Looking Toward the Real World: Student Conceptions of Engineering

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BACKGROUND
This paper contributes to the growing body of scholarship on engineering students' conceptions of core concepts in engineering, including their conception of engineering itself. Understanding how students view engineering practice can provide guidance into student responses to course features such as collaborative projects.

PURPOSE (HYPOTHESIS)
The research question addressed in this study is: What do student portfolios reveal about student constructions of engineering?

DESIGN/METHOD
Texts from portfolios created by mechanical engineering undergraduates were analyzed qualitatively using concepts drawn from discourse analysis. This approach makes it possible to examine conceptions through close reading of linguistic structure of a body of writing.

RESULTS
Students conceived of engineering practice as "the real world," with most students not conceiving school experiences as integral to practice. Students conceived of engineering practice in terms of strongly contrasting elements rather than as a system of intrinsic elements. Two major aspects in student conceptions were present in the portfolios: values in engineering practice and the role of other people. Largely missing also from the student discourse was the sense that engineering is inherently collaborative.

CONCLUSIONS
Student conceptions formed continua which bear further study to more completely characterize student views. Conceptions of engineering leaders and engineering educators deserve greater attention as well as contrasts and models for comparison to student conceptions. The benefits of understanding conceptions more completely include understanding student resistance to exercises, predicting student difficulties with exercises, and understanding the distance between what educators are trying to teach students and what students are "hearing."

KEYWORDS
conception, discourse analysis, mechanical engineering, portfolio

INTRODUCTION
This paper contributes to the growing body of scholarship on engineering students' conceptions of core concepts in engineering, including their conception of engineering itself. It also complements this body of scholarship by bringing the additional method of qualitative textual analysis to the table. Consider the following examples of fruitful qualitative studies. Stevens, Amos, Jocuns, and Garrison (2007) have been using ethnographic methods to understand how engineering students navigate their engineering studies and
have identified engineering as "a" lifestyle as a key way that students think about engineering. Also, Walker and King (2003) used concept maps to explore how bioengineering students think about bioengineering, while Mann and colleagues (Mann, Dall'Alba, and Radcliffe, 2007) have been using phenomenographic approaches to explore how practitioners of sustainability engineering think about their field.

Such studies are part of a broader movement in the learning sciences to explore how students understand things conceptually such as the work that has focused on helping students develop a conceptual understanding of physics. Consistent with other explorations of students' conceptions, the present study was motivated by the idea that understanding student conceptions and thinking about how student conceptions align with what we would like students to ultimately know can help us to: a) understand, make sense of, explain, and even predict student behavior and b) gain ideas about how to proceed with teaching activities such as setting learning objectives, configuring appropriate assessments, and determining promising instructional activities.

The study of students' conceptions of engineering, in particular, is fundamental to our goal as engineering educators of helping students prepare to contribute to the demands of engineering practice. Thinking about a conception of engineering as similar to a physics conception such as force may seem strange. For example, some think of it as as a process, "professional development," rather than as a cognition. However, there is every reason to believe that this is a promising direction for engineering education. In particular, investigation into students' conceptions of engineering holds promise for helping us to address retention challenges such as why students leave engineering (perhaps their aspirations do not match what they believe engineering is all about) and motivation challenges (what they put energy into).

This paper contributes to this body of scholarship by reporting on mechanical engineering students' conceptions of engineering (an additional disciplinary perspective) and by showcasing a new method for understanding these conceptions. In particular, the insights into students' conceptions of mechanical engineering reported in this paper derive from essays written by students as part of a professional portfolio assignment in which students were asked to make an argument about their preparedness for engineering practice. As part of making this argument, the students revealed a great deal about their thinking of what constitutes and characterizes engineering.

The remainder of the paper is organized as follows. The next section discusses ways in which the profession of engineering has been characterized in recent years, as a backdrop for the later characterization of how the students talked about engineering. The next two sections explain how portfolios can be used to gain insight into students' views of engineering and then discusses the details of the study we conducted. The results section lays out the students' conceptions of engineering as a field of sharp contrasts rather than as a field of systematic relationships. The two major areas characterized as sharply contrastive are the connection between engineering and school and the connections between different aspects of engineering. The concluding sections comment on how the students' conceptions align with characterizations of engineering by practicing engineers and engineering educators. We also discuss implications for engineering education.

The Push From Leadership

Since the mid-1990s, engineering education has been the subject of prolonged national study. "In this last decade of the twentieth century, the need for sweeping changes in engineering education appears more credible than at any time in the past
several decades" (National Science Foundation, 2006). In response to this need, national councils were formed, meeting in conferences and issuing reports. Among the specific concerns voiced has been the need to prepare engineering students for the changing working world of engineering. Among the dimensions of preparation often mentioned are enhancing communication skills and dealing with a globalizing economy. These remarks by Senator Jeff Bingaman addressing the ASEE 2006 Deans Council Public Policy Colloquium are an example of this construction of the engineering profession:

What are the implications of these trends for the engineer of 2020? First, he or she must be educated to have a truly global perspective. Technology transactions of the future will essentially be seamless across many countries, languages, and cultures. As part of this flexibility, future engineers must appreciate the nature of the global teams they will work with. They must know how to communicate effectively and think multiculturally; they must have analytical skills that can integrate information from team members who are in Bangalore, Sao Paulo, and Seattle as if they were all in the same room. (Bingaman, 2006)

The final report reviewing progress under the National Science Foundation’s Engineering Education Coalitions program highlighted “the ability to work in teams; a systems approach to problem-solving; greater knowledge and consideration of social, environmental, and other implications of problem-solving efforts, along with management skills…” (National Science Foundation, 2001).

For national leaders in engineering education, the NSF, political leaders, and industry representatives, the world of engineering in practice is a world of communication, teams, and multiple fields impinging on design solutions, as well as a world of engineering science fundamentals and design and manufacturing practices. The needs of this world have also been translated into traits to foster in engineers. John Roundhill, then a vice president of The Boeing Company addressing the 2001 Engineering Deans Institute, included on the list of desired attributes of engineers:

- A good understanding of engineering science fundamentals
- A good understanding of design and manufacturing processes
- Good communication skills
- A multi-disciplinary, systems perspective
- A basic understanding of the context in which engineering is practiced
- A profound understanding of the importance of teamwork (Roundhill, 2001)

Such a construction of the working world of engineering is deemed an accomplishment in and of itself as evidenced by its central placement in efforts to reshape engineering education. Student attainment of such a complex construction of the engineering profession is expected to be part of engineering education.

The many recommendations to include closer exposure to industry in engineering curricula arise from a belief that exposure to engineering practice is necessary to foster this understanding of engineering. What these recommendations point to is a desire for students to emerge from their degree programs thinking more like working engineers. The councils, national research agendas, and revisions of accreditation standards are in pursuit of an integrated conception of engineering where engineering fundamentals are only part of the picture.

Because of the public statements of engineering leaders, we have a sense for their conception of the engineering profession. What do we know of student understandings of engineering and how students connect their educational experiences to engineering in
practice? Some research has been done. For example, Downey and Lucena (2003) articulated student resistance to design in terms of student conceptions about the design process and its connection to engineering. They used ethnographic analysis of a capstone design course to identify student conceptions as the basis for pedagogical reform. In our study, we present findings on student construction of the engineering profession and its connection to their educational experience. We explore the potential for using a common pedagogical tool—portfolios—to gain insight into this key student conception as a contribution to pedagogy.

Portfolios as Evidence of Student Views

In this study, selected portfolio content was analyzed for evidence of the connections students make between school and profession. While portfolios have been used to promote a variety of learning outcomes (Plumb and Scott, 2002; Williams, 2002), we used portfolio content as a window into student views of the engineering profession. Prior studies have suggested portfolios as a direct source for research into student knowledge (Turns, Atman, Adams, & Barker, 2005, p. 33). Among the types of knowledge Turns, et al. identify are “perceptions about engineering” and “context of engineering” (Turns et al., 2005, p. 32). In addition, portfolios have been found to assist students in forming an identity and connection with the professional world they aspire to join (Eliot and Turns, 2009). Gottlieb also discusses reflective portfolios as centering on student perceptions and interpretations, arguing that student “attitudes and reactions” are “as valuable as what they learn” (Gottlieb, 1995, p. 13). In their study of the effective use of portfolios, Jensen and Harris argue that portfolios in public speaking courses “can propel students toward mindfulness” (Jensen and Harris, 1999, p. 225). Based on these and other similar findings, we expected student portfolios could help us understand student views of engineering as a profession.

Portfolios as Discourse

While a considerable body of research exists on effectively reading portfolios for assessment purposes, portfolio content may also be read as discourse. In this study, we propose to work with situated texts. That is, to analyze texts with an awareness of the social context in which they were created. This, broadly, is approaching texts as discourse.

Following Fairclough, we treat language “as an irreducible part of social life, dialectically interconnected with other elements of social life” (Fairclough, 2003, p. 2). The use of the term discourse refers to this “particular view of language in use...” (Fairclough, 2003, p. 3). Language in use (discourse) then, becomes an indicator of the understandings of those producing the discourse. This is fundamentally possible based on the theory of understandings as being socially constructed (Berger and Luckmann, 1966). We can look at portfolios as student discourse; that is, as the social constructions of the students in the context of a specific class, in an engineering undergraduate program, in a society in which engineering is a profession the students expect to join. When students respond to a question about their connection to engineering, they are in dialogue with the instructor and with received social constructions of engineering. Given the connection between individual construction of reality and its reflection in discourse, we can ask, what does portfolio content tell us about student constructions of themselves, their educational world and how they connect education to their future profession?

Such a question is qualitative in nature. A qualitative methodology offers insight into meaning construction; for example, what meanings do students attribute to their
experiences? A qualitative approach does not speak to causation, however, and we do not make claims as to what caused the students in the study to form the conceptions they expressed. Nevertheless, qualitative data can be a resource for causal studies. It can suggest new variables and relationships which may then generate hypotheses. In our concluding discussion of implications of our findings, we point to several areas where testable propositions could be developed, perhaps after additional qualitative studies.

Analysis of portfolio content, provides insight into how conceptions are articulated. The nature of the articulation itself provides evidence of student constructions of these relations. The structured nature of language use constrains meaning creation for language users; that is, language production is not arbitrary with respect to structure. Close reading of linguistic structure produces information about the conceptions underlying the text (Fairclough, 2003; Tannen, 1993). Syntactical and lexical choices, implicit and explicit comparisons, the order in which concepts appear in a text, and other linguistic features may all be treated as evidence, then, of how students construct their connection to engineering. Treating the nature of the articulation as evidence of student constructions of the engineering profession makes it possible to ask: what does the discourse in the portfolio content indicate about the relationship students formulate between course content and engineering as a profession?

Looking beyond the level of how course knowledge is reflected in portfolios, it is possible to gain insight into how students view society and their place in it. Asking this question expands the value of portfolios beyond their capacity to demonstrate course knowledge or a specific skill. Specifically this study asks: What does student portfolio content reveal about student constructions of engineering?

The next sections present the course context for the portfolio production, the structure of the portfolios and the approach taken to analyzing them.

Study Setting

This study analyzed portfolio content that mechanical engineering undergraduates produced as part of an introductory course on manufacturing. The discourse analysis is part of a larger effort studying portfolios as a learning intervention that may foster knowledge integration. For the purposes of this study, knowledge integration is understood as the connecting of concepts. Connections of different types suggest differing levels, qualities, or forms of integration. The connection examined in this study was the connection students made between the course and the engineering profession.

The study site was a required introductory mechanical engineering course in manufacturing processes at a large university in the western United States. Students enrolled in the course ranged from sophomore to seniors. For this course in manufacturing processes, students were placed in situations emulating industry practice and asked to solve problems that they were told occurred in industry. The lab portion of the course required them to work in teams to design and construct a Stirling engine (an engine that runs from a heat source rather than from electricity) that was to drive a fan (which they also manufactured). The steps required to complete the project were divided up between teams, some of whom met at different times and were not in the lab together. The lab portion of the class emulated working conditions of engineering practice where specifications must be communicated within and across organizations. In addition, the initial specifications were incomplete, requiring students to integrate theoretical knowledge in a practical situation.

The course included a portfolio assignment worth 5% of the total course points; that is, not quite as much as two weeks worth of homework assignments, about four to six
hours of work. The assignment was introduced in the third week of the course and explained in greater detail in week nine, near the end of the course. The assignment constituted a minimal demand both in scope of work for the students and in course time devoted to teaching about portfolios. Students volunteered their portfolios for inclusion in the study. Portfolios were collected and analyzed from 27 students enrolled in the course (out of a total of 35 enrolled, or 77% volunteering).

The portfolios were in the form of Web sites the students constructed using a basic template, with one exception where the student significantly customized the website look. The portfolios were made available as individual files making up the pages of the Web sites. Most could also be accessed directly by URL making it possible in these cases to view the website as a working whole. The portfolios included a statement and three artifacts from their course experience, together with annotation of the artifact. The statement, artifacts, and annotations appeared sometimes all on one Web page and sometimes as separate Web pages. Among the artifacts students provided were photographs of the finished engine/fan, homework assignments, and references to the textbook and their notes. The statement was described in the assignment instructions as the backbone of the portfolio. It was also described as a cover letter and as a thesis statement. Students variously formatted the statement, sometimes identifying it as a thesis statement or cover letter.

The assignment instructions asked the students to show their understanding of course concepts and of the engineering discipline and to connect the course to the engineering discipline. This is one level of connection students were explicitly asked to perform. In addition, they were asked to connect the artifacts to the statement. The artifacts and annotation were described in the instructions as evidence.

Analyzing the Portfolio Content
For this study, only the portfolio statements were examined in detail to answer the research question. Other portions of the portfolios (such as the artifacts) were examined as supplemental texts. To establish contextual understanding in preparation for analyzing the portfolios, one of us (Dunsmore) reviewed the course syllabus and portfolio assignment description, toured the machine shop where the lab sections were held, and interviewed the shop instructor.

The portfolio statement pages were converted to Word documents in order to use Atlas.ti (software that facilitates textual coding and analysis) for word counts, collocation analysis, and coding supporting interpretative reading of the corpus. In addition to the detailed analysis of the portfolio statements, full readings of the annotations and artifacts were also completed. The portfolio statements contained many malapropisms, typographical errors, and places where words had apparently been omitted. Many text analysis methods were problematic in this "noisy" environment. Consequently, a very conservative approach to interpretation was adopted. Multiple indications of a construction had to be present for it to be considered a valid observation. The problem is illustrated with the following example where italics are added for emphasis. In one portfolio statement page, the student wrote:

Regardless of being a designer, manufacturer, or tester, each specialization is intimately connected. Manufacturing parts based off of engineering drawings provided an input to designers on what can be feasible to manufacturers. This connection between two areas creates a unity that allows engineers to cooperate and produce the best products. #02
The preceding paragraphs to this were general definitions and descriptions of mechanical engineering, the connection between education and the work force, and learning about manufacturing—all in present tense. Neither the course itself nor the student author was mentioned. The use of "provided" (see italics) in this instance implies an actual experience undergone. That is the implication of the use of the past tense. If, however, the student meant to type "provides," this sentence is consistent with the tone of generalization found in the use of present tense in the surrounding sentences (see italics). The very general and impersonal tone of the portfolio statement to that point and in this paragraph (absence of personal pronouns, for example) counts against interpreting this as an instance of personal experience in the course.

The analysis of the portfolio statements proceeded through iterations of reading, open coding, axial coding, and selective coding (Strauss and Corbin, 1990). This emergent process was appropriate as this was the first analysis of portfolio material for this research project. The iterative, inductive readings were informed by concepts drawn from discourse analysis. Coding was conducted at the level of linguistic features, such as the prevalence of specific words, absence of personal pronouns, and presence of constrastive terms. From coding at this linguistic level, student conceptions were inferred. Tannen (1993) argues for this form of inference on the basis that linguistic features reveal expectations about the circumstances of the discourse. In combining a grounded theory approach with concepts drawn from discourse analysis, we exploit this inferential nature of discourse while retaining the ability to develop categories in a grounded theoretic manner. Our evidence was linguistic in nature, but our findings are about student conceptions rather than about language as such. Throughout the analytical process, discussions with the research team shaped successive iterations.

The iterative readings were conducted as readings of the full portfolio statements and as readings of extracts from computer-assisted coding and manual coding of the portfolio statements. The initial full reading of the portfolio statements was augmented by the use of the Atlas.ti auto-coding feature for selected terms. The terms engineering, manufacturing, process, and machine in various forms were auto-coded based on the impression of their prevalence formed through open coding. The prevalence was confirmed with a word frequency analysis in Atlas.ti. The auto-coding provided selections from the corpus that could then be subjected to a closer reading. The use of the first person singular pronoun was auto-coded based on the markedly impersonal framing of many of the professional statements, as also became evident in open coding. As portfolios are thought to promote reflection and self-awareness, the contrast between impersonal framing and expressions of explicit agency was of particular interest.

Close reading of each set of quotations gave rise to categories based in semantic relations such as causal terms and expressions indicating that one thing was part of another. The full portfolio statements were then again closely read to create greater interpretive depth around these semantic relations. Further auto-coding was also conducted as a check on interpretation and to assist in further interpretation. A number of features of the statements and annotations were coded to provide contextual information as recommended by Briggs (1986). Explicit references to structuring and description of the portfolio were hand-coded in Atlas.ti. Other structural features such as the titles of the statements were also coded. Additional terms coded were learn and understand. Each of these features provided suggestions about the importance students attached to different dimensions of their connection of the course to engineering overall.
Through the rounds of iteration of the full set of portfolio statements and extracts, a sense for the largest features of the discourse emerged. These were the themes found most pervasively throughout the portfolio statements, indicated primarily by word choice, semantic structure, or topic. The results of analyzing these pervasive features are presented in the next section.

RESULTS

From the analysis of the portfolio statements, a main structure in the discourse appears. The main structure across the discourse tells this story about engineering as a profession: Engineers are leaders because of their competence in the world of theory, design, ideas, and creativity. The real world of manufacturing is in conflict with this world of “brilliance” and presents many limitations (machinery, real-world tolerances, costs, and time constraints, for example). Putting ideas into reality inevitably requires working with and through others (machinists, for example). This unfortunate necessity opens up a range of possible constraints, difficulties, and mistakes. Through the skills of teamwork, collaboration, and communication, engineers can overcome the real world aspects of feasibility, constraints, and hands-on manufacturing.

This main structure is, itself, a complex landscape of conceptions of “the real world.” We will examine this landscape from two vantage points: First, the construction of engineering as being in strong contrast to school. Second, the construction of engineering itself as inherently conflictual. The main features of the structure appear in all the statements, with inflection across the set of student statements. Appendix A provides a graphical representation of the continua these inflections formed. The inflections may appear as different emphases on particular concepts or as different, but consonant, word choice. There is also variation in the quality of writing and articulation. As discussed earlier, this analysis attempts to be conservative in constructing the storyline reported here.

From the first vantage point, engineering practice is constructed as “the real world,” with school defined in a residual fashion as somehow not the real world. The assignment did not describe the engineering profession as “the real world.” It asked only that students explain how school connects to engineering overall. For students to use the term “real world” reveals this conception as a readily accessible part of students’ mental landscape. Students expressed a sharp contrast between school and profession, with a range of views as to the relative value of school. In the next section, we will discuss the differing values students expressed regarding school.

From the second vantage point (the student construction of engineering professional practice itself) there was a continuum of conceptions of how elements of engineering practice related to each other. For the students, engineering practice is made up of discrete parts which somehow rattle and clash together. It is in this conception of these elements as an ill-fitting assemblage only roughly cohering into results that student discourse diverges most prominently from an engineering leadership discourse of engineering as a closely integrated system. Many of the attributes engineering leaders expressed as intrinsic to the engineering profession instead have a contingent role in the student discourse. In this sense, they are constructed as obstacles to avoid, rather than as part and parcel of engineering. Important aspects of the engineering profession are thus construed discretely, rather than as intrinsic to engineering practice.
In the next section we discuss the first vantage point on student conceptions: the contrastive discourse about school and the engineering profession.

**Engineering as “The Real World”**

Engineering practice was consistently constructed as “the real world.” School was more of a residual construction. It was constructed as being in contrast to “the real world;” that is, it was constructed in terms of what school was not. This contrastive discourse was strongly present in the portfolios. Of course, the assignment itself assumes a divide in asking students to make a connection between the course and engineering overall. However, the nature of the divide is not defined, and in fact, the emphasis in the assignment is on connection. In some cases the portfolio statements explicitly acknowledge the divide implicated in the assignment to make a connection, as in this example:

This portfolio is designed to help make a connection between the real world of engineering and the world of engineering in academia. #25

It is notable that the actual directions in the assignment description were to connect the course with engineering overall. It is the students’ construction of this as “real world.” In this declarative sentence, the recourse to the construction “real world” indicates the presence of this construction apart from the assignment description. This framing is part of the expectations the student brought to the situation. Many students described the course as a place to learn about this “real world.”

Too many labs in the program were simple sections with measuring and equation work rather than hands on real world activities. #04

The real is the world of the “hands-on” as opposed to the idealized world of the classroom. This involves a distinction in work produced. Students do not construe “measuring and equation work” as hands-on. The work of taking measurements and solving equations belongs not to the “hands on real world” but to an abstract or artificial world where performance of tasks is not getting your hands on work. While in this example the adjectival phrase “too many” indicates a contrast from a preferred state, across the set of portfolio statements there is not uniformly a sense of one or the other being superior. Here is a neutral expression of the distinction:

Whether or not one chooses to specialize in manufacturing technologies, an overview of the processes currently used is beneficial for any mechanical engineer. It provides examples of real-world applications for the basic engineering concepts learned previously. #09

The term “real-world” is used as a neutral descriptor supporting the previous positive statement of the value of “an overview of the processes currently used.” The use of “real-world” as a descriptor in this instance underlines that this framing of the professional world is the default frame. In the next example, the student, who had extensive work experience, was very positive about the qualities of engineering in practice as compared with school, but also with an expectation that school would enhance engineering practice:

I was able to attend class with a mindset that enabled me to really focus on what was going to better my engineering talent in the industry and focus less on the “textbook” tasks. #27
The use of quotation marks in this extract set off certain aspects of school as somewhat suspect or at least less valuable. Furthermore, the utility of class was constructed as conditional on the student adopting an industry-based focus not perceived as inherent in engineering education. The following extract expresses a sharp conflict between what are often called engineering fundamentals and some other, more “real” aspect of engineering. The use of “so” is emphatic, and “completely” is an absolute term. Together they describe a clean split with a strong preference for what the student conceives as the professional world of engineering in which, apparently, theory plays no role.

We are so engulfed in the theory of engineering, we completely by-pass the basic skills of engineering a.k.a. building stuff. #16

Thus we see that even within the unanimity of student construction of engineering as “the real world” there are nuances in how the “real” and somehow “less real” are related to each other. We turn now to one expression of this complexity—the second major theme in the student discourse—values in engineering practice.

Values in Engineering Practice

Students frequently expressed their sense of the values they perceived as operating in the “real world.” The value of utility was frequently recognized as central to engineering, perhaps most succinctly stated in this extract:

The primary job of a mechanical engineer is to produce a[n] item or product of need to society.... A key to doing this however, is bringing a concept from the drafting table or program into the real world. #08

This is a relatively neutral way of discussing the contrast between the creative process and “the real world.” There is an absence of descriptive terms beyond the term “primary.” The use of “however” suggests a contrast with the “primary job.” It is a mild contrast in comparison with that found in the following two extracts. In these we see the conflict between the “brilliance” associated with the ideal design and the requirements of the real world of production:

Without a way or understanding how to manufacture or fabricate an engineering design, a brilliant design is just about useless. While the design may function and theoretically perform well on paper but requires a tangible means of producing the design for real world application for it to be useful. #20

Brilliant ideas for products and parts are many, but some options of how to manufacture these parts to precise specifications are less feasible than others. #10

In the first extract the term “useless” has a far more negative valence than the contrastive “however” in the previous extract. The second extract employs the more tempered term “less feasible” to distinguish “some options” from others. The employment of the contrastive “but” was very common in the student discourse in discussing design and manufacturing, indicating a widespread conception of a conflictual relationship between design and manufacturing. Also note that the requirements of production do not diminish the brilliance of the paper solution. The employment of the unequivocal term “brilliant” to describe designs, regardless of their actual utility, indicates an association of design and brilliance. The practical requirements are a separate consideration related to
the separate goal of utility. Thus a design may be deemed brilliant even if it is not useful or realizable, while a successful implementation is not described as “brilliant,” but rather as “useful” or “feasible.” The segregation of the adjectives suggests the strength of the divide between the ideal world of theory and the real world of production. The expression of conflict between brilliance and practicality demonstrates a conflicted conception of engineering practice. An integrated conception might lead to the conception of “brilliant design” as inherently being realizable.

The value of usefulness, then, is expressed as a site of conflict. It requires acknowledging a world of constraints separate from the ideal world of theory, as opposed to inherently part of theory. Conceptions in this regard were also not uniform across the portfolio statements, indicating a continuum of conceptions. Some portfolio statements treated constraints as closely related to the theory and calculations of the classroom as articulated in an unusually clear manner in these examples:

There were a lot of underlying physics that went into each of the elements so that the finished product would function efficiently in the manner it was designed. From leaving enough dimensional tolerance to compensate for any contraction upon cooling to determining RPM speeds so the tool functions efficiently with minimal wear. #13

This class actually shows the students why and how certain things are produced. It shows the process of all the calculations and theory put into a physical form. #15

For others, the connection between theory and real-world constraints is not voiced. Instead real-world constraints are discussed quite separately from theoretical considerations. The following extract expresses the nature of manufacturing in a way that is very common throughout the statements.

Understanding many manufacturing processes is very important when holding a mechanical engineering position. It allows engineers to make decisions based on the ease and cost of manufacturing. This can greatly reduce the overall cost of the product and the time it takes to produce it. #17

Ease and cost of manufacturing, economic factors, and feasibility recur throughout the portfolios as considerations engineers should have as a separate agenda from theoretical knowledge and skill with calculations. There is a suggestion that they are not core to engineering as such, although they are key considerations in the working world.

As much as we would like to allow our imaginations run wild, engineers do not work in a vacuum. Just like any other job, tasks must be completed with an eye towards efficiency and cost of implementation. #22

The constraints of feasibility are related to business requirements, not design requirements as such. The imaginative, brilliant world of theory coexists in some uneasy sense with the concrete world of feasibility and the actually possible. For example, the world of imagination is not constructed as imagining design solutions that take into account “efficiency and cost of implementation.” Rather, ideal design takes place in “a vacuum.” The emphasis in the student discourse is on a contrast between worlds rather than on a deep interrelation between different considerations within one world. The sense of contrast is also reflected in the third theme in the student discourse, engineers in relation to other people.
Engineers and Other People

The relations of engineers to other people figured prominently in the student discourse. These references also were marked by strong contrastive language about the actions underlying and shaping the connection between engineers and others. Throughout the set of portfolio statements, reference was made to decisions. Implicit in these references is the construction of engineering as a site of decision-making. In this construction, engineers make design decisions and then must cope with the real world constraints on their designs. These constraints intersect with the creative world at the point where communication takes place. That is, there are two types of decisions: one that relates to the world of theory, and one that facilitates the real world of constraints. In this extract, creating complex objects is constructed as separate from the act of communicating with others. This contrast is marked by the contrastive term “even though” as well as the description “hard to accept,” characterizing the attitude toward the “real-world” need to connect to others.

As an engineer, it is hard to hold back our egos (and tongues). It is hard to accept that even though we are able to create complex objects that could save lives or millions of dollars, it is all worth nothing if we cannot communicate our ideas or work with others. Having real-world skills differentiates the good from the great. #16

Engineers are creative, the source of ideas, but must live with and respond to the “real-world” presence of others. The “great” engineers accept this necessity of communication and, by implication, the presence and impact of other people on the creation of “complex objects” of great value. In this extract, communication and working with others is equated with “real-world skills.” Note also that the communication discussed here is solely uni-directional, from engineers to “others.”

Throughout the statements, repeatedly and in different ways, the students constructed working with people as belonging to the real world rather than to the idealized world of theory, design, and ideas. As in the earlier example, the negative expression of this is related to the necessity for communication and the occurrence of mistakes.

But it is not just knowledge you need, sometimes you must work together in a team. #23

Because there are many different teams specializing in different areas, the emphasis of teamwork and communication became a crucial factor in completing projects. #02

Within the portfolio statements, there is little sense that the skills of teamwork are fundamental to engineering in the way design-related skills are positioned. The “must” and “because” point to some additional burden beyond some “real” core of engineering. The term “sometimes” creates a contrast to an alternative case when, preferably, knowledge is enough. The preference is indicated by the term “must.” In the second extract above, teamwork and collaboration solve an otherwise unavoidable problem created by the structure of different teams being assigned different tasks. The second extract marks a neutral area on the continuum of constructions regarding relations with others.

In addition to the need for teamwork based on the structure of the manufacturing environment, teamwork and collaboration also were related to reducing cost and time of production. A more positive expression of this necessity was the construction of
teamwork and collaboration as skills; skills, as an accomplishment, being intrinsically positive. This construction was very common throughout the statements, and "teamwork" was one of the most common artifacts chosen (usually represented by a photo of the completed engine/fan, occasionally by a photo of team members).

While the basic knowledge learned from the books and classroom can be used in our future classes and workplaces, skills gained from our lab can be applied as well. Three important ones are the ideas of teamwork, machining processes, and machine skills. Furthermore, teamwork is hardly something that will only be applied to engineering jobs. It would benefit almost anything we do in the future.

Note the contrast between "knowledge" and "skills," with teamwork equated (through its inclusion on a list) with machining processes and machine skills. This is especially noteworthy given that the students knew (and sometimes discussed in their portfolios) that non-engineers rather than engineers would actually perform the machine processes and exhibit the machine skills in industry settings. This distinguishing of teamwork as a skill, most closely related to a non-engineer interface, suggests that teamwork is somehow less integral to engineering as such in student conceptions.

Teamwork and collaboration were repeatedly identified, as above, as "real world" in contrast with academic skills such as solving equations. This is treated neutrally in the following extract, where it is presented as a fact without evaluative adjectives. In this construction, then, the contrast between school and profession exists, but without emotional emphasis.

In the engineering world, one rarely works on a project by himself. Collaboration with other people—frequently strangers, frequently people one is never in direct contact with (such as subcomponent manufacturers and foreign labor)—is prevalent throughout the industry. This project demonstrated two aspects of this.

Many students wrote about the structuring of the teams in the lab sections and the challenges it created, emulating engineering in practice. Some felt that this would advance their employment opportunities by introducing them to real-world conditions. The following extract represents this more positive valence regarding these challenges. The evaluative term "unique" indicates the more positive construction of the course requirement to work with others.

The team dynamics was [sic] unique in the fact that many groups were making their parts on different days of the weeks. In manufacturing, I learned, it is common to be in that type of work setting.

Another dimension of the role of people in engineering practice concerns hierarchy and responsibility. In articulating this dimension, students voiced, sometimes very directly, their concepts of themselves in engineering practice. They invariably saw themselves as being in authority, taking the lead, and directing the work of others as these extracts exemplify:

Having a class like Manufacturing and Processing improves our understanding in what tasks we are asking of those who will work for us.

An engineer also has to have a broad knowledge of the different types of technology available to manufacture his/her design. This is very important because if we engineers do not know what kinds of tools are available to us, then we are like hunters hunting with bows or guns.
Understanding many manufacturing processes is very important when holding a mechanical engineering position. It allows engineers to make decisions based on the ease and cost of manufacturing. 

The construction of the engineer as a leader is seen in the phrases “tasks we are asking of those who will work for us,” “technology to manufacture his/her design,” and “allows engineers to make decisions.” People work for engineers; engineers own designs; manufacturing processes are the tools available to engineers; and engineers make the decisions. In each case, the engineer has oversight responsibility, plays the role of decision-maker, and provides the ideas that others carry out using tools to achieve the engineer’s vision. Indeed, by extension, people involved in the manufacturing process are part of the “tools [that] are available to us.” Teamwork and collaboration facilitate the realization of the engineer’s vision. As such it is constructed as being part of the toolbox.

In addition to this sense of communication as an instrument to manage teamwork and collaboration, humanistic concerns were occasionally referenced. These are also part of the real world as opposed to the world of theory.

Another feature that companies look for in a potential hire is ability to work with others. The major project for [the class], the construction and assembly of a working Sterling engine, went a long way in teaching us students to trust each other in a team environment.

These humanistic concerns were not so commonly expressed as was the consciousness of instrumental advantages to communication. Only a few directly expressed them by using words such as tolerance, selflessness, ethics, etiquette, or humility. In many cases the humanistic concern was present, but framed by an instrumental concern as in this example:

A common ground has to be reached for the work to flow, and to prevent resentment within the group, reducing overall productivity.

These concerns were, however, present and are noteworthy in such a product-oriented environment. The use of the phrase “sympathetic and responsive” in the next extract is perhaps the most explicit reference to humanistic concerns. It represents the thoughts of only this one student in that this choice of words is unique in its emphasis.

Giving mechanical engineering majors an idea of what goes into the manufacturing side of production will allow them to be more sympathetic and responsive to the wishes of the people whose job it is to take the engineer’s idea and make it a reality.

Although humanistic concerns are a minority construction within the statements, even the most instrumental discussions of the role of people did acknowledge the interactional nature of teamwork and collaboration. This suggests a continuum may be present in student understandings regarding the role of people in engineering and manufacturing.

**DISCUSSION**

In this section we summarize the two major contrastive elements found in the portfolio statements. First, there was the contrast between school and engineering as a profession. Second, there were two contrastive elements in the construction of engineering: the
conflictual framing of theory and utility and of relations with people. Rather than seeing
school and engineering and the practice of engineering itself as systematically related,
student constructions were polarized, concatenated roughly rather than integrated
smoothly, and expressed as conflict. Students set up an opposition of varying intensity
between school and work. The sense of a divide between school and work was stronger
than the sense of course content as the stuff of engineering practice. However the pres-
ence of some students articulating this latter view demonstrates the presence of a contin-
um of sorts.

Regarding the nature of engineering practice itself, students divided this world into
discrete elements connected, again, by conflict. Thus, usefulness and feasibility were not
acknowledged as constraints on the design process with the same sense of acceptance that
engineering fundamentals were. An integrated view, such as that expressed by the course
lab manager in describing how tolerances for fit were developed and codified, recognizes
engineering fundamentals as being historically driven by the necessity to solve the prob-
lems that feasibility and “real world” constraints pose. In this integrated construction,
“brilliance” inheres in resolving the problems set by “real world” constraints. This inte-
grated sense was barely represented in the portfolio statements.

Largely missing from the student discourse was the sense that engineering is inher-
ently collaborative, a reality illustrated for example in Mike Rogoway’s story about Intel
engineers working on a new generation of computer chips:

Each team took on one step in the process, and relied on others upstream and
downstream to make sure their portions worked and fit.

“No one person actually understands the whole thing,” said Mistry, the engineer
coordinating all the work. (Rogoway, July 30, 2007)

The sense of acceptance of collaboration present in this senior engineer’s statement is
quite different from the expressions of frustration and regret that pervaded student
accounts of the collaborative aspects of their course. Absent also was a sense of the
strength of collaborative effort. Rather, teamwork and communication were stumbling
blocks necessitated by the vulnerability to the errors of others.

To see the contrast, consider this portion of Roundhill’s address, appearing under the
slide heading, “Similar Issues Facing Higher Education and Business/Industry:”

• The imperative of teamwork
• Understanding the human resource to be the only appreciating resource in an
  organization (Roundhill, 2001)

In the student discourse, working with people is constructed as an additional hurdle,
something to be railed at rather than as an “imperative” fundamental to engineering
practice.

Implications for Future Research

There was a continuum of student constructions for each of the major aspects of engi-
nineering practice as well as of the relation of school to practice. Further research into the
form of these continua of constructions of the engineering profession could generate
leverage points to foster more effective student understandings of engineering practice.
First, additional study of student conceptions is needed to more completely characterize
the nuances of their views of school, engineering practice, and the relation between them.
Studies in different engineering disciplines, comparing beginning and advanced students, and other comparative studies could provide a basis for generalization and application to curriculum design. Second, conceptions of engineering leaders and of engineering educators deserve greater attention as well, as contrasts and models for comparison to student conceptions. Such work is suggested by that already done in cataloguing differing conceptions (expert, novice, naïve, etc.) of math and science content by educators in those fields (for example, Bingolbali, Monaghan, and Roper, 2006; Greenbowe and Meltzer, 2003; Parker, Krockover, Laserh-Trapp, & Eichinder, 2008). Third, conceptions of engineering educators should also be studied. What are the terms faculty use, both casually and formally? What constructions of engineering practice are embodied in teacher discourse? What assumptions of student understanding are implicated in teaching discourse? Such research could build on the recent work of Pawley (2009), which explores "universal narratives" of faculty such as "engineering as making things." Further work could articulate the connection between the macro and micro level of discourses shaping individual lived experience; for example, the specific statements of students engaged in a particular project as a case of the broader understanding of engineering as "making things."

Implications for Teaching

As a starting point, this information on how students understand engineering represents a resource that educators can use to think about instructional activities. For example, an educator might use the information on students' ideas about teamwork to anticipate how students might behave in project experiences that require them to interact with people from other disciplines. However, the larger issue is how to help students construct more integrated conceptions.

A principal finding of this study is the complexly nuanced nature of student constructions of engineering practice. Adopting a celebratory view that embraces this complexity creates far more opportunities for reaching students where they live. Knowing the landscape of their constructions enables educators to create multiple approaches to the integrated constructions we hope to foster. Making differences in conceptions more transparent creates a basis for the reflection, discussion, and even debate that would enable students to work from their present construction—whatever that is—toward others and to evaluate the efficacy of their own and other conceptions. In this way, they would also come to appreciate the complexity of conceptions and how our construction of a field of action may limit or expand our options for action.

In this regard, we believe the portfolio exercise is a promising tool. Creating a portfolio, even the simple one from which this study data was drawn, provides an opportunity for reflection and articulation of these issues. Having students articulate their ideas creates a referent that educators can use to reach students more effectively, design course experiences that take student constructions into account more fully, and engage students in a conversation with the profession they seek to join.

Research on student conceptions of engineering is an emerging phenomena. Understanding such a fundamental aspect of engineering learning; namely, what do students think engineering practice is about and how does this compare with the views of educators and of practicing engineers—has significant potential benefit. Yet it is a challenge to pursue as it is unclear in the current educational context of engineering education who exactly is the "we" that would responsible for these broad types of issues. It is not a matter of simply choosing one construction and teaching it authoritatively. This is
simply not how constructions develop, as has been shown in the work on math and science conceptions (for example, Bingolbali, Monaghan, and Roper, 2006; Parker et al., 2008; Greenbowe and Meltzer, 2003). The process by which constructions develop must always be taken into account.

Thus, another implication is that we should consider how students have developed such ideas in the first place. Such ideas as represented by the student discourse do not arise de novo. Gaining a more precise sense of the genesis of the ideas would ground engineering education more fully in the larger societal context. A more sophisticated understanding of the context of student conceptions could lead to more sophisticated approaches to fostering student conceptions. We suggest investigating educator and practitioner contributions, but other contributions also merit attention. Examples include media depictions of engineering, the impact of interpersonal interactions in curriculum settings, and unexamined social assumptions in course materials. In short, there is a rich field for future research into the roots of student conceptions.

CONCLUSION

The development of students into effective engineering practitioners is a pressing issue for engineering educators. The present study indicates that portfolios can advance this teaching objective. This paper argues that, in addition to providing a means of assessing knowledge, teaching skills, and fostering social cognitions, portfolios are also an important source of information for educators about social cognitions students hold. This paper presents an argument for the relevance of student conceptions of the nature of engineering practice and for the value of portfolio content as direct evidence of these conceptions.

The inflections in the student discourse across the set of portfolios indicate variance among students in their conceptions of engineering practice. The range of inflection suggests continua of student conceptions. In this paper we explored continua of conceptions for how school relates to practice, for how engineering fundamentals relate to "real world" engineering conditions, and for how people work together in practice.

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APPENDIX A

Continua in portfolio statements — Engineering practice as clash and conflict

Conception of contrast between school and “real world”

School Relevant ↔ School Tolerated ↔ School Irrelevant

“Brilliant” design and “real world” constraints

Brilliance = integrating ↔ Constraints ↔ Constraints undermine constraints ↔ tolerated ↔ brilliance

Relations with people

Integrated, systematic ↔ Manageable ↔ Openly conflictual

Teams = power ↔ Teams = endurable ↔ Teams = obstacle