinating a test with an outside facility, or scheduling a trip to China to meet with a client. As one engineer said, "I probably don't spend more than say two or three hours [per day] on looking at technical stuff."

Engineering problem solving generally requires connecting multiple people from varying backgrounds who all need to be on the same page about the product or problem specifications, and about the budget and time available to complete the project. More and more of engineering overlaps with the business world. As another engineer reported, "Engineering is not about numbers and formulas. Engineering is more about interacting with your customers." Therefore, the key skills needed in engineering work become people skills. From our survey responses, the number one skill that engineers see as essential to their work is communication. The second is technical problem solving ability, and the third is teamwork. Generally, engineers saw that the main challenges in their work did not stem from technical issues, but from coordinating their work with others, including co-workers, managers, clients, etc. As one mentioned, “Engineering is the easy part. It’s the people that are difficult.”

When engineers reflect on their undergraduate education, they express mixed views. From survey responses, most engineers (62.5%) noted that this education prepared them well or very well for their current work. On the other hand, some of these same engineers and many others said that their real learning came “on the job.” When engineers positively talked about their undergraduate preparation, we inferred that some felt it prepared them as well as it could for their work, given its limitations. Practicing engineers mentioned encouraging new engineers to “put away your textbooks and find a mentor” to learn how to be an engineer and do their jobs. A few engineers were more critical of their undergraduate education, noting that they did not receive the training that would have been most helpful. As one said:

> “In my current position I feel that college did not prepare me for much of my job roles. I needed more training in business and economics... Additionally, I didn't receive adequate training regarding how to manage projects. Obviously we did projects as students but that's completely different than scheduling and planning, dealing with contractors, writing scopes of work, etc... Probably my courses in technical communication are most beneficial because a poorly written project scope can result in misunderstandings and a request for funding of a $1M job that isn't written well will decrease the chances of the job getting approved.”

In our observations of their work, we found that about half of the engineers were able to connect what they were doing with specific technical skills they developed in undergraduate coursework. Most said that the problem solving and thinking skills were the most beneficial results of their education in all that they now did at work. When interviewed or surveyed about where they learned the skills they now use, the most common response was on the job—by learning from others and by doing it.

While engineers often said coursework did not teach them to be engineers, they sometimes mentioned that internships and extra-curricular activities did. One interviewee talked fondly about working on a nuclear reactor project and machining a room full of electrical parts. He credits this experience with giving him the skills to land his first job and to understand real engineering. Many interviewed engineers felt that an internship, co-op or other similar experience should be required as part of undergraduate education.

Implications

Based on these findings, specific efforts at improving engineering education should be continued or begun. First, college of engineering faculty should emphasize authentic problem-solving that connects with real or mock clients, that requires learning new skills, and that requires coordinating efforts with a diverse group of people (including engineers from various disciplines, technicians, and business students). Because engineers note that they did not learn to think like engineers until they were working on real problems while being mentored by more senior engineers, faculty or graduate students should take on roles as practicing engineer mentors. They could also take on roles as mock clients where actual clients are not available. This type of learning needs to move beyond the senior design seminar and become a greater portion of learning throughout undergraduate education.

Additionally, faculty members need to explicitly connect learning about proper communication to engineering courses. There should not be an assumption that these skills will be sufficiently learned in communications courses that are devoid of technical content. Instructors cannot assume that students will be able to work in groups properly, give good presentations, send clear emails, or write proper technical reports. Standards and expectations on those assignments need to be clear, such as could be done in a rubric. Faculty could also emphasize tools to coordinate work and communicate efficiently and clearly—keeping the projects well organized.

One way to accomplish these goals would be to require participation in extracurricular programs, internships, or cooperative programs, which engineers repeatedly cited as crucial learning experiences. Such programs would be further improved by creating scaffolded learning experiences connected to them: students would be part of a seminar or course that specifically connects learning within these programs with learning in other courses, making the transfer of knowledge more explicit.

Overarching Conclusions

Much is being done around the world to improve engineering education at the secondary and post-secondary levels. Many programs exist to teach engineering to students in K-12 and to teach undergraduates to think and work like professional engineers. Nevertheless, more needs to be done. There continue to be misalignments in this educational process. In precollege engineering programs, educators should be working toward aligning curriculum that is intended to integrate engineering, math, and science with what is actually taught in classrooms. In undergraduate coursework more needs to be done to connect students' experiences with what they will actually encounter in the workplace.

One significant connection between these two misalignments is in the area of knowledge transfer. Both undergraduate and secondary students need more explicit help in connecting the learning and skills of coursework (such as mathematics, physics, etc.) with the actual design, build, and test processes in engineering. Perhaps, practicing engineers do not always see the benefit of their undergraduate education because they are not taught in such a way as to transfer their technical and theoretical knowledge to workplace situations. Engineers frequently stress that they learned how to think and solve problems in undergraduate education, which makes sense as these broad skills more clearly apply in most situations. High school students, like undergraduates, may find it easier just to play around with design parameters instead of systematically applying theory and mathematical knowledge to support their efforts to find the correct answer.

These findings suggest that it would be beneficial to explicitly connect or even integrate foundational coursework in math and science with upper level design work or actual internship experiences. Precollege engineering could also be an integrated math and engineering course over two class periods. Professors and secondary teachers should be working in interdisciplinary teams across math, science, and engineering, as suggested in recent ideas on convergence in research (Sharp, et al., 2011). While these connections are supposed to happen within *Project Lead the Way,* actual practice varies in foundational courses. In most undergraduate programs these connections are not the norm, although some institutions are beginning to emphasize such practice.

In both precollege and college engineering, students should be involved in teamwork, with individuals of varying specialties (high school) or departments (college). As they come together to design, build, and test a device or product, instructors should not only consider technical output, but also application of foundational knowledge and group coordination and communication in meeting their goals.

Final Recommendations

Precollege and college educators should:

- Align curriculum that is intended to integrate engineering, math, and science with technical concepts that are part of courses and taught in classrooms
- Connect students' experiences with what they will encounter in the workplace.
- Help students connect learning and skills of coursework such as mathematics, physics, and chemistry with the actual design, build, and test processes in engineering.
- Help students systematically apply theory and mathematical knowledge to support an answer rather than just play around with design parameters.
- Connect or even integrate foundational coursework in math and science with all levels of design work and actual internship experiences.
- Work in interdisciplinary teams of instructors across math, science, engineering, and business.
- Involve students in teams and help students learn group coordination and communication as well as the technical knowledge.

Researchers, assessment directors, and faculty development professionals need to:

- Help instructors understand the importance of explicit integration for students to effectively transfer knowledge to new situations. Why? Explicit integration is essential for students to be able to effectively transfer knowledge to novel settings (Bransford and Schwartz, 1999).
- Study teacher beliefs and expectations and work to align policies and programs with teacher views. Why? Teacher beliefs have an impact on curriculum reform efforts (Nathan, 2010).
- Continue analysis of teacher beliefs compared to what is observed in the intended and enacted curriculum. Why? The success of reform-minded curricular materials depends on teachers' beliefs and understanding, as what is intended does not necessarily match what is enacted (Ball and Cohen, 1996).

- Design workshops to help instructors implement conclusions from and contribute to research in engineering education. Why? General teaching methods in engineering education still do not follow best practice according to research (Rugarcia, Felder, Woods, & Stice, 2000).

All instructors and engineering educators should:

- Make engineering appealing and accessible to all students, not just the academic elite.

We hypothesize that as engineering education continues to make these changes it will attract and retain more students and a greater diversity of students to the field—a design challenge worth undertaking.

Special Session Connections

We believe that incorporating these findings into a special session would be of great value to the Educational Research Methods (ERM) community as well as our partners in other ASEE divisions and those at the secondary school level. The session we have designed includes an interactive, engaging set of activities—along with supporting information—that will enable participants to better understand the nature of these misalignments and the challenges facing instructors and curriculum developers (see appendix 1 for session outline and appendix 2 for example assignment). Participants will leave the session with concrete ideas, based on empirical research, for how to better align their instruction with foundational technical/mathematical skills and engineering practice. We will share: 1) insights into engineering epistemologies within current social and economic contexts based on ethnographic work within six engineering firms; 2) insights into how to improve engineering learning mechanisms based on research into *Project Lead the Way* curriculum and instruction and on alignment with current engineering practice; and 3) insights into how to improve engineering assessments through explicit connections to authentic practice and multiple disciplines, and through student self-reflection.

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Appendix 1: Special Session Agenda

Phase 1: Welcome and Introductions (10 minutes)

1. Welcome participants to the session, share the desired learning outcomes for the session, and explain the nature of our research group (College of Engineering and School of Education collaboration)
2. Provide a quick overview of the group's basic research methods and main findings about the epistemic frame of engineers as well as the challenges and successes in *Project Lead the Way* programs.

Phase 2: Finding the Threads (30 minutes total)

1. Show classroom video clip (3 minutes) of a "missed opportunity" to explicitly connect mathematics skills to a secondary level engineering task
2. Open up guided discussion to participants in small groups. (7 minutes)
   a. What did the high school students think they were doing here?
   b. What opportunities for naming their actions were missed here?
   c. How could this opportunity have been captured instead of missed?
3. As a whole group, review key components in how people learn: application, reflection, authentic context, being explicit, making work count. Discuss the idea of threading understanding through multiple modalities (e.g., from mathematical equations, through design sketch, to physical fabrication, assembly and testing). Discuss the differences between the intended (or "idealized") curriculum and the enacted (or actual) curriculum experiences of the students and instructor. (5 minutes)
4. Show classroom video clip #2 (3 minutes) of a "missed opportunity" to explicitly connect project work to authentic problem solving process of engineers
5. Open up guided discussion to participants in small groups. (7 minutes)
   a. What did the high school students think they were doing here?
   b. What opportunities for naming their actions were missed here?
   c. How could this opportunity have been captured instead of missed?
6. Whole group share-out: Where does this happen in your own teaching or curricula? (7 minutes) How can you take opportunities to thread key conceptual understanding (such as mathematics) through all modalities of learning?

Phase 3: Drawing the Connections (30 minutes total)

1. Review best practices in education: Learning in context, Group-based learning, Increased time on task, Increased frequency of feedback, Positive classroom climate (Cabrero & LaNasa, 2002). (5 min)
2. Hand out an example assignment that demonstrates how an engineering assignment might look which incorporates these best practices in pedagogy, as well as practice-based engineering skills and connections with authentic problems (also explaining what curriculum and pedagogy looked like previous to this assignment). Discuss how the assessment portion of the assignment integrates these practice-based skills and provides exemplary feedback (7 min)
3. Have participants, in their small groups, discuss how the provided assignment could be altered, applied, and assessed as per their needs on-site. Have group members

discuss how they could incorporate their understanding of the epistemic frame of engineers in their assignments. Notes will be taken on 3-M poster size paper. Session leaders will work with groups as facilitators, working with the application/assignment example provided as a base for the discussion. (15 min)

4. Whole group share-out: Have a couple groups share specific ideas for connecting the epistemic frame of engineers with one of their assignments in a way that incorporates best practices in education. Notes taken by each group will be made available on project website.

Phase 4: Summary, Invitation to Share, Evaluation (10-15 minutes)

1. Summarize the key take-home ideas of the session, referring back to the stated learning outcomes.
2. Invite participants to share important applications of the learning they can see making within their own courses and work.
3. Show project website with published papers and presentations, share contact information, and point out handouts available including other engineering assignments that connect with our group's findings. http://www.engr.wisc.edu/services/elc/hplengr.htm
4. Complete an evaluation of the session for ERM/ASEE and for our group.

Appendix 2: Example Assignment – Incorporating Authentic Engineering Experiences in Undergraduate Education

Assignment from: Hoopes, J., Courter, S., Seabury, L., Lee, B., Payne, G., & Boecher, C. (2011). Connecting Student Experiences with Concepts, Principles, and Methods of Fluid Mechanics. Proceedings of the 118th Annual American Society for Engineering Education Conference, Vancouver, Canada.

Civil & Environmental Engineering App (Applied Learning Activity)

Real-world Application of Fluid Mechanics Concept (5% of grade)

One week during the semester, you and your partner/s will have the opportunity to demonstrate your understanding of a fluid Mechanics concept. This assignment has four parts:

1) Identify example and relate it to a fluid mechanics concept

2) Design and deliver presentation

3) Review feedback and revise slides

4) Write and post reflection with slides

Each week, the teaching assistants will select one of the three presentations from the three labs for the large lecture. The teaching assistants will use the peer assessments as well as their own assessments to select the most accurate and professional presentation. Their decision will be final. You may want to make revisions to your presentation if yours is chosen for the large lecture.

Learning Objectives: As a result of this assignment, you will be able to

1) Demonstrate your understanding of a specific fluid mechanics concept
2) Apply a specific fluid mechanics concept to a real-world situation
3) Communicate your application in a clear, concise manner to your peers
4) Design visuals to accurately demonstrate.

Here's how the application will work:

Phase One: Identify example of real-world fluid mechanics. Think about your work experiences, observations around campus, and current events described in newspapers and journals. You may choose a concept that has been demonstrated before. However, you will get an extra point for demonstrating a new concept, that is, one that has not been the focus of a presentation in your lab.

Phase Two: Design and deliver a five-minute presentation to include these parts

- Identify context (what happened, when, where, why)
- Describe fluid mechanics concept/principle
- Explain application of principle to situation
- Recommend solutions or alternatives, if applicable

Phase Three: Review feedback and revise slides for completeness and accuracy based on your presentation and feedback. Add one slide that lists the important changes in content. The title of that slide could be, "Slide Revisions"

Phase Four: Write and post reflection with slides. With your partner/s, write a reflection after reviewing assessments from peers and video. Include what worked well and suggestions you have for future presentations. Post the reflection and the visuals onto a discussion forum.