A Framework for Interpreting Students' Perceptions of an Integrated Curriculum

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Abstract

Undergraduate engineering reform efforts to better integrate math, science and engineering courses have recently been conducted at the University of California at Berkeley. Since 1998, faculty from the mathematics, physics, and engineering departments at Berkeley have collaborated to restructure first year and lower division courses. Several changes were made to specific courses to improve students' integrative understanding of calculus and the physical sciences, and to emphasize applications to engineering. Various data have been collected to investigate the impact the reforms had on student learning, as well as to gain insight into students' experiences during their undergraduate engineering career. Interviews were conducted with engineering students and faculty to garner feedback about integration efforts and students perceptions of the curriculum. This paper describes the interview project and outlines the interpretive framework we established for the analysis of the interview data. Initial analysis suggests that students have difficulty understanding lower division math and physics courses because of the following reasons; 1) the pedagogical approach is inadequate for properly integrating and reinforcing the material, and 2) student perceptions and beliefs about the disciplines conflict with the goals of integration.

Introduction

The ability to effectively integrate physics and calculus knowledge and skills into engineering is essential for engineering students. Many engineering faculty report that students do not adequately transfer knowledge from required physics and math courses and are not able to successfully integrate and use these skills in their courses. As part of a grant funded by the General Electric (GE) fund[1], faculty at the University of California at Berkeley implemented several reforms aimed at improving the integration between physics, math, and engineering courses. The reform efforts focused on using computer learning technologies as a mechanism to integrate these curricula and to emphasize collaborative learning, small group work, and solving "real life" problems.

In part, the GE grant reform efforts built on previous work done under the Synthesis Coalition [2]. As an NSF funded engineering education coalition, Synthesis projects focused on reforming the undergraduate engineering curriculum to better meet the new ABET criteria. Some of the Synthesis projects included the creation of hands-on design and dissection courses [3, 4], the development of innovative assessment techniques to measure open-ended design process skills [5], and employing innovative uses of technology to enhance student learning [6,7]. Several of the GE projects built upon and expanded on the work initiated by earlier Synthesis projects.

One specific example of a GE grant reform effort was the introduction of a new course 'Animating Physics'[8]. The objective of the course is to explore challenging physics concepts through the use of physically realistic animations. Students designed, planned, programmed, and implemented animations of physical phenomena of their choice. The combination of these activities is inherently integrative; students are required to use concepts and skills from math, physics, computing, and engineering. Designing these different animations allowed the student to apply their math and physics knowledge to explore physics concepts. By manipulating the animations students visualized kinematic relationships and explored physical effects that would not otherwise be possible.

Participating faculty from the math, physics and engineering departments also met regularly to discuss course content and to coordinate their efforts. These meetings created a dialogue among the faculty and resulted in their improved awareness of the material covered in each course and a better understanding of course curricula. Faculty decided to supplement math lectures, physics lectures and discussion sections by introducing engineering applications of the concepts as the material was presented. For example, in math, faculty and teaching assistants worked together to develop worksheets for discussion sessions where students worked collaboratively to solve application-oriented problems.

Although the GE grant included work integrating math, physics, engineering and chemistry, the chemistry integration was not included in the study described here. Only one semester of chemistry is required by most engineering majors, and over a third of the engineering students were able to use high school advanced placement chemistry to satisfy the degree requirement. Thus the impact of differential treatment in freshman chemistry would be hard to isolate in the study, whereas most engineering students take physics and calculus in their first two years.

Many engineering universities have implemented similar, as well as more comprehensive, changes to the curriculum [9, 10, 11, 12]. Most of these changes are based on a common-sense assumption that an integrated curriculum is beneficial to student learning and will lead to a more integrative understanding of the discipline. While this assumption may be true, we seek to empirically explore the effects that integrative changes to the curriculum have on student learning. By taking this approach we do not take for granted that integration of the curriculum results in improved student learning. Rather, we probe for evidence that integrative learning has indeed occurred and uncover issues students struggle with as they engage in integrative activities. Several of the questions driving this research include:

- What does integration of math, physics and engineering mean to engineering students?
- In what ways does integration take place within the curriculum, as well as in student understanding?
- What are the factors that promote, as well as hinder, learning?

Our interviews with approximately 70 undergraduate engineering students related to these research questions. This paper describes the interview methodology and explains the process we used to analyze the data. As we engaged in the process of analysis, various themes emerged based on what students told us during the interviews. The dominant themes relating to integration are discussed along with examples of students' responses. The data and results reported here are fundamentally qualitative in nature. Our current results consist of a framework to analyze student interview responses. The framework consists of a set of categories that characterize student experiences in, and perceptions of, the curriculum. The framework is important, as it can be applied to other qualitative research studies taking place within the engineering education community.

Method and Procedure

Approximately 70 audio-taped interviews were completed between the spring 1999 and spring 2000 semesters. A team of graduate and undergraduate researchers from education, sociology, physics and engineering performed the interviews. Initial and on-going training sessions were conducted with the team to review the protocol, to learn and practice interviewing skills, and to discuss the results of the interviews. The team consisted of three male and three female interviewers. Participants in the study were obtained by contacting all undergraduate mechanical engineering students by email and inviting them to participate in the project. Participation was voluntary and based on total number of students contacted we had a response rate of approximately 22%.

The students interviewed for the current project represent a diverse population with respect to gender, ethnicity, and grade point average (GPA). Of the students interviewed, 51% were seniors, 23% juniors, 21% sophomores, and 5% freshman. Approximately 67% of the students interviewed were male and 33% female. The range of participants' ethnicity is given in Table 1. As indicated in Table 1, the ethnicity of the participants closely matches the ethnicity breakdown of the overall college of engineering. Note that the percentages do not add to 100% because not all of the students we interviewed gave consent to report their ethnicity, and not all undergraduates reported their ethnicity. The students also covered a range of ability as measured by their GPA with 1.7 being the lowest and 3.9 the highest.

Ethnicity	Percent in GE Interview Project	Percent of Undergraduates in College of Engineering, Fall 2000
African-Amer.	1%	1%
Asian-Amer.	59%	52%
Caucasian	26 %	23%
Hispanic	None reported	5%
International	3%	8%

Table 1. Ethnicity of participants in GE interview project vs. all undergraduates in college of engineering.

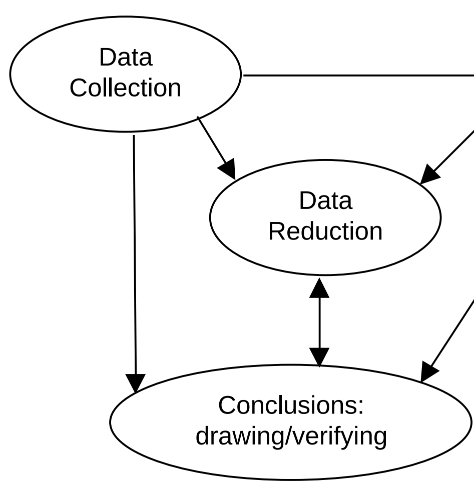
In order for the reader to get a sense of what we asked students during the interview, four sample questions (out of 32 total) are provided in Figure 1. These questions were created to align with the research questions in order to provide data to understand student experiences within the curriculum. As the interviews were conducted over the course of the academic year, the interviewers met regularly to discuss progress and any issues that arose during the interviews.

These meetings ensured that the protocol questions were effective in eliciting appropriate responses. Over the length of the project, questions were rephrased, new more relevant questions were added and ineffective questions were deleted.

1. In physics [math], many students report that they understand the concepts, but can't solve the problems. Why do you think this happens?
2. Suppose that you are consulting with the university, what advice would you give faculty about how to improve the curriculum?
3. Overall, how well do you think the Physics 7 series prepared you for upper division engineering? Why?
4. Since this project is looking at ways to improve the science, math and engineering curricula, do you have any suggestions as to how we could better tie these courses together?

Figure 1. Sample questions from the interview protocol.

Once all of the interviews were completed, the audio tapes were transcribed and copied into the qualitative software package NVIVO[13]. The analysis described in this paper reflects the iterative tradition of qualitative research corresponding with the grounded theory approach of Glaser and Strauss [14, 15] and the strategies for analysis of Huberman and Miles[16]. Qualitative analysis strategies are an integral part of a study's design and influence the selection of research questions, sample selection, instrumentation, etc. Our process of data collection and analysis closely followed Huberman and Miles' model as shown in Figure 2. Critical to this model is the notion that the analysis is on going and occurs during study design and planning, during data collection, and continues after data collection has been completed. This process is inherently iterative, building upon the researchers' observations during data display and reduction processes as well as observations during (in this case) the interviews.



From: Huberman, A.M. & M.B. Miles (1984). *Qualitative Data Analysis.* Beverly Hills: Sage.

Figure 2. Huberman and Miles' model of qualitative data management.

Following the grounded theory approach, we first developed a broad coding scheme, which allowed us to categorize student responses for initial analysis. 25 categories were established for the initial coding and all of the interviews were read and student responses were coded based on these original 25 categories. Examples from the first coding scheme are provided in Figure 3. It should be noted that some of the responses fell into one or more categories. In such cases the response was assigned multiple codes. Comments that did not fall under these original 25 were not coded. Typically these responses were unrelated to the research questions therefore it was not necessary to document them.

- Suggestions students give to better integrate math/physics/engineering together
- How students say math has prepared student for engineering courses
- How students say physics has prepared student for engineering courses
- Examples or descriptions of factors that help learning
- Examples or descriptions of factors that hinder learning
- Examples or descriptions of the nature of problems and/or problem solving

Figure 3. Initial coding scheme for interview data.

After all of the interviews were read and coded according to the initial coding scheme, we began the second phase of the analysis. We reviewed the engineering literature on curriculum integration and the goals of the GE project to focus our analysis. Based on these sources we decided to focus on the broad question; "How do students talk about integration?" Since the first coding included categories that were unrelated to this specific question, we selected a subset of six of the original 25 categories that most closely aligned with the this broad research question. Since NVIVO allows one to sort the interview data along many dimensions, we created new coding reports for this subset of categories. We then carefully read through the responses and identified new emergent themes. Based on this reading, we refined our research questions, and created a new coding scheme that better addressed the question. Our new more focused research question was two fold; 1) "What factors in the curriculum contribute to an improved, more integrative understanding?" and 2) "How do students' beliefs about the discipline and the nature of learning affect their understanding?"

As we read through the interview data during this second phase, the research team met regularly to discuss and interpret the results. We identified and categorized the specific comments students made regarding curriculum and knowledge integration. After multiple discussions, grounded in the actual interviewee responses, we established a new fine-grained coding scheme. This new coding scheme was more detailed and allowed for a more thorough analysis of the interview data. Examples of the new coding scheme are given in Figure 4. In this new coding scheme, a main category was created along with several 'branches' that further elaborate on the main category. A total of 8 categories were created along with several branches for each.

Factors that Help Learning

1. linking concepts across classes/disciplines
2. establishing relationship between math/physics and how they are relevant to future courses
3. interest level, motivation
4. discuss applications

5. …

Beliefs about Math

1. lacks relevance (to real world applications, or to future eng. courses, etc…)
2. is abstract/theoretical
3. consists of tricks and/or algorithms
4. math problems can be solved without understanding the concept
5. …

Beliefs about Physics

1. is theoretical/ concept driven / is an abstraction (or not related to an application)
2. goes against intuition/ require students to shift their fundamental intuition
3. deals with ideal situation/ hypothetical
4. answers are 'exact'

Beliefs about Engineering

1. analysis applies to a real life situation (pressure, force on beams, etc)
2. deals with complexity
3. involves approximations/assumptions and/or empirical
4. uses design
5. …

Figure 4. Examples of categories and branches from new fine-grained coding scheme.

Once we established this new coding scheme, we began phase three of the analysis. During this phase we re-read all of the transcripts and re-coded using the new codes. The following section presents examples of several student comments that fall under this new coding scheme and outlines our framework for interpreting the data.

Results

As described in the methods section, we started with a broad coding scheme in order to preliminarily sort the data. From this initial coding we focused on a subset of codes that aligned with the broad research question; 'How do students talk about integration?' After carefully reading this subset of codes and reviewing the literature, we identified dominant themes in the data. Based on these themes we developed a more fine-grained coding scheme that captured the main ideas relating to the issue of integration. Basically, by creating the specific categories in the final coding scheme, we have classified the interview data according to an interpretative framework. In this section we outline our framework and present examples of student comments from the interview data.

A. Assimilation and Accommodation (how students develop and build mental models)
B. Communication
C. Curriculum
D. Factors that Help Learning
E. Nature of Problem Solving
F. Beliefs about Math
G. Beliefs about Physics
H. Beliefs about Engineering

Figure 5. Eight categories of the final coding scheme.

The eight categories in the final coding scheme in our framework are shown in Figure 5. Each of these categories also includes a subset of branches as illustrated in Figure 4. These categories classify how students talk about integration and the curriculum. Based on the students' responses in these eight categories, we identified a framework for interpreting the data. This framework suggests that integration should be considered from a pedagogical as well as an epistemological point of view. The pedagogical point of view takes into account issues regarding the curriculum such as teaching style, classroom activities, course sequencing, etc. Most integration reform efforts focus on issues of pedagogy in terms of affecting change through altering the curriculum [9,10,12]. While pedagogical change is essential and inherent in any reform effort, our interview data suggests that there are complementary, and equally important, epistemological issues to consider.

Epistemological issues refer to students' perceptions about math, physics, and engineering and their beliefs about the nature of learning and problem solving. Based on our data, the epistemology of integration can be defined as the students' understanding of the nature of integrated knowledge. The epistemological point of view takes into account how students perceive the curriculum and what role math and physics play in the practice of engineering. Our data suggests that students hold strong beliefs about the nature of the disciplines and these beliefs interact with the curriculum and pedagogical reform efforts.

The eight categories are grouped according to our framework as shown in Table 2. The codes under 'pedagogy' capture student comments regarding the curriculum, classroom issues, and communication among faculty, students and teaching assistants. Data within the pedagogical framework relate to issues external to the student. In contrast, the codes under 'epistemological' relate to students' beliefs and perceptions. These comments relate more to an individual student's internal cognitive mechanisms.

Based on our data, we see a distinction between what happens *to* the student and what is done (or thought) *by* the student. For example, pedagogical changes to the curriculum are external to the student and these factors can be characterized independent of the individual student. Changes such as revising course content and structure, enhancing communication, implementing design projects are most often done at the departmental or faculty level. Student input may be provided on curricular aspects of the course, but this input is provided collectively from students who have taken the course in the past and not students currently in a course. Epistemological issues, on the other hand, relate directly to what the student thinks, perceives, and understands. These issues are intrinsically internal to the extent that they can not be characterized without obtaining feedback from the individual. We view these two sides of our framework as complementary data sources. Students' epistemological comments tell us about the effect of the pedagogical reforms, and pedagogical reforms theoretically affect students understanding and beliefs. Both sides of the framework are therefore necessary to provide a comprehensive understanding of integration curricula reform.

Literature on engineering education reform suggests that integrating the curriculum can serve as a scaffolding mechanism [9,17]. The literature argues an integrated curriculum inherently "helps students to visualize and understand links among different disciplines. These links can help practicing engineers synthesize multidisciplinary solutions." [9] While this quote was originally offered as an abstract theoretical argument for an integrated curriculum, our data confirm this notion and provides evidence to support this theory.

Pedagogy	Epistemology
B. Communication	A. Assimilation and Accommodation
C. Curriculum	E. Nature of Problem Solving
D. Factors that Help Learning	F. Beliefs about Math
	G. Beliefs about Physics
	H. Beliefs about Engineering

Table 2. Framework for analyzing and interpreting interview data.

Representative examples of student comments from the two groups of codes are provided in Figures 6 and 9. Figure 6 presents examples from the interview data that align with ‘Code D’: Factors that help learning. These student comments directly address the topic of integration and offer suggestions to improve the learning experience. A common suggestion from the data was to provide learning activities that allow students to link concepts across classes. Students indicate that this is helpful because it provides them the opportunity to see the relevance of the concepts and how these concepts might apply across disciplines and to future courses. Comments given in Figure 6 fall under the pedagogical side of our framework since all of the comments deal with issues regarding problems with, or changes to, the curriculum.

JE: … You always try to look for ways of solving problems by avoiding integration. I think everyone’s just a little bit scared of it. Maybe because the fundamentals weren’t covered enough… we had problems that said, ‘Integrate this, integrate this.’ But it didn’t have a relation to, like, you know, an actual system, like water draining from a tank or something … I think the best way to improve that part of it is by giving a little more real world connection to math problems in the beginning. I think if we had integrated math in math, knowing that this is like draining water from a tank, then we wouldn’t be afraid to use it later when you’re draining water from a tank as an engineer. [D1, D5] [Sr., Male]

TC: …the professor that I had was insistent on bringing in real world examples. She was amazing. She brought in broken springs from her trailer. I mean every day she had a new example of how so many concrete things you could look at and see "this is how this applies, this is why this is real. This is why I need to know this." [D3, D5] [Sr., Female]

RI: The better you learn a subject, the more you tend to attach it to other subjects. You don’t see the lines between classes and subjects anymore. It takes a while, because around here, you’re forced to discover that on your own. Classes are rarely, to never, tied into each other… The best way I think is to create some sort of hub - some sort of command central - where a student can either work on a project. . . at freshman year right off the bat, that ties all this stuff together. That would make people so much happier. They would learn better, there’d be motivation, there’d be group work, you’d make friends. [D1] [Sr., Male]

SR: …the math classes sometimes gave examples related to physics. I also liked the fact that the math and physics classes were fairly well synchronized, that concepts we were covering in a math class we also covered in physics at the same time. For example, in Math 1B when we were covering differential equations, at the same time in Physics 7A we were covering springs and oscillating springs. The two concepts are very closely linked. So we could see essentially the same examples in both classes which made it easy to relate. So I thought that the synchronization helped reinforce the concepts and show us an application for the math that we were learning. [D1, D2] [Sr., Male]

JT: …I had an interview for a job and they asked me really simple problems.… put a force on it and then they ask you where it would fail. Obviously here, right? But then I was thinking I guess [bending] from both sides, it would be the middle, right? So I said it too fast…And then he started asking me why I would support the other end. I never thought of the cable stuff, even though that's pretty obvious now. So then he asked me, "What type of material would you make the beam out of?" I still couldn't answer him. But then when he suggested, "How about carbon fiber?" And I said all the characteristics that I knew about carbon fiber. And I listed them, but I didn't make a connection. He would say, "Well, you're trying to prevent tensile failure." And I was like, "Oh, yeah. That's right." I guess carbon fiber is very strong in one direction but not the other. [D5] [Jr., Male]

Figure 6. Representative examples of student comments, Code D: Factors that help learning.

All of the comments that fall under the general code 'D' are further categorized based on the branches defined for this code. The branches serve as a detailed explanation for the type of comment given. The full set of 7 branches for code D is listed in Figure 7.

Code D: Factors that Help Learning
1. link concepts across classes/disciplines 2. establish relationship between math and physics concepts and how they are relevant to future engineering courses 3. increase relevance of course content to real world 4. interest level, motivation 5. discuss applications 6. visualization 7. reinforcement and revisiting of concepts

Figure 7. Code D: Factors that Help Learning

Using this framework we can perform a pseudo-quantitative analysis by sorting the data to determine the total number of comments in each branch. The totals in each category indicate where students have the most comments and present an overall picture of the data within the framework. This analysis affords a visual inspection of the data and an approximate tally of student comments. However, we are careful not to impose statistical rigor to data that is inherently qualitative in nature. Figure 8 shows the total number of comments for each branch in Code D as well as the total number of students who made comments for each. For example, 120 comments were made that fall under D1. Of the 70 students interviewed, 60% commented on the benefit of linking concepts across disciplines. Figure 8 also shows that branch D5 (discuss applications) received the most comments, 130. Approximately 70% of the students interviewed mentioned benefits of including applications as concepts were presented and discussed. The majority of students describe the importance of attaching concepts to something 'tangible' in order for them to understand and make sense of the theory and analysis.

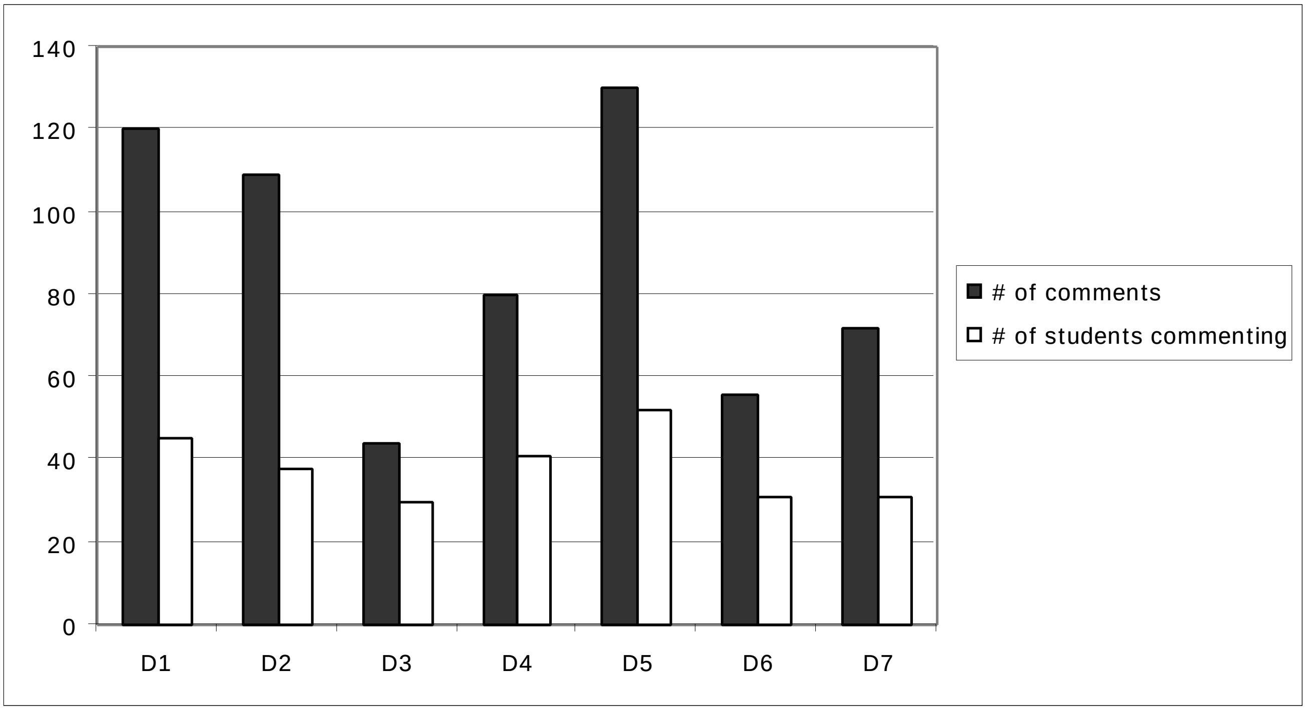


Figure 8. Total number of comments given for each branch in Code D.

Our data also give us insight into students' perception about the nature of the disciplines. Figure 9 provides comments under the epistemological Code F: Beliefs about Math. These comments suggest that students believe that mathematics is abstract and has no relevance. The data we have captured about students' beliefs are compelling for two reasons. First, by default, these comments tell us something about the effect the curriculum has on student understanding. For example, if the goal of integration is to provide links and increase relevance, these comments suggest that this goal is not being achieved. Second, these comments can serve as a guide for future pedagogical reform efforts. These student comments clearly expose their underlying understanding about the nature of math, physics, and engineering. This helps us to identify 'pedagogical gaps' that affect students' perceptions. For example, student ML in Figure 9 believes that math is pointless, abstract, and lacks a tangible application. One could argue that these beliefs are a direct result of the student's classroom experiences and, by extension, the entire curriculum. These perceptions interact with the student's learning experiences and ultimately affect the success of any pedagogical reform effort. Therefore, the epistemological aspect of our framework uncovers the individual student's belief structure that provides clues to the direction and overall efficacy of reform efforts.

ML: Well, mathematics is, basically…abstract, because unless you apply it to something you don't have a physical foundation…there is nothing really to attach it to in your physical world. It's more conceptual, you have to be able to manipulate symbols…You got to get over the fact that it may seem pointless, and just do it. That's probably one of the hardest things in math, that's there's no reward, there's no tangible physical thing that you have. You didn't find out how far this ball is going to fly, or how long it will take for this thing to cool down. You have a number, and you can't do anything with this number. [F1] [Sr., Male]

SP: The problems in math have absolutely no significance at all. It's purely an exercise. [Sr., Female]

SR: I think studying math is different than studying physics particularly for engineers because there's less physical reasoning behind the problems. I think engineers revert to their physical intuition to give them some insight into homework problems. It's much more difficult to do it in math because in a lot of cases there's not a physical basis for the problem--and second of all, because we don't have that intuition. I think a lot of us who are engineers have practice with physical intuition in how things work, and how physics works…But we don't have that intuition with math. [F1] [Sr., Male]

ST: The thing with math is the concepts are a lot less broad, so there's no real life situation to relate it to. It's just sort of to see little tricks here and there, to change this term…It's not very realistic. Like I said, I don't have very much purpose in following math problems. I just sort of get it done. I don't know what's going on and I don't know how I can apply it any further. [Sophomore, Male]

Figure 9. Representative examples of student comments, Code F: Beliefs about Math.

Summary

Over the past two years we conducted a research project at the University of California at Berkeley to study the impact that various integration reform efforts had on student learning. We conducted over seventy interviews with engineering students to collect feedback on their experiences with the curriculum. This paper described the interview project and outlined the framework we created to begin analysis of the interview data. Based on the interview data we found that student comments can be categorized along two dimensions: pedagogical issues and epistemological issues.

Pedagogical issues involve factors relating to the curriculum such as classroom practice and course content and structure. The second dimension captures data that refers to epistemological issues such as student beliefs about the discipline, and the nature of problem solving and learning. This dual framework allows us to provide a comprehensive analysis of the data to study the impact of integration efforts. More importantly, the framework can serve as a template for similar qualitative research studies taking place within the engineering education community. Ultimately the framework will help us understand the nature of student learning and inform future reform efforts.

The current paper lays the groundwork for the analysis of our data and provides examples of student comments within our framework. We recently completed the data entry (coding) in NVIVO and are working to complete the final analysis based on the categorization of student responses using the new coding scheme. Once this is completed we can perform additional quantitative analyses for other categories in the framework. We have included this analysis for one of the categories, D, and further analyses will provide a comprehensive picture of the data by illustrating where the majority of student comments are located and which issues are most prevalent.

Future work will analyze the interview data for differences along gender and/or grade level. For example, perhaps student perceptions change as they advance in the curriculum and come to align more closely with the goals of an integrated curriculum. Or, perhaps there is a fundamental difference between how males and females perceive the disciplines. In addition, we have also interviewed participating faculty from the physics, mathematics, and engineering departments. We will examine faculty interview data and compare it to the student interview data. This comparison may uncover differences between the faculty and students' perceptions about the classroom environment and changes that were implemented.

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