AC 2009-1444: MATHEMATICS AND PHYSICS FACULTY CONCEPTIONS OF TEACHING IN A FIRST-YEAR INTEGRATED PROJECT-BASED ENGINEERING CURRICULUM

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Mathematics and Physics Faculty Conceptions of Teaching in a First-Year Integrated Project-Based Engineering Curriculum

Abstract

This paper examines the experiences, perspectives, and concerns of mathematics and physics faculty involved in implementing a first-year integrated project-based engineering curriculum. Carried out at a small engineering college that uses project-based learning (PjBL) as its main curricular and pedagogical practice, this curriculum expects that mathematics and physics faculty team-teach in the environment of integrated course blocks. A semi-structured, open-ended interview protocol is employed and grounded theory is used to identify answers to the following questions: (1) What are the conceptions of teaching held by mathematics and physics faculty involved in implementing a first-year integrated project-based engineering curriculum as defined by Kember's categorization of faculty conceptions? (2) To what extent does the context, in which faculty instruct, affect their teaching approaches? (3) To which extent does passive involvement (i.e., no instruction or assessment of teaching techniques) in a student-centered educational environment affect faculty's adoption of learner/knowledge-centered teaching approaches? Preliminary analysis indicates that most mathematics and physics faculty teaching in the project-based environment have student-centered intentions in teaching and the context in which the instruction is implemented (e.g., academic discipline) plays an important role in shaping faculty intentions and teaching approaches. Most faculty identify a need to continually adjust their conceptions of teaching to have a successful teaching and learning experience.

Introduction

Despite the fact that numerous engineering schools, including top institutions of higher education,[1] have transitioned to more hands-on, collaborative curricula, changes in engineering education are still described as "slow."[2] One of the proposed reasons for such a slow change is attributed to "faculty members who 'are very, very protective of their curricula.'" Moreover, the process of "changing faculty attitudes" towards teaching and learning is identified as "the key" to advancing engineering education reform in U.S. institutions of higher learning.[2] Numerous studies support the claim that faculty conceptions of teaching strongly impact their willingness and ability to support education reform.[3] Faculty come into academic settings with pre-existing beliefs about teaching and learning that are based on their own experiences in education.[4] These beliefs are often resistant to change and may serve as filters for attainment of new knowledge about teaching and learning.[5]

Conceptions, which are used synonymously with beliefs in this context, are defined by Pratt as "specific meanings attached to phenomena which then mediate our response to situations involving those phenomena. […] In effect, we view the world through the lenses of our conceptions, interpreting and acting in accordance with our understanding of the world."[7] Faculty conceptions of teaching, which are distinct from conceptions of learning, comprise

beliefs about effective instruction, meaning of a "good teacher," and teaching methodologies used in a classroom environment.[8] Closely related, faculty conceptions of learning involve faculty understanding of how students learn and structure knowledge. These conceptions may differ from the corresponding student conceptions of learning.[9]

Based on a qualitative review of existing literature, Kember (1997) describes five primary categories of faculty conceptions of teaching:[6]
- Imparting information,
- Transmitting structured knowledge,
- Student-teacher interaction,
- Facilitating understanding,
- Conceptual change/intellectual development.

These categories range from highly faculty-centered, where students are passive recipients of knowledge, to highly student-centered, where student knowledge structures are challenged and remolded as part of the learning process. The 'student-teacher interaction' category is an intermediate between these two extremes of Kember's categorization spectrum.[10]

Several other theoretical frameworks of faculty conceptions of teaching are currently in use in education research.[11] These frameworks are often context-specific and may be dependent on a number of contextual factors including student background, institutional values, academic discipline, faculty teaching and learning experience, etc.[12]

For example, Trigwell et al. (1996) describe faculty conceptions of teaching by separating intention from strategy.[8] As a result they add four intentions to the two teaching strategies (faculty-centered and student-centered):
- Information transmission,
- Concept acquisition,
- Conceptual development,
- Conceptual change.

Trigwell et al.'s study, which focuses on chemistry and physics faculty, cites that slightly more than 50% of faculty uses a faculty-centered strategy with the intention of transmitting information to students.[8]

In another study by Van Driel et al. (1997), which specifically focuses on engineering education, only three categories of faculty conceptions of teaching are used:
- Teacher-centered,
- Student-directing,
- Student-centered.

Cited most frequently, the 'student-directing' category describes a faculty member's desire to encourage student-student and student-faculty interactions.[13]

Despite the wide range of theoretical frameworks of faculty teaching conceptions, there is a great deal of consensus and overlap between them. While most sources identify the importance of acknowledging faculty conceptions prior to the use of new pedagogical methods,[4] this study examines faculty conceptions after the introduction of the innovative pedagogical techniques into the curriculum. Specifically, this paper describes the teaching conceptions of mathematics and

physics faculty upon completion of delivery of an innovative first-year integrated project-based engineering curriculum.

This study employs the framework of Helle *et al.* (2006) to define project-based learning (PjBL) as a self-guided experience centered on a project. This focus on a project positions instructors in the role of advisers rather than authorities.[14] Moreover, as a very multifaceted approach to teaching and learning, PjBL is often taught in an integrated manner that Everett *et al.* (2000) define as "the act of making individual courses become integral components of a whole, while at the same time requiring them to be interdependent upon one another and bound by a common thread of knowledge."[15]

Based on Helle *et al.* and Kember's theoretical frameworks, and using faculty interviews from a larger study, this paper examines the experiences, perspectives, and concerns of mathematics and physics faculty involved in implementing a first-year integrated PjBL experience. Specifically, the following questions are addressed: (1) What are the conceptions of teaching held by mathematics and physics faculty involved in implementing a first-year integrated project-based engineering curriculum as defined by Kember's categorization of faculty conceptions? (2) To what extent does the context, in which faculty instruct, affect their teaching approaches? (3) To which extent does passive involvement (i.e., no instruction or assessment of teaching techniques) in student-centered educational environment affect faculty's adoption of learner/knowledge-centered teaching approaches? Preliminary results identify the following themes: (i) while a wide range of strategies exist, most PjBL faculty have student-centered intentions in teaching; (ii) the context (e.g., academic discipline), in which the instruction is implemented, plays an important role in shaping faculty's intentions and teaching approaches; and (iii) based on their own experience in a PjBL curriculum, faculty identify a need to continually adjust their own conceptions of teaching, both in terms of class ownership and pedagogical methods, to have a successful teaching experience.

Study Population and Methodology

This study was performed during 2003-2004 and 2004-2005 academic years at a small private engineering college that uses project-based learning (PjBL) as its main curricular and pedagogical practice. In the first-year curriculum, math and physics faculty team-teach an integrated course block which combines lecture, small-group work and student-designed team projects to encourage understanding of fundamental concepts. However, the particular pedagogical methods employed in the integrated course block vary depending on the conceptions of teaching that members of each specific faculty team hold. The integrated nature of this curriculum expects that mathematics and physics faculty, who nominally teach 'service courses,' team-teach in the environment of integrated course blocks that support students' learning of engineering concepts. The latter are presented through a separate, but coordinated with mathematics and physics, class taught by engineering faculty. This overall structure of the first-year curriculum allows for much pedagogical experimentation and innovation. Of note is the fact that the innovative nature of the college attracts a significant number of faculty interested in implementing novel teaching practices and curricular design, project-based learning (PjBL) being one of them.

A semi-structured, open-ended, 1-2 hour in-depth interview protocol was employed with four mathematics and three physics faculty involved in this curriculum. Only two of the interviewed faculty were female. Engineering faculty participating in the delivery of the above curriculum were not interviewed for this study. Future work may include their perspectives. Using grounded theory, the data were coded and narrative summaries were written based upon emergent themes.[16] Validity and reliability were ensured through a group process of codebook development and peer debriefing. Further analysis included exploration and comparison of patterns within and among the identified themes. The scope of this study did not include classroom observations.

Analysis

Conceptions of Teaching of Mathematics and Physics Faculty

Using Kember's categorization of faculty conceptions of teaching, four of the seven faculty members, two mathematics and two physics, were identified as having a 'facilitating understanding' conception of teaching. Two faculty members, one mathematics and one physics, were characterized by the 'conceptual change' category. One mathematics faculty was qualified as having the 'transmitting structured knowledge.'[6] Overall, the mathematics faculty appeared to be closer to the faculty-centered end of intentions' spectrum in terms of their descriptions of teaching while the physics faculty leaned more towards student-centered end of spectrum. As a whole, the faculty intentions were shifted to the student-centered side. These results are visually represented in Table 1. This differs from the results of Van Driel *et al.* who identified most of the faculty involved in first-year in engineering courses as using the 'student-teacher interaction' category, which falls in the middle of the spectrum.[13] This is most likely a result of the institutional atmosphere since the school in the current study focuses on innovative teaching methods such as PjBL.

Table 1: Identified Conceptions of Teaching Based on Kember's Framework.[6]

Conception of Teaching	Imparting Information	Transmitting Structured Knowledge	Student-Teacher Interaction	Facilitating Understanding	Conceptual Change
Representation in Data		1 math		2 math, 2 physics	1 math, 1 physics

Effect of Context on Teaching Approaches

The faculty in this study were found to have a very complex set of intentions in the classroom. Some described themselves as being focused on teaching content; others portrayed their efforts of developing specific skills (e.g., diagnostic ability and communication) as most valuable contributions to student learning; while yet others perceived themselves as facilitators in student development into critical thinkers. However, almost all of the faculty interviewed felt that problem-solving was a particularly important skill to develop in a first-year engineering curriculum. As one mathematician explains,

[Students] can get information. They are starting to acquire the tools they need to learn things in terms of reading things, finding sources, talking to each other, negotiating with professors, giving presentations, and interrogating themselves. That is what I see as the biggest impact of that first year, is that I really feel that by the end of the first year [students] are really far along on that part. (Interview #1, 12/13/2005)

An important element for the instruction in the first year was identified to be teaching students how to teach themselves. Other studies have identified similar themes; for example, Van Driel *et al.* explain, "specifically, problem-solving abilities, such as selecting information, and identifying and analyzing problems, were identified as being crucial."[13] However, the current study found that faculty have a wide range of perspectives on how to best accomplish teaching this skill. Some believe that there is a basic set of content knowledge that students must have before they can engage in student-led activities while other faculty deem students capable of directing their own learning from day one. Although most faculty in this study agreed that student-centered intentions are ideal for encouraging problem-solving, the specific nuances of how these 'student-centered' intentions were implemented varied dramatically.

For example, one of the physicists described his value system associated with facilitating 'conceptual change' as follows,

I value student engagement. I value my relationships with students and I have a liberal arts sort of value system with regard to what I think is important for students. I feel it's important for students to graduate with having learned something about who they are and having learned something about how the world works and not necessarily having decided what they're going to do with their lives. (Interview #7, 1/2/2006)

On the other end of the observed spectrum of the value system, a mathematician described a very different approach to teaching, one in which the context the course is delivered in defines the pedagogical methodology,

The mode at which you teach something really depends a lot on what you are teaching. What are the students that you are teaching? And where are they? And, so on. And, of course, my teaching at [this school] is conditioned a lot by the fact that, ok, I don't have time to teach much at all, but none the less I put myself in the curriculum teaching about full time. So I have to teach in very efficient ways. Pretty classical ways. But, I feel that, unlike some of my colleagues, I do not think the lecture mode of teaching is necessarily ineffective or bad. (Interview #3, 12/16/2005)

While both of these faculty members care deeply about students, they have very different intentions in the classroom. The first faculty member is much more concerned with the development of the student as a whole person while the second quote describes an approach that is more focused on content comprehension. These conceptions lead very naturally into specific ways faculty implement relevant curricula. Faculty-centered conceptions are realized mostly through lecture style of curriculum delivery while student-centered conceptions are embodied, on the average, by the usage of small group work and projects. Surprisingly, even within the team-teaching environment, faculty are able to maintain very different notions of how to educate students.

Within this context, a team-teaching curriculum gives rise to further discussion of faculty conceptions of teaching vis-à-vis their implementation of curricular innovations. As one physicist explains, team-teaching can lead to conflict when faculty are accustomed to having ownership over their classes,

> *I think that a chunk of the faculty, and I'm one of them, that feels like the space that we ought to be talking about is sort of the entire student experience space, but that is not a space that one person owns, it's a space that a bunch of people own. Or that no one owns, and so there's a great deal of wailing and gnashing of teeth that goes on about who ought to be doing what and when and how those things coordinate with each other and whether it's too much time or not enough time.* (Interview #7, 1/3/2006)

Clearly, faculty beliefs highly influence their understanding and appreciation for new teaching methods. If two faculty members with different fundamental beliefs are expected to teach together, they may have radically different notions about what, how, and when to teach students particular subject matter. As described before, this can lead to tension which may affect student learning and engagement.[17, 18]

Yet, even the initially skeptical faculty agreed with the basic premise that innovative pedagogical methods are effective,

> *I recognize that there could be a lot of people who could have been physicists in my generation but just didn't learn the same way I did, and you sort of needed some other way to enforce ideas, so I try to do that.* (Interview #2, 12/13/2005)

This, however, comes at a cost of continual compromising,

> *If you're a traditional teacher and you are given an opportunity to teach in a traditional way, you're probably going to do much better job than if you were forced to do project-based stuff.* (Interview #5, 12/22/2005)

Most research supports the claim that a faculty member whose conception of teaching does not agree with a given pedagogical methodology will not be effective when forced to implement such methods.[3] The uniqueness of the school in this study is that faculty have the opportunity to continually reconsider their pedagogical philosophies and experiment with new classroom strategies they learn from their colleagues. By observing their colleagues in a team-teaching environment and discussing their pedagogical methods, faculty become aware of what they bring to the classroom and have an opportunity to critically examine new successful strategies.

Almost all of the interviewed faculty members had experimented with new teaching methods since coming to this school. As one physics professor describes, this was largely a result of the institutional culture,

> *I'm much more open to innovation and I'm much more open to hearing what others are doing and I'm trying to incorporate other things. It's very easy to teach traditionally because all of the literature is out there, the problem sets are out there, […] so it takes an extra effort to go ahead and find something new and fun to do; but because of the environment and because of others who are teaching here, and because of students' expectations, and also because I don't want to get bored either, I'm trying to go out of my*

way to find ways of involving students and letting them do something fun and innovate.
(Interview #5, 12/22/2005)

Even in the absence of institutional efforts to instruct faculty about the value of their teaching conceptions and innovation in their classrooms, this college created a culture, in which both faculty and students expect originality, creativity, and constant improvement in the classroom. As such, pedagogical experimentation in this environment becomes less of a novelty and more of a reality. This benefits not only the students, but also the faculty members, who find teaching experiences to be more rewarding.

Conclusion

Faculty conceptions of teaching and learning are driving concerns related to engineering education reform. Numerous studies have found that if institutions are to transition to more hands-on, project-based curricula, faculty education and change in their conceptions of teaching need to be at the center of such transition.

The analysis in this study focuses on faculty most of whom are already engaged in academic reform. Yet when considering faculty conceptions of teaching, this research identifies a wide range of perspectives. While none of the interviewed faculty felt that the 'imparting information' category must be the dominant pedagogical intention, a significant number of them described lectures as an important and useful tool for achieving student learning. Most of the interviewed faculty fell into the 'facilitating understanding' category of conceptions of teaching.

Despite the variability in faculty conceptions of teaching and the contexts in which faculty instruct, this study identifies a common goal shared by all instructors, that of encouraging and promoting students' problem-solving skills in a first-year engineering curriculum. To this end, an effective instructional methodology stimulating a shift in faculty teaching conceptions must take into account a wide range of contexts responsible for teaching beliefs currently held by instructors. These contexts include academic discipline, available time for teaching, educational background, goals for student learning etc.

Based on the variability of teaching conceptions that faculty in this study hold, it is reasonable to conclude that passive engagement in an environment of pedagogical innovation alone cannot produce significant shift in their belief system. Although such an innovative environment may contribute to faculty participation in pedagogical experimentation, this analysis suggests that faculty may need further support and instruction to guide their learning process about efficacy of various teaching approaches. In agreement with the work of McKenna *et al.,*[4] this study indicates that educational efforts focused on active faculty engagement and self-reflection are needed to effect the change in faculty conceptions of teaching and movement towards student-centered pedagogical practices geared towards student intellectual development and conceptual change.

Moreover, faculty teaching conceptions must be made explicit to facilitate a thoughtful, constructive dialogue regarding engineering education reform. It may be useful for faculty to come together and share best practices to encourage a culture of common pedagogical innovation. In addition, faculty may benefit from experience in team-teaching, which may expose them to alternative conceptions of teaching and learning.

Acknowledgements

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