The Nature of Biochemistry Instructors' Thinking: Factors Associated with Change and Growth

by

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DEDICATION

This dissertation is dedicated to my family: my siblings, my parents, and my husband. To my siblings, who despite the distance kept me laughing, even when I thought I had forgotten how. To my father, my personal cheerleader, who has always believed that I can do anything and finally convinced me I could. To my mother, who like her own mother, taught me about the strength of women and the meaning of perseverance. And most importantly, to my husband Sam, who has all but forgotten hot meals together, lazy Saturday mornings, and evening walks with the dog. He has been a bottomless well of patience and support. It would have been impossible to complete this chapter of my life without him.

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ABSTRACT

The objectives of this study were to (1) characterize the nature of biochemistry faculty members' "instructor thinking" with regard to teaching upper-level, large-lecture biochemistry courses, (2) identify factors associated with changes in instructor thinking, and (3) investigate the relationship between instructor thinking and teaching practice. For the purposes of this study, "instructor thinking" was defined as an instructor's thoughts about (1) teaching, including the role of instructors, student engagement, instructional strategies, and assessment and (2) students and learning, including personal experiences with learning, student roles and capabilities, and student learning. Instructor thinking of three university faculty members was investigated over the course of two semesters. Semi-structured in-depth interviews, faculty members' reflective journals, e-mail, course documents and investigator observations and field notes served as qualitative data sources. Descriptive and interpretive data coding methods were applied to the data and emergent themes were reported in three individual case studies depicting instructor thinking. A cross-case analysis of the three cases was conducted and revealed factors associated with changes in instructor thinking: pedagogical dissatisfaction, creation of productive spaces for reflection by a knowledgeable other, and experimentation with assessment strategies. These factors opened the door for new lines of instructor self-inquiry and introspection about teaching and, in some cases, created new prospects for change in teaching practice.

INTRODUCTION

Upon entering academic positions, science faculty members are often well-prepared for their research roles. Yet most receive little, if any, formal training in the teaching of science that would prepare them for their roles as instructors. Graduate students in science are more likely to hold research, not teaching, assistantships. As teaching assistants, they are typically assigned to facilitate labs rather than teaching whole sections by themselves, and are seldom assigned to TA positions with their development as future professors in mind (Austin, 2002; Kugel, 1993; Menges & Austin, 2001). Despite this inadequate preparation in teaching, colleges and universities are under increased pressure to shift the focus of undergraduate education from one on teaching to a focus on student learning (Barr & Tagg, 1995; Handelsman, Ebert-May, Beichner, Bruns, Chang, DeHaan, Gentile, Lauffer, Stewart, Tilghman, & Wood, 2004; Huba & Freed, 2000). The ever-increasing literature on how people learn provides evidence that traditional, teacher-centered instructional strategies, such as lecture, are not the most effective at promoting deep student learning (NRC, 2000; NRC, 2003; Huba & Freed, 2000). Broadly defined, a teacher-centered orientation to teaching is one that focuses on the instructor and the transmission of content or knowledge to students. In contrast, a learner-centered orientation can be generally defined as one that concentrates on the student and developing conceptual understanding in students (Åkerlind, 2003, Barr & Tagg, 1995, Gibbs & Coffey, 2004; Huba & Freed, 2000; Kember, 1997, Kember & Kwan, 2000, Martin & Balla, 1991; Samuelowciz & Bain, 1992, 2001). A teacher-centered orientation to teaching is consistently considered to be less sophisticated than a

learner-centered orientation that is generally thought to be associated with students' adoption of deeper learning approaches (Åkerlind, 2003; Handelsman et al., 2004, Menges & Austin, 2001). Given the lack of opportunities for university faculty to learn about teaching, how can the transition between paradigms be supported in higher education?

The practice of teaching is highly complex, encompassing more than just instructors and students. External variables such as type of institution, departmental culture, subject matter, and class size all influence teaching practice (Gess-Newsome, Southerland, Johnston, and Woodbury, 2003, Kember, 2000, Pickering, 2006). Moreover, it has been suggested that internal factors such as an instructor's thoughts, judgments, and assumptions may guide teaching behavior (Gess-Newsome et al. 2003; Dall'Allba, 1991; Devlin, 2006; Pratt, 1992; Prosser, Trigwell, & Taylor, 1994, Shavelson & Stern, 1981, Woodbury & Gess-Newsome, 2003). The implication of this assumption is that changes in teaching practice are likely related to changes in thoughts, judgments, or decisions related to teaching. Within the K-12 literature, there has been much research focusing on teacher beliefs and how they are related to teacher practice (Calderhead, 1996; Fang, 1996; Munby & Martin, 2001; Pajares, 1992; Richardson, 1996; Shavelson & Stern, 1981). Yet, there is a lack of empirical research examining the relationship between university instructors' beliefs about teaching and how they relate to practice in higher education (Kane, Sandretto, & Heath, 2002; Devlin, 2006; Hativa, 2000).

The purpose of this study was to gain insight into teaching in higher education. Specifically, the first objective was to characterize the nature of "instructor thinking" for biochemistry faculty members engaged in teaching upper-level, large-lecture biochemistry courses. For the purposes of this study, "instructor thinking" was defined as an instructor's thoughts, beliefs, and attitudes about teaching, students, and learning. The second objective was to uncover factors associated with changes in instructor thinking. The final objective was to identify which, if any, changes in instructor thinking were related to revised teaching practice. This study was guided by the following research questions:

Research Questions

1. What is the nature of science faculty members' "instructor thinking" with regard to teaching upper-level, large-lecture biochemistry courses?
2. What factors are associated with changes in instructor thinking?
3. In what instances are changes in thinking associated with revised teaching practice?

LITERATURE REVIEW

In the 1970s, a portion of the research that was investigating teaching effectiveness came to focus on teacher cognition (Calderhead, 1996; Clark & Peterson, 1986; Fang, 1996; Kane et al. 2002; Richardson, 1996; Shavelson & Stern, 1981). Since then, much of the research on teacher cognition has been conducted with primary and secondary teachers, with significantly less in higher education (Kane et al., 2002). Although teaching in higher education has its own distinctive elements, it likely has characteristics in common with teaching at all levels (Entwistle & Walker, 2000). As a result, in this literature review I will include select investigations of K-12 teacher beliefs and practices and how they serve to inform research in higher education.

Teacher Cognition

Teacher cognition is a term that has been broadly used in the literature to describe teachers' knowledge, beliefs, and thinking (Calderhead, 1996; Kagan, 1990). Studies of teacher cognition have looked at teachers' planning, thought processes, judgments, and decisions (Calderhead, 1996; Shavelson & Stern, 1981). I have chosen to focus on the subset of teacher cognition literature that investigates teachers' thoughts, beliefs, and attitudes that are associated with teaching practice.

Within teacher cognition, theoretical models have been proposed that make a distinction between teacher beliefs and teacher knowledge (Calderhead, 1996; Richardson, 1996). Yet these constructs are seldom clearly defined in studies, if at all. When definitions of belief and knowledge appear in the literature they vary greatly

(Kagan, 1992; Kane et al., 2002; Pajares, 1992). The distinction that is most commonly made between them is that, "belief is based on evaluation and judgment; knowledge is based on objective fact" (Pajares, 1992). One might imagine an instance where two instructors have similar knowledge, but due to differing beliefs about teaching, teach in starkly different ways. In this case, understanding the beliefs of the instructors would be important for predicting their teaching decisions (Calderhead, 1986; Pajares, 1992). Kagan (1992) makes the assumption that teacher knowledge is situated in three aspects: in context (the teaching environment); in content (the subject being taught); and in person (the teacher's unique belief system). In this manner, teacher knowledge and belief are intimately related and difficult to distinguish. Moreover, even if it is clear which construct is under investigation in a study, the terminology may still be ambiguous. For example, Pajares (1992) notes that the term belief is often referred to by a number of different aliases such as values, judgments, preconceptions, conceptions, perceptions, implicit theories, explicit theories, and rules of practice. In order to fully inform my study, I reviewed literature that explicitly examined beliefs, but due to the imprecision in terminology I included literature investigating conceptions of teaching, theories of action, thoughts, and intentions as well.

Studies that have aimed to better understand teacher beliefs have faced the difficult task of measuring them. Some argue that beliefs cannot be directly observed or measured. Beliefs are often held unconsciously; individuals may be unaware of the range and variety of their underlying beliefs. Moreover, individuals may not be able to accurately articulate their beliefs in words. Finally, it is possible that an individual would

be unlikely to share an unpopular belief when probed by a researcher (Kagan, 1990; Kane et al. 2002; Pajares, 1992). Therefore, most agree that beliefs must be measured through indirect means. For example, extended interviews and stimulated recall have been cited as acceptable methodologies to employ when trying to gain access to teacher beliefs (Calderhead, 1996; Eley, 2006; Kagan, 1990; Kane et al. 2002; Kane, Sandretto, & Heath, 2004; McAlpine & Weston, 2000; Pajares, 1992; Prosser et al., 1994). Extended interviews provide opportunities for teachers to describe specific cases and the events leading up to them. Stimulated recall events are prompted by videotaping teaching events and subsequently asking the teacher to make explicit the thinking, theories, and beliefs that guided their teaching (Kane et al., 2004). Similar to stimulated recall, engaging teachers in reflective practice, where they think about their practice and try to see it in new ways, is a way to learn about belief (McAlpine et al., 2000). All of these tasks generate data that can subsequently be used to infer teacher belief through qualitative analytical techniques. Kagan (1990) identified five alternative approaches to measuring teacher beliefs: (1) direct and non-inferential ways of assessing teacher belief, (2) methods that rely on contextual analyses of teachers' descriptive language, (3) taxonomies for assessing self-reflection and metacognition, (4) multi-method evaluations of pedagogical content knowledge and belief, and (5) concept mapping. Ideally, a researcher would employ more than one method to increase the number of lines of evidence that converge on an inference about teacher belief.

The teacher beliefs literature in higher education is relatively sparse. In his 1997 review, Kember identified 13 studies that investigated teaching beliefs, which he referred

to as conceptions of teaching. He noted that his search may have missed conference papers or book chapters. All of the studies used interviews to measure teacher beliefs, with reported interview lengths of 30-90 minutes. Kember (1997) noted that the findings were consistent in characterizing conceptions of teaching across all the studies. Although exact terminology varied, all of the studies characterized conceptions of teaching in a framework that ranged from a teacher-centered/content-oriented pole to a student-centered/learning-oriented pole. Kember (1997) further interpreted the findings to create a hierarchical categorization model of conceptions of teaching. In his model, there are two higher-level orientations with the same labels as above: teacher-centered/content-oriented and student-centered/learning-oriented. Subordinate to each orientation are two conceptions (Figure 1). The broken line between the conceptions indicates that development across the pair is relatively easy. He introduces a fifth intermediate conception, student teacher interaction/apprenticeship, which serves to bridge the two higher orientations.

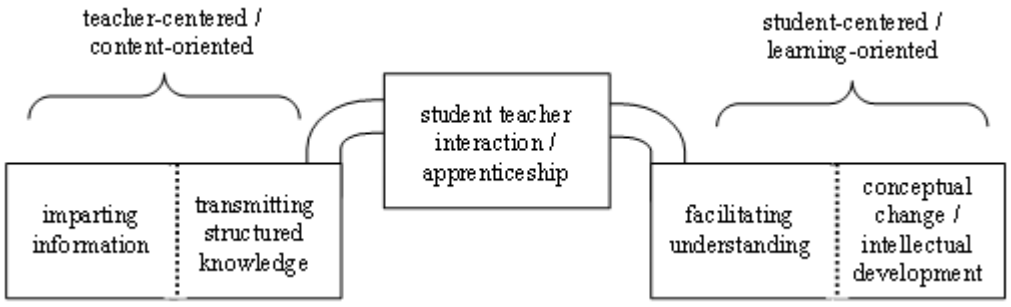

Figure 1: A hierarchical model of conceptions of teaching adapted from Kember (1997, p. 264).

In support of this hierarchical model for conceptions of teaching, Entwistle and Walker (2000) conducted a case study of a university lecturer that documented the development of his conceptions of teaching. They concluded that teachers' beliefs about teaching grow through hierarchical stages in a manner similar to models of how students' conceptions of learning develop. Kember and Kwan (2000) attempted to build on this model to infer a relationship between conceptions of teaching and approaches to teaching. They concluded that not only are conceptions and approaches related, but that conceptions determine the teaching approach adopted. Their results should be considered with caution given that the same interview transcripts were used to develop categories for both conceptions and approaches.

Other researchers disagree with a hierarchical model for conceptions of teaching. In order for a model to truly be hierarchical, elements present in the lower levels should be present in all higher levels and new elements should be added to the higher levels to distinguish them from lower levels. In contrast to hierarchical models of teacher beliefs, some propose an ordered model, in which distinct categories can be delineated. For example, in a study by Samuelowicz and Bain (1992) of 13 university instructors from two institutions, five qualitatively different conceptions of teaching were identified. Similarities and differences between each of the conceptions were described in terms of five dimensions. Each dimension was coded as an A, B, or a combination of the two. Ordering of the conceptions was accomplished using the number of B codes describing the conception; the greater the number of Bs, the more advanced the conception. This

ordered model can be thought of as a continuum ranging from teacher-centered conceptions of teaching to student-centered conceptions. The number of As and Bs are an indicator of teacher- or student-centeredness. They revisited this framework in another study of 39 academics from three universities (Samuelowicz & Bain, 2001). Data analysis resulted in a refined framework of conceptions of teaching. In their revised framework, the nature of teaching conceptions is represented by seven orientations, each one described in terms of nine belief dimensions.

More recent reviews of the teacher belief literature report on a greater number of studies in higher education. Kane et al. (2002) offers a review of 50 studies that investigated the beliefs and conceptions of university teachers. They approached their review from a theories-of-action theoretical framework:

> "Theories of action are based on a view of humans as agents acting purposefully on their environment. Humans learn from their actions and use this learning to plan further actions. As a result of the complexity of the world, humans have created models of their environment, along with a variety of theories on how to act according to those models, in order to create actions that achieve certain desired outcomes."

In this framework, there are two types of action theories: espoused theories of action and theories-in-use. Espoused theories are what individuals are most likely to respond with when asked about their behavior in an event. These theories often relate to intentions. Theories-in-use, on the other hand, are what were actually used to determine their actions in the event. As such, theories-in-use are similar to beliefs; they are often implicit and difficult to articulate easily. In this light, Kane et al. (2002) suggest that examining both theories when investigating teaching in higher education will yield greater understanding. Yet many of the studies they reviewed investigated only espoused theories, thereby

limiting what can be understood about teachers' beliefs and teaching practice in higher education. In their review, they identified a large number of studies that investigated espoused theories-of-action (i.e. teachers' beliefs) and made unsupported claims about teaching practice. In other words, these studies commonly used interviews or other direct measures to identify beliefs. But rather than conduct classroom observations, the researchers used information shared in the interviews to infer teaching practice. However, they also reported on a smaller number of studies that were careful not to make claims regarding teacher practice even though they had information about teachers' espoused theories. Of the 50 studies reviewed by Kane et al. (2002), they described only nine that examined the connections between espoused theories and teaching practice. They conclude their review by calling for more studies examining not only the relationship between teacher beliefs and practice, but also between beliefs, practice, and student outcomes.

A more recent study by Kane et al. (2004) examined both espoused theories and theories-in-action of 17 lecturers in multiple science departments. They used interviews and repertory grids to measure espoused theories; stimulated recall interviews examining videotaped teaching episodes were used to identify theories-in-use. All interviews were inductively analyzed and coded. Content analysis was performed with the repertory grids. Patterns in the coding were used to develop a model of tertiary teaching. This model includes five cognitive and affective elements of teaching that are all related through reflective practice. Not only does their model highlight the complex nature of

teaching, but it also has implications for the development of teacher beliefs through reflective practice.

Norton, Richardson, Hartley, Newstead, and Mayes (2005) utilized an instrument originally developed from interview data by Gow and Kember (1993) to measure conceptions of teaching in university teaching staff. Norton et al. (2005) used a revised version of Gow and Kember's instrument to measure instructors' beliefs and intentions (intentions were equated with teaching strategies). The revised instrument received responses from 696 teaching staff members in the United Kingdom. Since no classroom observation data were collected, these teachers' espoused theories alone were being measured. Norton et al. (2005) conducted a multivariate analysis of variance on the subscale scores for beliefs and intentions and found that they had 94% of their variance in common. Additionally, a correlation analysis and a factor analysis were conducted on the nine subscales measuring each of the two constructs. They concluded that teachers' intentions are "more oriented towards knowledge transmission than their beliefs". Moreover, they found that teachers with varying levels of teaching experience possessed similar teacher beliefs but exhibited different intentions. Given that the authors equate intention with teaching strategy, these results can be interpreted in one of two ways. First, teacher belief may not influence teaching strategy. Second, teacher beliefs are related to decisions about strategy, but other factors, such as teaching context, might weigh in more heavily.

Eley (2006) investigated whether or not teachers' conceptions of teaching play a functional role in determining teaching practice. He noted that although previous studies

often make the assumption that conceptions of teaching influence teaching practice, this may be a function of the methodologies employed and may not reflect a true relationship. Most studies investigating teacher beliefs relied on interviews for data collection (Kane et al., 2002). Eley (2006) argued that interviewees may have never before been asked to respond to a question such as "What is teaching?" He postulated that in composing an answer to such a question a teacher would think over previous teaching experiences. He suggests that this might mean that conceptions of teaching actually are outcomes of reflective activity and nothing more. Eley (2006) hypothesized that if conceptions of teaching do indeed influence teaching practice, then evidence of this influence should show up in the planning and decision-making process. His investigation involved interviews with 29 university teachers from multiple science, engineering, and liberal arts departments. Small episodes of teaching were recorded for each interviewee. During the interview, the teachers were asked to recall and describe the thinking that went into the planning of the event. Interview transcripts were used to identify teaching and learning issues that were explicitly considered by the teachers. Eley (2006) identified six categories of issues that the teachers paid attention to during planning. One of the categories was "explicit use of teaching conceptions in decision making." Each interview protocol was subsequently scored according to whether or not each category was clearly present, apparently present, present, or not evident. Eley (2006) emphasized that this methodology contrasts with other studies on conceptions of teaching because the responses found in the interviews are considered to be demonstrations of thinking steps evoked in planning. As such, "it is those particular thinking steps themselves that are

categorized, and not the teachers exhibiting them." He continues by writing, "the concern here is not about whether a conception might exist for a given teacher, but whether such conceptions are functional components in teachers' specific decision chains." His data suggest that conceptions of teaching can function independently from planning and teaching decisions. These results are significant in that they call to question the relationship between conceptions of teaching and practice. Moreover, they imply that the development of conceptions of teaching may not result in changes in teaching practice. Eley (2006) suggests that changes in teaching practice might occur as a result of introducing instructors to a variety of instructional practices rather than through the development of conceptions of teaching.

In a similar vein, McAlpine, Weston, Timmermans, Berthiaume, and Fairbank-Roch (2006) used interviews to examine the relationship between thinking and action. They conducted six in-depth interviews with two lecturers. The lecturers were asked to explain their thinking in relation to their actions at distinct points throughout a semester of teaching. Using a consensual coding approach, the interview transcripts were analyzed and four zones of thinking were identified. The first zone, conceptual, is related to the lecturers' conceptions and includes statements and beliefs about teaching. They identify the conceptual zone as being the most abstract of the four. The next two zones, strategic and tactical, are described as approximating approaches to teaching. These zones represent the juncture between conceptions and actions. Finally, the most concrete zone is enactive, which refers to lecturers' thinking in the moment of action. McAlpine et al.

(2006) contend that a zone model for teacher beliefs is more effective for examining the breadth and depth of conceptions of teaching as they relate to practice.

In summary, this study is informed by the subset of teacher cognition literature that examines teachers' thoughts, beliefs, and attitudes as they relate to practice. Within the literature, there is much ambiguity about terminology, which often makes it difficult to compare and report on studies. Belief is a difficult construct to measure, and most agree that it cannot be measured directly but must be inferred. The literature examining teacher belief in higher education is relatively sparse. Research results have led to disagreement about whether or not teacher belief is a hierarchical or ordered construct. Much of the literature has focused on identifying espoused theories of action, but little on theories-in-use. Newer studies have attempted to understand more about the relationship between espoused theories and theories-in-use in hope of learning more about how teaching belief and practice are related. Recent reviews call for an examination of teacher belief and how it relates to practice. Although an assumption of much of the teacher cognition research is that teacher belief is related to teaching practice, few empirical studies have been able to pinpoint the relationship precisely.

Growth in Teacher Beliefs

Much of the literature on teacher beliefs serves to characterize it as a construct, as seen above. However, many studies have gone further to investigate how teacher beliefs grow or develop. Many studies suggest that teacher beliefs develop through stages, similar to the way students' learning abilities develop through stages. Some of them have

focused on the unique role that reflection may play in supporting transitions between these stages.

In developing a description of teaching excellence, Sherman, Armistead, Fowler, Barksdale, and Reif (1987) identified four stages of teaching, with each stage consisting of three components. One of these components was conceptions of teaching. In their developmental model, the first stage is "teaching is telling". Within this stage the instructor is perceived as having little or no control over student learning. Stage two is "teaching is leading and hoping students will learn"; the instructor is thought to have some influence on student learning through the direction of students to proper materials and information. The instructor puts students in contact with the content, but students still work alone. In "teaching is transmitting knowledge", the third stage, the instructor is perceived to have influence over both what and how the students learn, particularly if student characteristics are considered. Finally, in stage four – "teaching is a complex interaction which is unique and dynamic" – the instructor recognizes that learning comes about through interactions with students, teachers, and the content and requires mental actions on the part of the student.

In a similar fashion, Ramsden (2003) proposed three theories of teaching through which instructors shift as they acquire more sophisticated conceptions of teaching and learning. Theory 1, teaching as telling or transmission, is characterized by a focus on the instructor, not the students. In this theory, knowledge is to be instilled in students. Any failure to learn is attributed to student attributes which cannot be changed by teaching. In teaching as organizing student activity, or theory 2, the focus shifts from instructor to

student. Instructors see teaching as the organization of student activities and providing techniques that will ensure student learning. Student learning is viewed by the instructor as a perplexing problem. Ramsden describes Theory 3 – teaching as making learning possible – as looking "at teaching and learning as two sides of the same coin". This is different from the first two theories which focused on the teacher activity (theory 1) or student activity (theory 2). Instructors operating within this theory are more likely to focus on student learning. Teaching is perceived as a complex process of working cooperatively with students to help them gain understanding. Similar to Sherman et al. (1987), these theories represent a progression toward more sophisticated conceptions of teaching.

Another theoretical piece was offered by Kugel (1993) as a result of informal observations of himself and colleagues. He proposes that conceptions of teaching grow through two phases which can be characterized by five stages of development. Instructors' conceptions of teaching in Phase 1 focus on elements of teaching, whereas in Phase 2 the emphasis shifts to an emphasis on learning. Phase 1 is comprised of the first three stages. In Stage 1 the focus is on self. Instructors in this stage assume that their effectiveness as teachers relies completely on what they do. They are concerned about what they will say, how much content to cover and at what depth, and the logistics of teaching. In Stage 2, the focus shifts from self to subject. Instructors in this stage are generally more confident about their rudimentary teaching skills and their attention moves toward the content to be taught and how best to convey it to students. Kugel suggests that "professors at this stage think of the courses they teach much as cooks think

about the courses they serve. They lay out the information as attractively and enticingly as they can, hoping that their students will enjoy it and digest it (p. 318)." In Stage 3, instructors' thoughts become more concerned with the students. Instructors recognize that students have a range of abilities and backgrounds. They begin to consider new ways to target this range in their teaching. As they progress through this stage, instructors' thinking begins to transition from the first phase to the second, and the focus shifts from teaching to learning. In Stage 4, students as active, instructors no longer think of students as passive receptors, but as active agents in learning. Instructors view themselves more as coaches than content experts. In the final stage, Stage 5, instructors' conceptions change to consider students as independent. The focus of this stage is letting students learn how to learn on their own.

Building upon these theoretical models for development of teacher beliefs, Åkerlind (2003) conducted a study to identify instructors' conceptions of their own growth and development as teachers in higher education. 28 academics that ranged in discipline, teaching experience, rank, gender, age, and language background were interviewed. A phenomenographic approach was applied in the analysis. Interview transcripts were iteratively analyzed until a consistent set of categories representing different ways of experiencing development as a university teacher were identified. The results were three distinct categories where the instructors viewed their own development as increases in:

- the teacher's comfort with teaching, in terms of feeling more confident as a teacher or teaching becoming less effortful;

- the teacher's knowledge and skills, in terms of expanding content knowledge and teaching materials, and/or an expanding repertoire of teaching strategies;
- learning outcomes for students, in terms of improving students' learning and development. (p. 380)

In an extension of this study, Åkerlind (2007) conducted further phenomenographic analyses of the 2003 data to identify five approaches to growing and developing as a university teacher. These findings are different from the previous study in that they describe how instructors in higher education approach their development as opposed to how they view the process of developing. These approaches were described as:

- building up a better knowledge of one's content area, in order to become more familiar with *what to teach*;
- building up practical experience as a teacher, in order to become more familiar with *how to teach*;
- building up a repertoire of teaching strategies, in order to become more *skillful as a teacher*;
- finding out which teaching strategies do and don't work for the teacher, in order to become more *effective as a teacher*;
- continually increasing one's understanding of what works and doesn't work for students, in order to become more *effective in facilitating student learning*. (p. 27, original emphasis)

The work of McAlpine and Weston (2000) acknowledges the models of developmental stages described above, but investigates the role of reflection in developing conceptions of teaching. They investigated six professors, three in Faculties of Education and three in Faculties of Science. Each was videotaped while teaching as well as interviewed before and after the teaching episode. The post-interview was designed as a stimulated recall event. Interview transcripts were coded, drawing on constructs from previous literature as well as emergent constructs. An initial model of

the process of reflection was created and then presented to the instructors for validation (Figure 2).

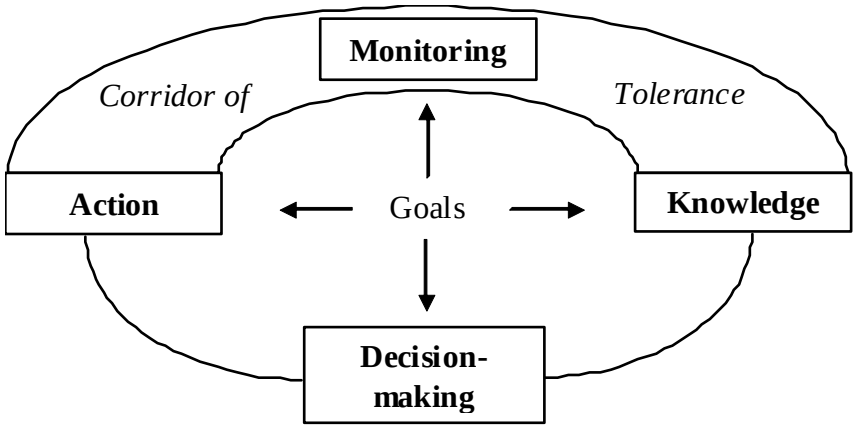

Figure 2: Metacognitive processes of reflection
(adapted from McAlpine & Weston, 2000)

In this model, reflection is anchored in the experiences of the instructors, in teaching action. These experiences are monitored in order to track goal achievement. Monitoring can happen before, concurrently, or after instruction. In some instances, monitoring can lead to decision-making. The corridor of tolerance explains why some decisions lead to changes in teaching action and some do not. They suggest that repeated and ongoing use of this process can lead to development and growth in knowledge, or and in development as instructors.

McAlpine, Weston, Berthiaume, Fairbank-Roch, and Owen (2004) studied six more professors in addition to the six previously examined in McAlpine & Weston (2000). Using the same analytic techniques, data from the 12 professors were used to identify three types of reflection (formative evaluation, formative evaluation/advancing

thinking, advancing thinking) and four goals of reflection (assessing teaching effectiveness, improving teaching, assessing student learning, fostering learning). These characterizations serve to further elaborate their previous model. Their model has implications for understanding the role of reflection in the development of conceptions of teaching.

In summary, there are several models that represent the growth of teaching beliefs as developing through stages. Although they vary in terminology and the number of developmental stages, most of the models describe a progression from conceptions of knowledge transmission and the teacher and teaching strategies to more sophisticated conceptions where the focus shifts to students and their conceptual development. Moreover, instructors' conceptions of their own development and approaches to development appear to correlate with these developmental models. Additionally, preliminary work suggests that instructors' reflective practices are related to growth of teacher beliefs.

Professional Development

Professional development for university faculty is not a new idea. However, prior to the 1970s most of the professional development opportunities provided were designed to assist faculty in developing further discipline-specific expertise. Beginning in the 1970s, institutional support was provided with a focus on instructional development. Initial professional development emphasized the teaching roles and related skills of faculty members. In the 1980s, the new emphasis was on curricular change. By the

1990s, professional development tried to incorporate all three approaches so that professional development included disciplinary expertise, improvement of teaching skills, and curriculum development (Emerson & Mosteller, 2000).

Emerson & Mosteller (2000) manually searched over two dozen education psychology journals and two databases (Educational Resource Information Center and Harvard Universities Library Catalog) for material on faculty development in higher education. Although they limited their search to material from 1990 to 1998, their search did turn up earlier references. In total, they found 103 articles/chapters. Of those, only 37 were empirical studies of outcomes and effects. King and Lawler (2003) conducted a survey which sampled the membership of the Professional and Organizational Development Network (POD), which has members in USA and Canada. In their study, they targeted 976 members who provide professional development in higher education. Although a portion of the 976 professional developers likely collaborate on common programs, it appears there is potential for studies of the outcomes and effects of professional development. Considered in this light, the number of empirical studies identified by Emerson & Mosteller (2000) appears miniscule. Despite their small number, many of these empirical studies provide insights into the nature of teacher beliefs as they relate to teaching practice.

Amundsen, Gryspeerdt, and Moxness (1993) studied the effectiveness of faculty discussion groups in moving faculty members from “casual observations to sustained reflection”. The discussion groups were organized by The Centre for University Teaching and Learning at McGill University. Discussion included topics such as analysis

of subject matter, analysis of learning task, matching teaching methods and learning expectations, and evaluating learning and teaching. Observations and end-of-semester evaluations indicated that instructors' conceptions of teaching evolved through sustained reflection and experimentation.

One of the discussion group participants, Myron, was subsequently the focus of a case study designed to capture changes in thinking about teaching and teaching practice, including changes associated with participation in the faculty discussion group (Amundsen, Saroyan, & Frankman, 1996). They found that Myron's growth followed the process proposed by Ramsden (2003). However, they noted two aspects of Myron's growth that were not explained by Ramsden's model. These were the personal nature of the change process and the nature of the change process itself. The process of change in this study was not always consistent. Myron's beliefs about learning aligned with Theory 3 whereas his beliefs about teaching were more consistent with Theory 1.

Pickering (2006) conducted case studies of four novice lecturers who were enrolled in a one-year university professional development program. For each lecturer, she identified core beliefs about being a lecturer, teaching, and learning that did not change significantly throughout the study. However, incongruence between the lecturers' daily teaching experiences and their core beliefs produced tensions which disturbed their beliefs. The result was an adjustment in the lecturers' senses of what was possible, plausible and desirable. Pickering (2006) suggests that changes in teaching beliefs result from external influences resulting in tensions between belief and experience that must be resolved.

In sum, formal professional development opportunities for university faculty have existed for over three decades. Few empirical studies have been conducted of the outcomes and effects of these opportunities. Those studies investigating professional development efforts involving teacher beliefs as they relate to practice contribute to the literature on teacher cognition.

THEORETICAL FRAMEWORK

Teaching in higher education occurs within universities and colleges that are complex organizations with distinct departmental cultures and diverse student populations. As such, it is difficult to isolate a single aspect of teaching, such as teaching practice or teacher belief, and determine its exact effect on any other aspect. Gess-Newsome et al. (2003) depict the complex nature of teaching in their Teacher-Centered Systemic Reform (TCSR) model. This model was first proposed by Woodbury & Gess-Newsome (2002) as a way to understand classroom practices that change (or not) as a result of science education reform efforts. It was later modified by Gess-Newsome et al. (2003) to understand teaching practice as influenced by university-level reform efforts (Figure 3).

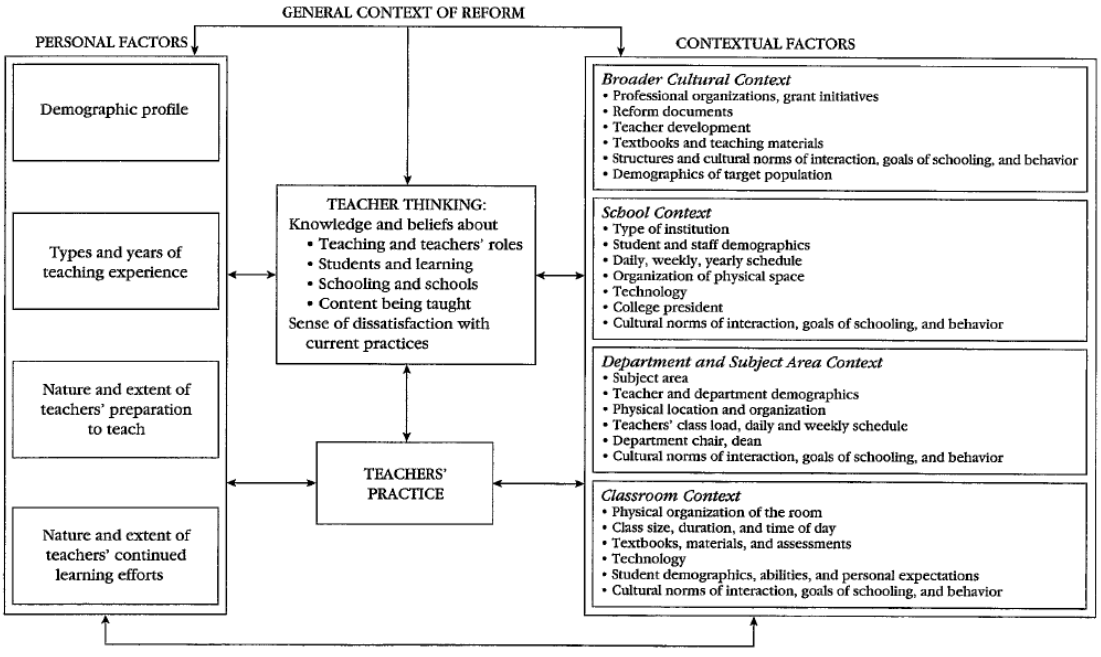

Figure 3: The TCSR model for a college classroom (Gess-Newsome et al., 2003, p. 736)

The TCSR model is unlike other models that situate a teacher's professional knowledge within contexts such as content, context, and person (Kagan, 1992). Instead, the TCSR model better demonstrates the complexity involved in teaching by recognizing the simultaneous influence of personal and contextual factors on teacher thinking and practice, and vice versa. *Contextual factors* include the physical setting, subject area taught, student population, departmental and university culture, and national reform initiatives. Prior teaching experience and demographic profile are examples of *personal factors*. They both impact *teacher thinking*, which Gess-Newsome et al. (2003) define as "teachers' knowledge and beliefs concerning teaching, learning, learners, schools, schooling, and subject matter" (p. 737). This model underscores the importance of considering multiple factors and contexts when trying to understand teacher thinking, especially as it relates to practice.

Initial data collection and analysis for this research were guided by the TCSR model. My first research question focused on characterizing "instructor thinking" instead of "teacher thinking", and was defined as a university instructor's thoughts, beliefs, and attitudes about teaching, students, and learning. The data were queried for evidence of the aspects associated with "teacher thinking" depicted in the TCSR model. Themes such as "dissatisfaction with current practices" were highly visible in the data. However, some elements of the TCSR model, such as schooling and schools were not present. Furthermore, the TCSR model was insufficient for characterizing all of the data. For example, thinking about assessment emerged as a prominent aspect of instructor thinking. The TCSR model served as a preliminary framework for collecting and interpreting the

data. However, as greater complexity in instructor thinking was uncovered, my theoretical framework was expanded.

There are many models characterizing teacher thinking as developmental stages (e.g. Åkerlind, 2003, 2007; Kugel, 1993; Ramsden, 2003; Sherman et al., 1987). Despite differences in terminology and number of stages, these models are similar in that they depict less sophisticated conceptions of teaching as focused on knowledge transmission or aligning with a teacher-centered paradigm of instruction. Conceptions of teaching that focus on students and learning or align with a student-centered paradigm are generally considered more sophisticated. The hallmarks of both paradigms are summarized succinctly by Huba and Freed (2000) and shown in Table 1. They were instrumental in characterizing the nature of instructor thinking and thereby answering my first research question.

Teacher-Centered Paradigm	Student-Centered Paradigm
Knowledge is transmitted from professor to students.	Students construct knowledge through gathering and synthesizing information and integrating it with the general skills of inquiry, communication, critical thinking, problem solving and so on.
Students passively receive information.	Students are actively involved.
Emphasis is on acquisition of knowledge outside the context in which it will be used.	Emphasis is on using and communicating knowledge effectively to address enduring and emerging issues and problems in real-life contexts.
Professor's role is to be primary information giver and primary evaluator.	Professor's role is to coach and facilitate. Professor and students evaluate learning together.
Teaching and assessing are separate.	**Teaching and assessing are intertwined.**
Assessment is used to monitor learning.	**Assessment is used to promote and diagnose learning.**
Emphasis is on right answers.	Emphasis is on generating better questions and learning from errors.
Desired learning is assessed indirectly through the use of objectively scored tests.	**Desired learning is assessed directly through papers, projects, performances, portfolios, and the like.**
Focus is on a single discipline.	Approach is compatible with interdisciplinary investigation.
Culture is competitive and individualistic.	Culture is cooperative, collaborative, and supportive.
Only students are viewed as learners.	Professor and students learn together.

Table 1: Comparison of teacher- and learner-centered paradigms (Huba & Freed, 2000, bold-face emphasis added).

As assessment thinking emerged as a prominent element of instructor thinking, I drew more heavily on the teacher-centered/learner-centered models. In Table 1 above, the elements within each paradigm that were associated with assessment have been bold-faced. As seen above, these descriptions of ways of thinking about assessment guided

my interpretation of the data. They are not meant to represent absolute definitions, but rather a way to characterize assessment thinking as less or more sophisticated.

Although there is little literature investigating how university academics' conceptions of teaching develop (Kane et al., 2002; Menges & Austin, 2001), there is a significant literature base about the processes involved in changing personal beliefs. The K-12 literature suggests that future teachers enter teacher education programs with preexisting beliefs based on their own personal experiences as students (Pajares, 1992; Richardson, 1996). These beliefs are often resilient to change, can be used as filters to allow or block the acquisition of new knowledge, and can be tacit or implicit, and therefore difficult to articulate (Kane et al., 2002; Menges & Austin, 2001, Munby & Martin, 2001). It seems reasonable to postulate that university instructors' beliefs would be equally robust and resistant to change. Transitioning to new understanding of a concept or event can be particularly problematic. The conceptual change literature suggests that personal beliefs act as a filter, influencing how key concepts are either replaced or reorganized within a person's conceptual framework (Phillips, 2000; Posner, Strike, Hewson, & Gertzog, 1982). For example, Posner et al. (1982) evoke a conceptual change model in describing how students' thinking changes. First, students must make their implicit beliefs explicit. They must then be confronted by some inadequacy or inconsistency in those beliefs. Finally, students eliminate or revise their preexisting beliefs through opportunities that enable them to integrate or differentiate old and new understanding. Feldman (2000) proposed a practical conceptual change model that is analogous to the conceptual change model. In this model, teachers must be discontent

with their practical theories. New practical theories must be intelligible to the teachers and must be viewed as beneficial to their teaching practice. Finally, the teachers must believe that acceptance of the new practical theory brings about new understanding of their teaching practice that is illuminating or enlightening. These models for how change in beliefs and understanding occur was useful in identifying factors associated with changes in instructor thinking.

Research into teacher beliefs often works from the assumption that there is a clear, causal relationship between teacher beliefs and practice (Dall'Alba, 1991; Devlin, 2006; Pajares, 1992; Pratt, 1992). Furthermore, some advocate that change in belief is a prerequisite for revised teaching practice. However, this has been challenged by others who argue that conceptions of teaching may be the relics of reflecting on teaching experiences. Instead, experimentation with teaching practices results in altered conceptions of teaching (Eley, 2006). Acknowledging and questioning the assumptions made in the literature was particularly important while investigating the relationship between instructor thinking and teacher practice to avoid biasing the data analysis.

In conclusion, initial data collection and analysis were guided by the TCSR model proposed by Gess-Newsome et al. (2003). Teacher-centered/student-centered paradigms were evoked to further guide characterization of instructor thinking, especially with regard to their assessment thinking. The literature on teacher beliefs as it relates to conceptual change was critical for understanding instances where instructor thinking changed throughout the study. Finally, identifying disagreements about assumptions made in the literature was useful for considering alternative interpretations of the data.

METHODS

Context

The context of the study was an upper-level introductory biochemistry course for biochemistry majors. It is offered through the biochemistry department of a research-based university in the southwestern United States. This course is the first in a two-semester series. It is the first biochemistry class that biochemistry majors are required to take and as such provides an introduction to the fundamentals of the discipline. Taught by three faculty members, this four-unit course was lecture-based with 125-150 students in a given semester. Students attended lectures three times a week and a one-hour discussion section once a week. Student assessments in the class consisted of weekly problem sets, four quizzes, three hour exams, and a final exam. This course was purposively selected (Berg, 2004; Marshall & Rossman, 2006) for study due to the unique nature of the instructors, described in the *Participants* section below, and because it was a course with which I worked as a graduate teaching assistant.

Data were collected for this study during the fall offerings of this course in 2005 and 2006. The course instructional staff consisted of three instructors and three graduate teaching assistants (TAs). Weekly instructional staff meetings were convened to discuss and edit problem sets, quizzes, and exams and to coordinate the logistical elements of the course. Assessments were developed primarily by the instructor lecturing during that portion of the course. Grading was conducted mostly by the TAs, except for exams, when each instructor graded one page of the exam. An exam consisted of a combination

of short-answer, multiple-choice, and calculation-based questions. A single exam page contained between two and four questions each on average.

In both semesters, the instructors tried out new instructional technologies and strategies. In fall 2005, the instructors adopted an electronic response system for use in their lectures. Electronic response systems, or personal responder systems, are a technology that instructors use to collect feedback from students in real-time. Students use small, hand-held devices, commonly referred to as "clickers," that resemble small remote controls or calculators. Prior to lecture, instructors create questions to ask their students during class and embed them in their electronic lecture notes. During the lecture, the questions are projected to the entire class and a portion of time is allotted for students to vote on the correct response using their clickers. Student responses are received, tallied by the computer, and totals displayed to the class. This was the first semester that any of the instructors had used clickers. In 2005, they used clicker questions to track student attendance, so a minimum of one clicker question was posed each lecture. In 2006, there was no attendance requirement, so there was not a similar constraint.

In fall of 2006, the instructors added the use of another piece of technology to the course. They introduced the use of a web-based course delivery software provided by the university to implement reading questions. Reading questions are questions that a student poses to the instructional staff after completing the assigned reading, but before the material is presented in lecture (Henderson & Rosenthal, 2006). In posing their questions, students are expected to describe the difficulties they have in understanding

some part of the material. Since questions are composed by the students themselves, they have the inherent property of revealing the level at which a student understands the material. They are not restricted to a pre-determined set of topics, so it is likely that students' novice ideas about a topic will be revealed to the instructor. This provides instructors with a more accurate depiction of their students' true level of understanding prior to formal instruction. During the semester, there was a predetermined number of reading assignments for which students wrote reading questions and submitted them via the internet. The reading questions were divided amongst the instructional staff, read, and each student's submission was personally responded to. In addition, common student misconceptions and reasoning difficulties were identified and became the subject of clicker or in-class discussion questions.

Five undergraduate biochemistry majors were recruited as undergraduate tutors for the fall of 2006. These students had previously completed the biochemistry course and received high marks. The undergraduate tutors offered up to four office hours a week for students in the course. They were required to maintain diagnostic learning logs of their interactions with the students. In the logs, undergraduate tutors recorded the type of difficulties students were experiencing, what was done to assist the student, and suggestions for follow-up for the instructors. Each week the undergraduate tutors would summarize the information from their learning logs in the instructional staff meetings. This provided a feedback mechanism which provided information about students to the instructional staff.

Participants

Participants were the three instructors of this course. From now on they will be referred to by their pseudonyms: Mari, Judy, and Brian. All three instructors had greater than 20 years teaching experience although only two of the three, Judy and Brian, had previous experience teaching this particular course. Judy was the course coordinator and was employed as a senior lecturer within the department. Both Mari and Brian were tenured faculty members. Brian was the department head. All participants were receptive to dialogue and activities related to the improvement of their teaching. Furthermore, they represented a range of unique roles within the department: senior lecturer, tenured faculty member, and department head.

Data Sources and Analysis

With one exception, this study employed predominantly qualitative research methods to answer its research questions. In general, qualitative research "refers to the meanings, concepts, definitions, characteristics, metaphors, symbols, and descriptions of things" (Berg, 2004, p. 3). The data collection instruments and analytic techniques used within qualitative research span a wide range. To facilitate understanding of the types of data collected and the analytical techniques employed in this study, a list of relevant terminology and definitions is provided in Table 2.

Term	Definition
coding	procedure for converting raw narrative data into "chunks" representing the same unit of meaning.
content analysis	any technique for making inferences by systematically and *objectively* identifying special characteristics of messages" (Holsti, 1968, p. 608 as quoted in Berg p. 267)
field notes	written or orated notes made by a researcher to record observations and interpretations of the observations.
semi-structured in-depth interview	situation in which the interviewer poses questions to the interviewee (1) from a predetermined set of questions that are asked of all interviewees (2) with leeway to spontaneously probe beyond interviewee responses. General topics from the perspective of the interviewee are explored; the interview is not guided by pre-determined response categories. (Berg, 2004, Marshall & Rossman, 2006, Taylor & Bogdan, 1984)
theoretical framework	the theory or conceptual model underpinning a research study
triangulation	the use of multiple data sources as a means for mutual confirmation of measures and validation of findings (Berg, 2004)

Table 2: Qualitative research terminology and definitions

Data were collected from a variety of sources and used to triangulate findings. In qualitative research, the term *triangulation* is used similarly to the way it is used in surveying or navigation. In those fields, three known points are used to draw three sighting lines to an unknown point. Assuming that all three lines are approximately equal in error, the true location of the unknown point is at the intersection of the lines. In this research, multiple lines of evidence from varied data sources were used to corroborate the same phenomenon or interpretation (Berg, 2004; Miles & Huberman, 1994; Stake, 1995, 2006; Yin, 1994). Data sources and analytical methods are summarized in Table 3.

Data Source	Data Analysis
Instructor Interviews	Descriptive and interpretive coding
Reflective Journals	Descriptive and interpretive coding
Electronic Mail (e-mail)	Descriptive and interpretive coding
Field Notes	Descriptive and interpretive coding
Course Documents	Document and content analysis
Reformed Teaching Observation Protocol (RTOP)	Descriptive statistics
Student Interviews	Descriptive coding

Table 3: Data sources and analysis

Instructor interviews. Semi-structured, in-depth interviews (Berg, 2004, Marshall & Rossman, 2006, Taylor & Bogdan, 1984) were conducted with each of the instructors over the course of two consecutive fall semesters. Each semester, the instructors were interviewed (1) prior to teaching, (2) during the time s/he was responsible for teaching, and (3) following instruction. Interviews were audio-taped and transcribed verbatim. The transcripts were subjected to *content analysis*, which can be broadly defined as "any technique for making inferences by systematically and *objectively* identifying special characteristics of messages" (Holsti, 1968, p. 608 as quoted in Berg p. 267). Response *coding* was the technique employed with the instructor interview data. Generally speaking, response coding is the analytic process of assigning tags or labels to bits of text. These tags are called "codes" and are used to assign a unit of meaning to individual portions of the interview. Codes can be allocated to single words, phrases, sentences, or whole paragraphs. The instructor interview data were first analyzed through response coding at the descriptive level (Miles & Huberman, 1994). Descriptive coding involves very little interpretation; it serves as the first step in designating meaning to a section of

text. For example, consider the following segment from an interview with one of the instructors:

> "I must say all my life, all my teaching career I have viewed my responsibility of being one of conveying factoids. You know, I just, here's how it is folks, that's what I've done."

A meaning conveyed in this segment can be summarized as "the role of the instructor is to transmit information". A single descriptive code of "RI-TRANS" is applied as an abbreviation representing this unit of meaning. In practice, this code would appear in the right-hand margin beside every segment that conveyed the same meaning. Codes are sometimes accompanied by researcher comments or notes for future reference. It is important to note that there is no single interpretive truth associated with a segment of text; the researcher designates meaning to the text. However, when guided by a theoretical framework, meaning can be applied consistently throughout data analysis.

After descriptive coding, the instructor interview transcripts were subjected to a second round of coding. This time the coding was interpretive rather than descriptive. Interpretive codes result from a higher level of inference and interpretation (Miles & Huberman, 1994). In the process of interpretive coding, the interview transcripts are reviewed in light of the descriptive codes. When a slightly more abstract unit of meaning can be attributed to a subset of descriptive codes, an interpretive code is created to represent this overarching theme or idea. For example, imagine that the following descriptive codes were assigned to various portions of interview text:

> RI-TRANS: The role of the instructor is to transmit information.
> RI-CONN: Connections between concepts are made for students.
> RI-MOT: Motivation for learning is created by instructors.
> RI-OBJ: Course and learning objectives are created by instructors.

RI-ASS: Assessments are used for summative judgments about student learning.

When considered together, the meanings conveyed by these five codes could be collapsed into a single interpretive code representing an instructor's thinking about teaching. They could be interpreted as characterizing an instructor's more general thoughts about the role of an instructor from a teacher-centered perspective. The interpretive code "TEACH-CENT" would be assigned to represent this new, more abstract idea.

TEACH-CENT: The role of an instructor is considered within a teacher-centered framework for instruction.

Coding the data was an iterative process. Data collection occurred over two years. As more data were introduced, descriptive and interpretive codes were created, deleted, and revised. When a final set of codes was achieved, they were used to construct the individual case studies for each instructor. In some instances, a single interpretive code was significant enough to be designated a research finding. In others, multiple interpretive codes taken together represented a finding.

Reflective journals. Private archives such as journals are noted for their utility in creating case studies because "the subjects' own definitions of the situation emerge" and "allow researchers to draw out complete pictures of the subjects' perceptions of their life experiences" (Berg, 2004). Instructors were asked to keep reflective journals of their teaching experiences each semester. They were asked to think of reflective journals as lab notebooks of their teaching, places where they could record things that worked and did not work in their teaching or questions they would like answered. Reflective journals

were either typed or orated and then transcribed. In some instances, reflective journal prompts were provided to stimulate reflection on key events. Reflective journal entries were analyzed using descriptive and interpretive coding as described above.

Electronic mail (e-mail). An interview is considered an intrusive data source because it requires a research subject to respond to an "intruding" investigator (Berg, 2004). In contrast, data sources such as e-mails can be unobtrusive. Unobtrusive measures are important because they provide access to aspects of the phenomena under investigation that are unreachable by intrusive means such as interviews and direct observation. As a graduate teaching assistant for the course, I was included in most e-mail correspondence between the three instructors. It was also not unusual for individual instructors to e-mail me directly with comments, questions, or requests for feedback about the students or aspects of the course. These e-mails served as another unobtrusive measure of instructor thinking. The e-mails were analyzed similarly to interviews and reflective journals.

Field notes. As investigator, I maintained detailed *field notes* of informal conversations in the departmental hallways, before/after instructional staff meetings, and in other daily venues. In keeping field notes, I paid particular attention to events that (1) demonstrated instructors' thinking about teaching, students, and/or learning, (2) illustrated contextual or personal factors associated with instructor thinking, or (3) supported or refuted interpretations emerging from the coding of transcripts, reflective journals, and e-mails. These field notes were most often recorded covertly during or immediately after the interaction. Less frequently they were recorded no later than two

days following the interaction. As a TA, I was present in the audience for most classes, and kept field notes of my observations of key instances. The field notes most commonly took the form of a summary of the event, my initial interpretations, and quotes from the event when possible. They were coded at the descriptive and interpretive level.

Course Documents. Course documents such as syllabi, lecture notes, end-of-semester evaluations, exams, quizzes and problem sets were also collected as an unobtrusive data sources. They were analyzed for supporting examples as well as negative instances of themes that emerged from the descriptive and interpretive coding of interviews, journals, field notes, and e-mail. Searching for negative instances is a form of hypothesis testing in qualitative research (Berg, 2004). In this process, examples are uncovered in the data that do not support or directly contradict a previously recognized theme or finding. The negative instance may be discarded as a non-representative example within the data. Or the theme or finding may be revised based on the negative instance. This process serves to verify and assess the applicability of emergent themes or findings.

Reformed teaching observation protocol (RTOP). Three formal classroom observations of each instructor were conducted per semester using the Reformed Teaching Observation Protocol (RTOP), an instrument initially designed "to provide a standardized means for detecting the degree to which K-20 classroom instruction in mathematics or science is reformed per the national science and mathematics standards" (Piburn, M., Sawada, D., Falconer, K., Turley, J. Benford, R., & Bloom, I., 2000). The purpose of employing the RTOP was to measure changes in teaching practice from one

semester to the next. The instrument is comprised of 25 Likert-scale items spanning five categories: lesson design and implementation, content – propositional pedagogic knowledge, content – procedural pedagogic knowledge, classroom culture – communicative interactions, classroom culture – student/teacher relationships. The instrument also recommends and has space for recording a qualitative description of classroom events in time sequence. In addition to me using the instrument for observing, I was assisted by another faculty member in biochemistry not involved with teaching the course. Prior to conducting observations, we read the RTOP training manual and completed an on-line tutorial together. The instrument was used to score the instructors individually. In instances when observer scores differed on individual RTOP items, they reviewed their notes and negotiated a consensus score. In most cases, this resulted in a single score. On the rare occasion that consensus could not be reached, an average of the two scores was recorded. After comparing the numerical results for each instructor, it became clear that the RTOP was not sensitive enough to measure the small changes in teaching practice that were apparent through classroom observations, field notes, and the qualitative description portion of the RTOP. Moreover, the RTOP was not designed to measure instructor thinking, a primary focus of this research. Consequently, the numerical RTOP scores did not significantly contribute as a data source. However, the qualitative description of events and summary paragraphs made by the observers were of use and analyzed similarly to field notes.

Student interviews. Ten semi-structured, in-depth student interviews were conducted and transcribed each semester. Excerpts from the interviews were used to

create scenarios for use during instructor interviews as a form of dilemma analysis (Marshall & Rossman, 2006). Instructors were asked to think-aloud about a problem or situation presented in the scenario. This type of dilemma analysis is commonly used to uncover an interviewee's thinking processes. Students were selected for interviews through their completion of a Thermodynamics Content Assessment Instrument at the beginning of each semester. A random, stratified sample of students was drawn from those that volunteered to complete the instrument; three students were selected from the top scoring 30% of the distribution, four from the middle 40%, and three from the bottom 30%. Interview transcripts were only coded at the descriptive level.

Summary. Data from these multiple sources were triangulated to identify emergent themes in instructor thinking. The emergent themes were used to construct case studies that serve to report each instructor's thinking about teaching. A cross-case analysis was then conducted to categorize factors that contributed to changes in their instructor thinking. Instances in which changes in thinking were associated with altered teaching practices were also identified in the cross-case analysis.

Case Study Inquiry and Cross-Case Analysis

The phrase "case study" has the unfortunate characteristic of signifying an empirical method of inquiry as well as the end-product report that communicates the findings of the inquiry. As a research strategy, case study encompasses methods for research design, data collection, fieldwork, data analysis, and reporting. It is used to investigate a case, which can be broadly defined as a bounded system. As such, a case

study usually centers on the study of an object or subject rather than a process (Stake, 1995). People and programs are usually the objects of case study, whereas events or processes are less likely to be so. Case study research results are disseminated in a case study report. This section strives to describe how a case study research strategy was employed in investigating three research questions. This process of inquiry should not be confused with each of the three subjects selected for investigation: Mari, Judy, and Brian. Nor should the process be equated with the final reports, the individual case studies describing Mari, Judy, and Brian that report the findings from the case study inquiry.

My research questions and the situation under investigation were well-suited for qualitative research methods, but particularly so for case study inquiry. As proposed by Yin (1994, p.13), a case study inquiry:

- copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result
- relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result
- benefits from the prior development of theoretical propositions to guide data collection and analysis.

Case study inquiry can further be characterized into three types: exploratory, explanatory, and descriptive (Yin, 1994). The purpose of an exploratory case study is to develop hypotheses or assertions for further investigation. In exploratory case designs, fieldwork and data collection can occur before a formal research question has been identified. Data collection and analysis is informed by an organizational framework designed prior to the beginning of the study. Explanatory case study designs, on the other hand, are often used for causal studies. Data collection is guided by established research questions. More than one multivariate case is sometimes investigated to

investigate the relationship between variables (Berg, 2004). Finally, a descriptive case study design requires an investigator to articulate a descriptive theory prior to posing research questions. This establishes a framework that the investigator follows throughout the study (Berg, 2004) to better describe a phenomenon. This study was both exploratory and explanatory in nature.

How does a researcher work from the identification of a research subject or question and arrive at a case study report describing the results of the case study inquiry? Data analysis naturally follows the defining of a clear research focus and data collection schedule. Initially, the data coding process was guided by the TCSR model as proposed by Gess-Newsome et al. (2003). They proposed that teacher thinking includes one's thoughts and beliefs about teachers and teacher roles, students and learning, the content being taught, and schools and schooling. So the data were queried for evidence of each instructor's thinking about these categories. However, not all of the data could be characterized using the TCSR model. For example, the instructors' thinking about assessment was highly visible in the data, but assessment is not depicted in the model. Moreover, some elements present in the TCSR model, such as thoughts about schooling and schools, were not represented in the data. The coding process was iterative; codes were created, deleted, or revised as data collection proceeded. Just as descriptive codes were collapsed and represented by interpretive codes, the resulting interpretive codes were used to identify themes in the instructors' thinking, such as thoughts about "the role of the instructor", or "students and learning." These themes then became sections of the case study reports.

The objective of the case studies of Mari, Judy, and Brian was first to understand the nature of each individuals instructor's thinking. Their case study reports represent the findings related to my first research question. This biochemistry course and these instructors were not only selected because of what they could reveal about instructor thinking, but also about the factors that are associated with changes in instructor thinking. Following creation of the individual case study reports, a cross-case analysis was conducted next to better understand the intricacies of each individual case study and how the case studies relate to one another (Stake, 2006). In short, a cross-case analysis provides interpretation across the individual case studies. It should not only identify similarities, but also highlight unique elements of the case studies. Moreover, it reveals insights into the greater context in which the subjects are situated, in this case the department and university. In this manner, the whole of the cross-case analysis is certainly more than the sum of its parts. Relationships that are not identifiable in the individual case studies emerge from the cross-case analysis.

The methods used to conduct the cross-case analysis were adapted from Stake (2006). He proposes three procedural tracks for doing cross-case analyses. My analysis followed Track I, which emphasizes the various findings and situations of the individual cases (Stake, 2006). The first step was to identify findings from each of the individual cases. All three cases were read in one sitting and the findings were summarized. These were recorded on finding strips, pieces of paper with single case findings printed on them. The finding strips were case-identified and numbered. Cross-case themes were identified based on the findings to the individual cases. For example, the three

instructors' initial thinking aligned with a teacher-centered paradigm of teaching and learning. These were recorded on a themes worksheet. The finding strips were then sorted and ranked according to their level of relevance to the tentative themes: low, medium, or high. Findings that provided description or supporting evidence of a theme were ranked more highly than others. Once the rankings were solidified, they were recorded on the finding strips and on the themes worksheet (Figure 4). Atypical findings were noted at this stage of analysis, and flagged accordingly. For example, the utility of reading questions was perceived much differently by Brian than Judy or Mari.

Theme-based assertions were created using the finding strips and themes worksheet. For example, all of the finding strips that ranked high for a theme were collected and distributed on the table. Tentative assertions were inferred from all the finding strips relating to that theme. This process was repeated for each theme and all the tentative assertions were recorded on another worksheet. Then the cases were reread to look for negative instances of the assertions. For example, a tentative assertion regarding the instructors' thinking about assessment was "Expanded conceptions of the value of formative assessment are not accompanied by revision in instructors' classroom teaching plans." But in re-visiting the data in search of negative instances, I found evidence that Judy dedicated time in her planning to thoughts about which clicker or discussion questions to implement. Indeed, she was planning for teaching differently. This caused me to re-examine the data further and revise my assertion about instructors' assessment thinking.

Theme 1:	Initial instructor thinking aligns with a teacher-centered paradigm of teaching and learning.	
Theme 2:	Dissatisfaction influences instructor thinking.	
Case of Mari	Theme 1	Theme 2
Finding I: Course evaluations are a source of concern and dissatisfaction.	L	H
Finding II: Making connections is important for deep learning.	M	L
Case of Judy		
Finding I: Feedback and achievement of community college students is regarded differentially from university students.	L	L
Finding II: Good teachers provide clear, organized, and content-rich lectures.	H	L
Case of Brian		
Finding I: Lectures are a useful instructional strategy.	H	L
Finding II: In-class questioning viewed as useful, but mostly for keeping students awake or “fresh”.	M	M

Figure 4: Abbreviated themes worksheet
Themes were recorded at the top for easy reference. The ranking of the relevance of each finding was recorded beneath each theme. Original themes worksheet had a greater number of and more detailed themes and findings.

The tentative assertions were further reviewed by my research mentors who were familiar with the data. Also, I reviewed the cases for cross-case themes or theme-based assertions that were notable but not inferred from the findings strips. For example, a finding from Mari’s case was the prominence of her instructor thinking about teaching effectiveness. Brian and Judy’s thinking about teaching effectiveness was not as prominent in the data, and therefore was not reported in their case studies. This discrepancy between the cases caused me to re-examine all the data related to thoughts

about teaching effectiveness. This led to the creation of a tentative assertion related to these instructors' thoughts about what constitutes good teaching and the types of evidence used to evaluate teaching. Once adequate evidence was established in support of all the tentative assertions, they were re-written as findings.

One criticism of case study research is that it lacks construct *validity*; it fails to "develop a sufficiently operational set of measures and that 'subjective' judgments are used to collect data" (Yin, 1994). To increase the construct validity of this study, three tactics were employed. The first was to identify multiple lines of evidence that would support convergent lines of inquiry (Yin, 1994). These multiple lines were used for triangulation and to substantiate findings. For example, themes that emerged from the interpretive coding of interviews and reflective journals were further substantiated by evidence resulting from the collection of e-mails and course documents. Negative instances were actively sought and used to revise the findings when appropriate. The second tactic was to establish a chain of evidence. This means that an external observer could trace the path of research to gather evidence and arrive at the same conclusions. This was accomplished by creating well-defined research questions and establishing a clear coding system. Finally, the case reports themselves were reviewed by the instructors as well as my research mentors. In a process often referred to as member checking (Stake, 1995, 2006), the instructors were asked to review the facts presented in their case studies and to comment on missing or inaccurate events. Of the three instructors, Judy was the only one to point out an inaccuracy in the report. The text was amended based on her suggestion. Two individuals familiar with the study and data were

also asked to review the case studies. In addition to inaccurate or missing evidence, they were asked to (1) identify interpretations or conclusions that were not supported by the evidence collected and (2) offer alternative interpretations evident in the data that were not yet identified. For example, in an early draft of the research findings, I wrote the following passage:

> "In contrast, Brian seldom talked about his teaching evaluations. Although he didn't believe he was the most talented teacher, he was generally more confident about his teaching effectiveness than Mari or Judy."

During her read through of the manuscript, one of my research mentors underlined the last half of the second sentence and posed the following question in the margin.

> "Or was he simply less confident in student evaluations as valid measures of teaching effectiveness?"

My mentor was able to identify an alternative interpretation because she was familiar with the data and the study. I reviewed her comments and the original data, but found little evidence to support her interpretation and could not identify negative instances that conflicted with the original interpretation. In this instance, the interpretation was left unchanged in the final write-up. Used in addition to the other two tactics, the construct validity of this study was increased.

In case study research, one must also minimize threats to external validity. Within this context, external validity relates to the problem of generalizing findings beyond the cases at hand. Unlike quantitative research studies with a large sample size, case studies cannot make statistical generalizations to the larger population. Instead, case study research relies on analytical generalization, where the investigator attempts to

generalize a particular set of results to some broader theory (Yin, 1994). For example, the TCSR model detailed a theory that guided the selection of the cases for this study. Some of the findings from the work of Gess-Newsome et al. (2003) also emerged in my individual case studies and cross-case analysis. Multiple case studies, and their findings, are generalized to the overarching theory. According to Yin (1994) this is "analogous to a scientist who generalizes from experimental results to theory (p. 37)." Findings from case studies are not generalizable to other cases, but work as a mechanism to perform model or theory testing.

In summary, a multiple case study inquiry was employed to answer my three research questions. Multiple data sources were collected and triangulated to create individual case study reports. These case studies were then subject to cross-case analysis, which resulted in four research findings.

FINDINGS

Three instructors engaged in teaching an upper-level biochemistry course were observed over the course of two years. The nature of instructor thinking for each faculty member is reported in the form of a case study report; each one appears as a subsection of this chapter. The three case study reports can be thought of as research findings because they serve to answer the first research question. Evidence of instructor thinking is included in the narrative of each case study report. In addition to the individual cases, four findings emerged from the cross-case analysis. These findings and their supporting evidence are presented in the last subsection.

The first subsection of this chapter is included to describe the role of the investigator in the study. Due to nature of the research design, a description of my role is important for understanding how data were obtained and analyzed, how my interactions within the department influenced my interpretations of these data, and for validating the findings presented.

Role of Investigator

In the original conception of my dissertation research, I naively believed my role would be that of a passive observer, chronicling key instances and events that would later serve as evidence to answer my research questions. Yet my involvement in the department, both as a graduate student and as a TA for the course, made it difficult to compartmentalize my research and my role as investigator. Rather, my research was ripe for participant observation, which "involves social interaction between the researcher and

informants in the milieu of the latter, during which data are systematically and unobtrusively collected" (Taylor, 1984). Although unanticipated at the outset, my role as a participant observer was critical for providing access to research subjects and data as well as informing later data analysis.

Prior to the study, I sat in on BIOC 462A, the first semester of a two-semester sequence of courses for biochemistry majors. This was significant for two reasons. First, it allowed me to see how the course flows from start to finish and how the instructors navigate their team teaching experience. Second, I began to develop a rapport with the instructors. Initially nervous to have a "science education expert" in their classroom watching them, they grew accustomed to me jotting down notes and informally asking them questions about their teaching.

Since my research interest focused on the faculty teaching BIOC 462A, I was assigned to be one of three TAs for the course. The TAs were required to attend all lectures and instructional staff meetings, hold weekly office hours, and grade exams, quizzes, and problem sets. We were also expected to proofread and work all the questions on problem sets, quizzes, and exams and to offer suggestions for improvement when appropriate. As a result of my preliminary observations and TA position, I became well-acquainted with the curriculum, student population, and course logistics and expectations.

Despite having similar TA responsibilities, my role was markedly different than the other two TAs in the course. The instructors frequently asked for my feedback both in person and via e-mail. For example, if one had devised a new discussion or clicker

question for class, they would send it to me via e-mail and ask for my input. They included me in e-mail discussions about grading issues and distributions and problematic students. In most cases the other TAs were not copied on these e-mails. This was most prominent with the course coordinator Judy who e-mailed me multiple times a day, frequently stopped by my desk to bounce ideas off of me, and occasionally phoned me at home to discuss issues related to the course. Before the start of each semester, she asked me to join her and the other instructors to discuss the syllabus, course schedule, and proposed changes to course format. During weekly instructional staff meetings, I was frequently asked for my opinion or for alternative ways of teaching a subject to students. On the occasions in which I freely offered my perceptions of how the course was going, they were carefully considered by the instructors. In many ways my role within the instructional staff was a hybridization of teaching assistant and instructional colleague.

As a graduate student in the department, I attend departmental events (i.e. colloquia, retreats) and interact with students and faculty. As a result, I am a visible member of the department and knowledgeable about its culture. Yet I am somewhat different from other graduate students in that I do not conduct theoretical or empirical research in biochemistry. Rather, I am the first student to research the teaching and learning of biochemistry as my dissertation work. Not only does this mean that I have received the approval and support of the department head to pursue this line of investigation, but also I am regularly seen as a resource to faculty members interested in teaching. Consequently, it is not uncommon for others to engage me in discussions or ask my advice about teaching.

My role within the department was also somewhat atypical of other graduate students. In many aspects, this was due to my relationship with our department head and his perceptions of the expertise I brought to the department. On several occasions, he elicited my participation in discussions about teaching and learning with other faculty members, the departmental advisory board, and colleagues outside the department such as the Provost. I collaborated with him on grant proposals for science education projects, and was asked to sit in on an advisory board for one of the funded projects. Twice I was invited as the only graduate student to an annual departmental faculty retreat. The first retreat I came to observe a faculty discussion about the creation of a departmental teaching philosophy. The second retreat I was instructed to share with the faculty the new instructional strategies we had been trying out in the upper-level biochemistry courses. And on one occasion the department head asked me to speak to a junior faculty member who had received poor teaching evaluations about how she could improve. Serving in these capacities provided insights not only into the department head's thoughts about teaching, but also into contextual elements of the department that are largely invisible to other graduate students.

The interactions between myself and my research subjects were multiple and varied. These interactions provided a rich context within which the data were interpreted. As depicted in the TCSR model, instructor thinking does not happen in a vacuum. Neither could the collection and analysis of the data related to instructor thinking. Interactions with other faculty members within and outside the department, graduate students, and biochemistry undergraduates contributed to a fuller characterization of

instructor thinking and subsequent identification of drivers for change. My unusual level of involvement in the teaching activities of this department afforded me opportunities to gather and interpret data in ways unavailable to an investigator with a more traditional participant observer role.

Case Study Reports

The first result of my case study inquiry was disseminating the findings in the form of three case study reports, one for each instructor. In general, instructor thinking consisted of two broad categories: (1) teaching and (2) students and learning. Instructor thinking about teaching was further characterized as thinking about the instructor's role, student engagement and instructional strategies, and assessment. Following each report is a table summarizing key findings emerging from the case. When possible, these findings have been aggregated by the semester in which they emerged. In some instances, no new findings emerged.

Case Study of Mari

It has been over 20 years since Mari, after finishing three years post doctoral research, accepted her first academic position and started a research laboratory. This is where she currently serves as a tenured professor, with a dual appointment in two departments. In her lab, Mari employs several undergraduate research assistants and the occasional public school teacher in addition to the usual graduate students and post-docs. Mari demonstrates her strengths as a teacher and mentor through her relationships with members of the lab. After doing a keyword search on the university webpage using her name, Mari's personal commitment to the intellectual engagement and growth of others became even more evident. The keyword search returned several matches, most of which were quotes and stories from Mari's past undergraduate research assistants about their overwhelmingly positive experiences in her lab.

In addition to her primary responsibility of research, on average Mari team teaches one course per semester. Her prior experiences with teaching are similar to the rest of the faculty. As a graduate student, Mari was required to spend a semester as a teaching assistant, but had little control over what happened in the learning environment. As a post doctoral fellow, she was not required to teach, thus enabling her to focus completely on research in the lab.

Following her post doctoral experience, Mari accepted her first, and current, academic position. As a tenure-track professor, Mari received no formal training or guidance in how to teach prior to her first teaching assignment. The practice in her department was to assign two or more faculty members to teach a course together. Consequently, Mari's first teaching assignment was with another faculty member. Although she had taught the class previously, Mari's teaching partner had only just been hired the year before Mari, making it unlikely that she had much more experience teaching than Mari.

Due to the lack of opportunities in her department to learn about teaching, as a novice professor Mari relied on her own experiences as a student and what she could glean from observing her peers to develop her own understanding about teaching. She carefully watched colleagues that she identified as good teachers. Sometimes she tried mimicking their teaching styles or instructional strategies in an effort to improve her own effectiveness as a teacher. After a decade or so of teaching, Mari participated in her first professional development workshop on teaching. It was an active learning workshop provided by the university. During that same time period, her department hired a faculty

member whose primary focus was on teaching. Mari believed that this was the first organized effort on the part of the department to focus on the teaching and learning of biochemistry. At the same time, Mari and her teaching team were inspired to make logistical changes in their large lecture courses, including adding discussion sections and requiring that the instructors take part in the grading of exams. Despite these initial movements toward reform-based teaching, relatively few changes in the department occurred in the way most courses were taught or how the faculty was prepared to teach. Although Mari personally continues to think about her teaching, she is limited by time, support, and resources.

Teaching: Role of Instructor

In a typical classroom, instructors and students alike seem to assume well-defined roles. These roles differ from course to course and person to person, but they all influence the learning environment and the dynamics therein. During our first interview, I asked Mari what she thought the role of an instructor is. She said that instructors should be able to give linear, well-organized lectures that minimize jumping around from topic to topic. She also noted that good instructors should be relaxed and comfortable in front of the classroom. She described an instructor as someone who should open doors and remove barriers for students, but indicated that it is the responsibility of the student to take advantage of these acts. As such, it is the instructor's responsibility to help students engage with the material, but students are responsible for arriving in the classroom with a basal level of self-motivation.

Throughout the next two semesters, Mari's fundamental ideas about an instructor's role did not change much. In later conversations, instructional staff meetings, and interviews, Mari expanded on her thoughts regarding barriers for students and what instructors can do to minimize them. In particular, she was concerned about (1) the clarity with which instructors' and course expectations are communicated to students and (2) the fairness of student tasks. In meetings and via e-mail with the other instructors, Mari would instigate conversations about the level and types of feedback that students should be receiving. She also described the types of feedback she was giving to students in an effort to ensure that they were consistent with others. In the instructional staff meetings, she frequently took issue with the wording of questions on the problem sets, arguing that they were too verbose, provided distracting details that would likely confuse the students, or did not make it clear what was expected of the students.

When reviewing problem sets, quizzes, or exams, Mari made an effort to determine whether or not the students had been given the tools necessary to complete them. She wanted these tasks to be fair; if something had not been covered well enough in the semester, students should not be responsible for the material. Furthermore, she believed that expectations should be clearly articulated to students, not only on the course syllabus but also for individual instructional tasks.

Teaching: Student Engagement and Instructional Strategies

Unlike the other two instructors, this was Mari's first time teaching the first semester biochemistry course for majors. Her usual teaching assignment was the second

semester biochemistry course, a course she had taught for several semesters. Upon her assignment to the course, she inherited a set of lecture notes from previous offerings. Although the lecture notes were quite detailed and comprehensive, she chose to create her own lecture notes for each day of teaching. Mari described the process of preparing for a lecture as the "learning/sorting process". In preparation for teaching, she would read the chapters in the book and skim the old lecture notes in an effort to make sense of the information and prioritize the concepts presented. She looked for cues in the end-of-chapter summaries and problems as well as from other biochemistry textbooks. In the old lecture notes she paid attention to topics that had been emphasized by previous instructors. Her main purpose in going through this process was to identify concepts that were important at two levels. At one level, she wanted to identify concepts that are important for students to learn in order to be prepared for the second semester biochemistry course. On another level, Mari was interested in concepts she thought students would find useful in other aspects of their life or in real-world applications.

In contrast to the lecture notes she was given, Mari worked hard to eliminate extraneous information from her lecture slides. She liked to think of her lectures notes as "stream-lined." Sometimes she left details off of her slides in hopes that students would be compelled to write them down and pay attention during lecture. This was one of her strategies for increasing student engagement. She also embedded questions in her lecture notes that she would pose to the class. Again, her intention was to engage the students by asking questions about key points. She noted that this was seldom successful, as indicated by low student response. Mari also included animations, websites of interest,

and images of real-world examples in an effort to entice student curiosity and questions. Finally, she constructed at least one clicker question per lecture for the purpose of drawing student attention to key concepts or modeling the types of concepts that might show up on a quiz or exam.

The first time Mari taught, she was not scheduled to lecture until the last third of the semester. Her lectures were presented using PowerPoint slides instead of lecturing from an HTML page, which meant she had significantly fewer words on the screen at any given time. Often she started the class with a brief outline of what was to be covered during the lecture and pointed out problems that students could work in order to become more familiar with the material. She frequently posed a clicker question at the beginning of class to get students warmed up. Usually she also made time for a second clicker question later in the class. When she came to one of her embedded questions in the lecture, her behavior would vary. Sometimes she would read the question aloud, but fail to wait long enough for a student to answer before she would answer the question herself. Other times, she would draw attention to the question and tell students that it was something they should think about. Occasionally she would not address the question at all. Although these questions were high-level and well-designed, they seldom played out to their full potential during the lecture.

During her lectures, Mari sometimes forwarded through several slides, telling students that they could read the information on their own time. It is unclear whether Mari did this because of her belief that an instructor's responsibility is to open doors, but that it is the student's responsibility to step through them or because she was worried that

the information was too basic and that students were getting bored. Mari often remarked that she found it difficult to know if the pace at which she covered the material was appropriate. At times, she feared that she was going too slowly for the students.

The second semester Mari taught the lecture schedule had changed. Mari taught a few lectures early in the semester in addition to the lectures she had taught the previous semester during the last third of the class. Mari followed a similar procedure when preparing for her lectures. However, during this semester she was compelled to include information she learned about her students from the reading questions in her planning. Mari noticed that many students' reading questions were asking about the relationships between phi and psi angles, secondary structure, and the Ramachandron plot. In particular, they seemed to be having difficulty visualizing the angles and how they contributed to secondary structure. In response, Mari created a model that could be manipulated in class to better demonstrate this concept. After the first day, some students commented that the model was too small to see from other parts of the room. So Mari started the next day's lecture with the model again, this time she had made it bigger. Mari appreciated the reading questions because they gave her insight into her students' thoughts prior to lecture and she was able to adjust her lectures accordingly.

Later in the semester it was not always the case that Mari would use the reading questions to inform her lectures. Mari had multiple doctoral theses to read, a few grant proposals that were due, and the time-intensive nature of the reading questions were taking their toll. Mari admitted that she spent less time preparing for her lectures than the

previous semester, partially because she had less time, but also because she felt more confident about the material having taught it one time before.

Nevertheless, Mari's lectures changed somewhat the second semester. Instead of a lecture outline, she generally began her lectures with a single slide containing learning goals. She did not have a bulleted list of things the students should know at the end of the lecture, but instead presented her learning goals as conceptual questions that students should be able to explain. Mari was still likely to leave the reading of some portions of the lecture notes to the students and to pose clicker questions. Although her RTOP scores may not reflect a significant change, Mari sometimes took more personal risks as an instructor. She presented discussion questions and was successful at eliciting student participation. She also allowed students comments or questions to determine the direction of the lecture at times. For example, during a lecture on protein structure, Mari began by passing her laser pointer around the classroom and asking students to identify the alpha carbon in a Jmol structure. When students failed to identify the atom, she did not gloss over it and begin lecturing. Instead, she asked them how they would find the alpha carbon. One student said he wouldn't know how because he didn't know which colors signified which atoms in the structure. Mari took advantage of his question to introduce the coloring scheme for atoms. She finished by re-visiting her original question about the alpha carbon and asked students to identify a peptide bond. These kinds of events never occurred during Mari's first semester teaching.

Mari also began to question some of the methods they as instructors had been using to engage students. Instructors, TAs, and students all agreed that problem sets were

a crucial aspect of the biochemistry course in engaging students with the material. Yet Mari wondered if the problem sets really helped students understand the basic concepts of the course. In particular, she noted that, "students can work the problems, but don't get the fundamentals sometimes." (RJ-M-F06-9-1). Not only were some students not understanding the fundamentals, they were also failing to make the connections between key concepts, to develop a more expert conceptual framework of biochemistry. Mari felt that providing outlines for the students was somewhat valuable, but that the outlines did not encourage students to make connections for themselves. This concept of pushing students to make connections themselves became a new line of self-inquiry for Mari. She explored ideas of how an instructor might structure the course differently and what tasks would be given to students to accomplish this goal. She identified that approaching teaching with this goal in mind would be more challenging and time-consuming for an instructor, that for many instructors, "it's a lot easier to stand up and say, to be the talking textbook (I3M-F06-167)." But for Mari, it was more than just the time and added effort. She personally needed some form of positive reinforcement from the students to motivate her to try doing something other than standard lecturing.

Teaching: Assessment

Mari put a great deal of thought into her teaching, especially during her first semester of teaching the course. Most of that time was spent thinking about what to say in lecture and what information should be included in the lecture notes. A much smaller amount of time was dedicated to considerations of assessment. Traditionally, the major

form of assessment in this course was summative in the form of exams and quizzes. Although problem sets were assigned and graded each week, none of the instructors assisted in the grading and therefore they had minimal exposure to the types and range of student responses and reasoning difficulties. Problem sets could have served the role of formative assessments if structured differently, but seldom were utilized in that manner.

During the weekly instructional staff meetings, the majority of time was occupied discussing the wording of problems and questions, with little attention paid to the rationale behind the task created for the students. Mari was not heavily involved in problem set, quiz, or exam construction for the first two-thirds of her first semester teaching, although she frequently offered constructive criticisms of the assessments during the weekly meeting. Only during the last third of the class did she pay much attention to the design of assessments, mostly because it was expected that problem set, quiz, and exam questions be created by the person teaching at the time.

The use of clicker questions during lecture became one mechanism of formative assessment for Mari. She liked using them in lecture because it was one way to make students' thoughts visible. However, she believed that there were limitations to the clicker questions. First, clicker questions might or might not accurately reflect the level of understanding of the students. Second, she found it difficult to write clicker questions that elicit higher level thought processes in students rather than simple regurgitation of information just presented in lecture. In class, Mari seldom used clicker questions in succession to probe students' understanding more deeply. If the majority of the class

answered incorrectly, Mari would explain the correct answer, but she generally did not pose a follow-up clicker question to see if students' confusion had been alleviated.

Mari valued discussion sections as a way to learn about her students' level of understanding. For her, their utility was in helping her identify the concepts that students struggled with that seemed obvious to her. Being confronted by students' misunderstandings in discussion sections caused Mari to re-evaluate her own assumptions about her students' knowledge. It was not clear that this influenced Mari's decisions about how to approach a topic in lecture, but it did cause Mari to think about alternative ways to teach some topics in one-on-one interactions.

Part of the way through her first semester teaching, Mari identified the utility of grading exams as a way to uncover student difficulties or misconceptions. She was assigned one page of each exam to grade, but did not participate in the grading of problem sets or quizzes. Yet based on what she learned from her exam page, Mari noticed some things that she would like to teach differently the following semester. She also identified a wide range of student responses to exam questions. This range also contributed to Mari's growing curiosity about the effectiveness of problem sets in teaching the students fundamental concepts.

Despite these modes of learning about her students, Mari repeatedly expressed frustration at not knowing what students did and did not understand, or how successful she was at engaging them during lecture. She lacked formative means to elicit feedback from her students. She wondered about ways that she could learn more about her students, and half-heartedly proposed that instructors participate in the grading of

problem sets. As a research faculty member, the demands on her time presented a prohibitive barrier to pursuing this idea. However, her frustration and desire to learn more about her students' understanding was one reason that Mari was open to trying reading questions the following semester.

The implementation of reading questions during the second time teaching the course was very novel for Mari and the other instructors. They came with their own sets of unanticipated problems, one of which was the large amount of time required to read and respond to them each week. Halfway through the semester, instructors and TAs were both tired of the reading questions, and debated about whether or not they should be recommended for use in other biochemistry classes. In one instructional staff meeting, Mari advocated reading questions as a tool for instructors. She said that despite their time consuming nature, she really appreciated the insights they provided into her students' understanding. As a result, she was not ready to entirely abandon the idea of reading questions, but was eager to find a way to simplify the logistics of implementing them in large-lecture courses.

Teaching: Teaching Effectiveness

Early interactions with Mari revealed insecurities about being a good instructor. Her perceptions of herself as an instructor were heavily influenced by end-of-semester teaching evaluations. She was quick to confide that she had recently received some of the lowest teaching evaluations in the department. When she first started teaching over two decades ago, her evaluations had been good. But she said that they had slowly

declined over the years. Her evaluations were of personal concern, and they were the topic of many discussions. When she contrasted her teaching with that of her colleagues, she often cast her own teaching style and ability in a negative light. She marveled at their seemingly flawless teaching, their innate ability to engage students, and, perhaps most importantly, their positive evaluations from students. Mari identified instructor personality as one of the hallmarks of a good teacher; outgoing, bubbly people are naturally good teachers. Mari contrasted her own, more reserved demeanor with the outgoing personalities of colleagues she categorized as "good teachers" and counted it as an automatic obstacle to effective teaching because she thought it put her at a disadvantage for engaging students.

While reflecting on her own experiences as a learner, Mari pointed out that some of the good instructors she had as a student weren't always the most outgoing. Rather, they managed to engage her as a student through their use of real-world examples. Mari perceived her more subdued demeanor as a lecturer as a weakness. She attempted to compensate for that weakness not by trying to be more animated or enthusiastic in lecture, like the instructors she had categorized as "good teachers", but by trying to identify exciting, real-world applications of the concepts covered in her portion of the class. When preparing for teaching, Mari dedicated more time than other instructors to skimming primary literature, medical journals, and popular media for interesting or unusual applications of the material to be covered that day in class. She believed that providing this sort of information in class would make her a better instructor because it would appeal more to the students.

Mari's perception of herself as an instructor was also influenced by her comfort level with the material to be presented. During her first semester of teaching, Mari frequently commented that although she was familiar with the concepts, she was relearning them at the same rate as the students. She believed that, on some level, this gave her an advantage over the other instructors because she could more easily see where students might be having troubles. On the other hand, Mari was worried that students might ask questions of her that she couldn't answer. She also said that it was a little intimidating to be lecturing in front of the other two instructors who were more familiar with the content due to their multiple years of experience with the course. During her second semester, however, Mari felt more confident about her teaching. She attributed her new confidence to having taught the course previously and being familiar with the entire scope and sequence of the overall two-semester course sequence.

> "I feel much better about it this year than I did last year. I mean, I actually had a really good time lecturing on carbohydrates and, you know, I felt like last year I guess I just felt I was only this far ahead of the students (indicates a half inch with her fingers) and now I feel like I'm this far ahead of the students (indicates a whole inch with her fingers). It's a little better. I mean, it's much easier when you've already picked out things that you think are important to emphasize and you see, you've seen the whole course put together and you see how one part builds on another part and you already know that this is coming up" I2M-F06-219

At the end of the first semester, some students described Mari as nervous and uncertain about the material she presented. Indeed, Mari was more timid than her colleagues when lecturing. However, in teaching staff meetings and one-on-one, her style of communication was direct, even occasionally sarcastic or witty. She remained steadfast on issues of concern. Students and colleagues alike noted a change in her

demeanor between class and one-on-one interactions. But her nervousness in front of a large lecture hall full of students did not seem to translate into a similar persona in front of a large group of scientists, for example. In contrast, she spoke in front of them as she might in personal conversations, directly and with more confidence. Students interpreted her quieter demeanor as a lack of mastery of course content. A few students also perceived her less-detailed lecture notes as an indication of lack of expertise in biochemistry. In end-of-semester evaluations, students from the second semester of teaching made no mention of Mari as a nervous or uncertain lecturer, although a few said that she seemed unprepared for class. A comparison of Mari's teaching evaluations from one semester to the next revealed that students thought Mari's delivery of material was more effective the second semester.

Student participation in class was also an indicator to Mari about whether or not she was effective as an instructor. On days where students posed more questions, or asked particularly high-level questions, Mari said that she thought she had done a "good job" teaching that day. She also lamented the general lack of student participation in class, and accredited some of this student apathy to her inability to encourage student questioning.

Seldom was Mari's judgment of her own teaching effectiveness based on student performance on assessments. On most occasions, poor student performance on an exam or quiz question from her lecture content would cause her to reflect on what she had presented in the classroom. If the topic was perceived as particularly easy, Mari would question what she had done as an instructor that did not yield higher gains on the part of

the students. For example, Mari lectured about protein structure during her second semester teaching. This was a topic that had been presented by one of the other instructors in the first semester. One question on the problem set asked students to construct a helical wheel, something covered in the lectures on protein structure. When a significant portion of the students had troubles with this "easy" problem, Mari worried that it was due to how she had covered it. Other than occasionally noting student performance on quiz, exam, and problem set questions, assessments were not generally used to measure teaching effectiveness.

Students and Learning

Even before they begin teaching a course, instructors often have well-developed ideas about their students. Mari was no exception. Although she had never taught this particular course before, she came into classroom with expectations that were shaped, in part, by knowledge gained through teaching other undergraduate science courses as well as her own personal experiences as a learner.

Although Mari had not taught this particular course previously, she had taught the semester that follows it in the two-course sequence, so she had some prior experience with the population of students that typically enrolls in the course. She also had experience teaching several other undergraduate science courses. Consequently, these prior teaching experiences helped form her general thoughts about students and student learning well before teaching her first semester of this course. Experience had, for example, caused Mari to think of these undergraduate students as an often disengaged

audience during lecture. Her previous students had seldom asked questions in class. If she were to ask them questions, she believed that most of them would not provide a response. Students in her courses represented a variety of backgrounds and skill levels. She held the belief that there are top students in every course who need to be challenged and, conversely, there are lower achieving students who may lack the skills, motivation, or ability to succeed in these science courses. Some of these lower achieving students Mari felt did not belong in these types of courses at all. She also believed that many undergraduates are preoccupied with the grades they receive as indicators of their learning, rather than the process of learning itself.

Not much time passed before Mari began to develop more specific ideas about the students who enroll in this course. Prior to the start of class, the entire instructional staff of instructors and teaching assistants for the course met. The instructors shared their prior experiences with the students in the course and their own perceptions of the population. For instance, she was told that students don't generally read or prepare for class, that it is difficult to engage the students, and that it isn't unusual to find students reading newspapers in the back of class. She was surprised to notice that, contrary to what she had heard and knew from own experiences teaching other classes, students in general seemed attentive during her lectures. Yet, although students were attentive, they seldom posed questions of Mari in class or in some of her discussion sections. At first, Mari was disappointed and frustrated that students didn't ask questions and took it as a sign that students were disinterested in the material. But later interactions with students caused Mari to draw a different conclusion. In discussion section, she asked some

students why they did not ask questions. They told her it was because they were sometimes so confused they weren't sure what to ask. And when she spoke with students about the reading questions during her second semester teaching, she discovered that her students sometimes thought that they understood a concept, but until they were challenged to formulate a question about the material, they weren't aware of what they didn't know. Mari's perception of the students changed. She came to view students as lacking metacognitive skills.

> "They don't really know what they understand or don't understand sometimes and this is this issue of asking people about their reading questions and then them saying well, it seemed understandable when I read it, but until you're posed a problem or something that they can't address." I1M-F06-108

As a student in science, Mari likely had experiences similar to those of her students taking this course. Due to her interest in the subject matter, she was primarily an intrinsically motivated student. However, depending on the nature of the particular course or instructor, her motivation would increase or decrease proportionally. Mari often referenced two memorable instructors when thinking about the interrelated roles of students and instructors. She described them as animated and engaging instructors who taught challenging and potentially boring courses. For her, the courses were interesting and engaging. Yet, Mari believed that, despite the instructors' skill at captivating her attention, had she not had a firm foundation prior to taking the course, she would have learned very little.

> "I mean I always know that the times I am learning the most are when I learn it myself. And then if I don't have, if I don't have some kind of foundation it doesn't really make any difference how someone presents it

> but, it's all going to, most of it will go by me, so I feel like I have to do the basic learning myself." I2M-F06-137

She felt strongly that she learned through her own desires and motivation, and that the instructor only provided a spark and path. And although she personally worked to make the class content more interesting as an instructor, Mari's underlying belief was that students must come with some level of intrinsic motivation if they are to have a successful learning experience. Her expectation for students was that they put in as much effort into learning as she did in providing opportunities to learn and engage with the material. She often used a familiar idiom when talking about student motivation, "you can only lead a horse to water, you can't make him drink… so I just expect them to have energy for the topic." (I1M-F05-74) After her first semester teaching the course, student motivation became a perplexing issue for Mari. The students who enroll in this course are generally biochemistry majors, students supposedly similar to her at one time. She was disappointed by students who did not read before coming to class, pose questions during lecture and/or office hours, or dedicate significant portions of out-of-class time to grappling with the material. She wondered why students lacked the motivation to do these things.

Mari's initial thoughts about student learning were not well-developed. She viewed learning as a personal process, one that usually happens outside of the classroom. Mari also believed that repetition is a key element of successful learning. In instructional staff meetings, she sometimes talked about her disappointment when students didn't seem to pick up a concept covered in class and suggested that maybe it had not been stated

enough times in lecture. She taught based on the assumption that the greater the number of times a person hears something, the greater the likelihood that they will remember it.

> "I'm a firm believer that the more those particular neurons are stimulated, the more they'll, those processes will stick there and the recollection will occur again so it's like good if I've done it myself and I hear it again and, I go back to it." I2M-F06-143

Mari drew on her experiences as a learner when she talked about how people learn in general. She described her own learning as a process of figuring out how different ideas are connected. She was most reflective about her learning when she was preparing for lectures. During her first semester teaching, each lecture presented an opportunity for her to learn and re-learn key concepts in biochemistry. She enjoyed restructuring the information in a way that made sense to her, exploring the connections between ideas, and creating a conceptual framework for understanding the material. She thought that the process of building a framework most often happens outside of the classroom, and therefore the number of hours a student spends outside of class on the material will be indicative of student success in a course. She made no distinction between the quantity of hours spent working with the material and the quality of the time spent. Toward the end of her first semester teaching, Mari began to question how in-class time should be spent. If she was correct in her hypothesis that most student learning occurs outside of lecture, then what should in-class time look like? Specifically, she wondered how she might structure her lectures differently to foster more of this "outside class" type of learning during class time.

Over the course of the second semester, Mari extended her personal model of learning as the process of making connections to think about ways to foster student

learning. At the beginning of a lecture, she initially thought it would be useful to provide students with a simple conceptual framework in the form of a basic lecture outline for the students. But just as she could not lecture from a set of inherited lecture notes because the material did not make as much sense to her, Mari began to doubt that significant student learning would result from students adopting a framework given to them. Rather, she thought it was more likely that students would try to memorize the connections in the framework instead of understanding how concepts are related to one another. Mari held that students needed to construct their own frameworks, to identify and describe for themselves how ideas are related.

> "I think that every individual has to construct their own framework and if they don't take the time to do that you can present it to them … looking like whatever and say, this is our framework, until they take it and make it their own framework, you can't [learn it]." I2M-F06-293

As the second semester drew to an end, Mari explored ideas about how future offerings of the course could be changed to align with her model for how people learn. She proposed giving students a list of course concepts on the first day of class instead of an outline or a list of learning objectives for each lecture. Throughout the semester, the responsibility of the instructor would be to encourage students to identify and articulate the connections between concepts. When proposing this alternative, Mari was drawing on an experience from earlier in the semester that had been new for the instructors and students alike. One week in discussion section, I developed a concept mapping exercise to assist students in their preparation for an upcoming exam. Mari liked how students had to identify the relationships between concepts and fit them into the larger framework of the overall course content. However, she thought that in order for this type of exercise

to reach its maximal potential in developing deeper conceptual understanding in students, one would need to coach the students throughout the semester on how to use concept maps. Therefore, she considered changing the focus of the course to be inclusive of concept mapping to support student learning.

Over the course of the two semesters, Mari's thoughts about students and learning evolved. And as her understanding of the students deepened, she began to use the new knowledge to think about her own teaching and interactions with the students. Although Mari often expressed frustration at the lack of feedback she received from students during lecture, it is clear that she achieved higher levels of success at understanding her students than she perceived.

	Fall 2005	Fall 2006
Role of Instructor	• Deliver linear well-organized lectures • Remove barriers to student learning • Be relaxed and comfortable when teaching • Help students engage with the material	• Communicate expectations and tasks clearly • Treat students fairly
Student Engagement & Instructional Strategies	• Lectures are important for presenting information to students • Embedding questions and illustrative examples in lecture notes will engage students • Minimal text on lectures will force students to take notes, thereby engaging them	• In-class questions based on student misunderstandings can be fruitful for student engagement • Students allowed to determine direction of the lecture more frequently
Assessment	• Problem sets, quizzes, and tests are the primary form of assessment • Little time dedicated to thinking about assessment • Interactions in discussion section reveal student thinking	• Reading questions and clickers valued for revealing student thinking • Clickers not used in succession to probe student thinking more deeply
Teaching Effectiveness	• Perceptions of teaching effectiveness strongly influenced by end-of-semester evaluations and in-class student participation • Personality perceived as obstacle to "good" teaching • Quiet demeanor interpreted by students as lack of course content mastery • Increased confidence with material perceived to increase teaching ability	
Students & Learning	• Students are disengaged during lecture and seldom ask questions • Students have varied skill levels and backgrounds • Top students need to be challenged; some students don't belong in these courses • Students are preoccupied with grades • Most learning happens outside of class • Personal experiences as a learner influence thoughts about how people learn in general	• Students are engaged • Students don't ask questions because they lack metacognitive skills • Students need to engage in connection making to maximize learning

Table 4: Summary of the Case of Mari

Case Study of Judy

As a senior lecturer, Judy's role within the department is different from most other faculty members. Instead of research, her primary responsibility is teaching. She is the course coordinator and an instructor for both the biochemistry majors' and the non-majors' courses. She spends most of the year teaching; in the fall she teaches the majors' course, and in the spring and summer the non-majors' course. In addition to teaching, Judy advises many undergraduate biochemistry students and is a highly visible and participatory member of the department. Judy attends all research seminars, faculty and departmental retreats, and discusses teaching and research with other faculty members.

Although Judy has been teaching for over 30 years, she has mostly only taught junior- and senior-level courses. Her first teaching experiences were as a graduate student when she was responsible for small discussion sections. As a postdoctoral fellow and later as a non-tenure track faculty member, Judy taught both lecture and lab courses. On a few occasions, she was assigned to teach honors biochemistry, a class she enjoyed teaching. As a result, Judy has well-developed ideas about teaching biochemistry and biochemistry students based on decades of teaching this population.

Despite her myriad of teaching experiences, Judy did not receive formal mentoring or training on how teach. Her first teaching experiences were not in her discipline; she was assigned to teach genetics labs. Trained as a biochemist, Judy had never taken a genetics course. To prepare herself for teaching her lab section in the afternoons, Judy would attend a morning lab section taught by another instructor. Before

teaching each week, she and the other instructors would prepare themselves for lab section by conducting the week's experiments themselves.

As a lecturer in biochemistry, Judy's teacher "training" was not much different than when she taught genetics labs. Her preparation for teaching biochemistry consisted of attending all of her colleague's lectures and taking notes as if she herself were a student. The next semester when it was her turn to teach, Judy's colleague lent her his lecture notes for use in preparing her own notes. As a result, Judy was quite familiar with what content should be taught and the level at which it should be presented, but was not exposed to discussions about pedagogy related to the teaching of that content. In fact, during this time she was teaching in the same department that Brian had described as lacking a culture of teaching.

Perhaps related to her early teaching experiences, Judy expends more time and effort thinking about what content should be conveyed to her students, in what order, and in what level of detail than she spends thinking about pedagogical issues. Yet as course coordinator Judy dedicates comparatively more time thinking about teaching than the faculty members who team teach with her. Much of her time is dedicated to the administrative tasks of teaching such as posting lecture notes, communicating with students, calculating grade distributions, and creating problems sets, quizzes, and exams. When focusing on her own teaching, her activities include tweaking her lecture notes, scouring textbooks for new or illustrative examples and graphics, and thinking of different ways of explaining concepts in lecture. Judy has been described by her colleagues as a "nuts and bolts" person who focuses mostly on course logistics.

Teaching: Role of Instructor

Since her position is non-tenure track, Judy has spent more of her academic career teaching than most of the other faculty members. Yet her thoughts about the role of an instructor are not markedly different. She believes that instructors should present clear, organized, and content-rich lectures. They should strive to be engaging and interesting to their students. An instructor should be a resource person, offering ample assistance to students struggling with aspects of the course. Judy also felt strongly that instructors have the responsibility to treat students with respect and to create assessments that are fair for all students. Finally, Judy thought that students in her class should get their money's worth; they should be challenged to learn as much as they are capable of learning.

After team teaching biochemistry for so many semesters, Judy had been exposed to a variety of other instructors. She sometimes remarked on the quality of the lectures given by her colleagues. Usually she identified aspects of their lecturing that she felt were particularly clear or flowed well and noted anecdotes or examples that she could use in her own lectures. It was important to create organized and content-rich lectures. Moreover, she felt that it was her responsibility to provide detailed notes to accompany her lectures. She spent long hours tweaking her lecture notes from semester to semester, striving to make them increasingly clear and comprehensive. She was always on the look out for figures, graphs, and drawings that would better illustrate a point in her lecture

notes. Ultimately, she thought of these lecture notes as a safety net for her students on the occasion that she failed to present the information clearly enough in class.

> "I provide written back up for everything that we're talking about in class and expect in a few situations, and there certainly are some, where I feel like, you know, I really didn't explain that very clearly in class and I'm, you know, feel that it was my failure that they don't have the right answer." I2J-SP06-52

Judy noted that even well-organized, content-rich, and clear lectures were not guaranteed to teach the students biochemistry. She thought that an instructor should demonstrate some element of showmanship. At a minimum, instructors should avoid giving lectures in a dull or monotonous way. Ideally they should convey enthusiasm for the subject and engage the students. To do this, Judy believed that instructors should know their audience, be able to explain things at a level appropriate to them, and provide stories or examples that really interest the students. Judy did not always feel successful at this, remarking that she knows students find examples from the field of medicine to be appealing but that she doesn't always include them in her lectures.

To Judy, the role of the instructor extends beyond what happens in the classroom. She was adamant that help in the form of office hours, review sessions, and practice problems be made available to the students. It was as if there were an unspoken contract between Judy and her students. Her responsibility was to transmit biochemistry content as clearly and completely to the students as possible. She and the other instructors were also responsible for making assistance available to students outside of class. But she felt that ultimately students have the responsibility to take the initiative for learning by

preparing for class, consulting lecture notes and textbooks, and taking advantage of the help provided.

> "I'll say again, anything we can do to realistically do, with the man power that we have, to help students catch up, we should." I1J-FA06-201

> "And then even if as an instructor I didn't carry out my side of the responsibility quite as well as I should have in terms of making really sure they understood it before we went on to something else, well maybe the students have a little responsibility too, even if I haven't given perfect teaching, to go and dig something out of the text occasionally that just didn't come across clearly in class." I3J-FA05-390

No matter what the situation, Judy felt that students should not only be treated with respect, but that they should be treated fairly. For example, Judy worked hard to create and enforce course policies that would result in consistent treatment of students. She often consulted with the rest of the teaching staff to elicit opinions about the fairness of her policies. She followed the university's guidelines for students with disabilities very strictly. Always aware that students have obligations outside of the classroom, Judy worried about providing everyone with the same opportunities. On quiz days, Judy opted to administer the quizzes during the last ten minutes of class instead of the first ten minutes of class so that students arriving late to class would not get less time and therefore be put at a disadvantage. Even this decision was troublesome to Judy as she worried that some students might have jobs after class for which they might need to leave early.

Judy was also concerned about the fairness of academic tasks. She paid particular attention to the clarity of questions posed on exams, quizzes, and problem sets. Furthermore, she worked hard to minimize inconsistent grading. The answer keys that

were given to teaching assistants often contained notes about how partial credit was to be assigned to student responses. She required the teaching assistants to keep notes of the rationale behind grading decisions so that they could be referred to throughout the grading of an assignment or exam. She expected the TAs to use the annotated answer keys and notes to ensure consistent grading of assignments. It was also expected that TAs hold weekly meetings to decide on how problems sets were to be graded. Judy occasionally spot-checked the grading herself to make sure they were being graded consistently. She felt strongly that it is the instructor's responsibility to develop a fair way to assign grades to students. And assigning a fair summative grade for the course necessitated fair and consistent grading on all coursework leading up to it.

Finally, Judy thought that instructors should challenge their students. Most of her teaching experiences had been with junior- and senior- level courses, all of them for science majors. She was accustomed to covering complex content, and constantly pushed students in her classes to excel. When Judy occasionally heard students complain about the rigor or pace of the coursework, she would joke that university students are the only people who grumble when they get their money's worth. Most often, Judy would talk about her responsibility to challenge the "good" students. In casual conversations and instructional staff meetings she would comment about not wanting to bore the good students. Particularly in the course for biochemistry majors' course, Judy felt responsible to teach content at a high level.

> "I think you already know that he [Brian] and I both think that in a majors' course, maybe even in a non-majors' course, that even though it's a big university you have to aim your teaching at, well above the median, or you're not serving the students who are going to benefit most from the

> college education. And you don't want to leave people in the dust but neither can you let that drive how you teach." I3J-FA06-233

In summary, Judy's thoughts about the role of an instructor align with a teacher-centered approach to teaching and learning. She believed that the role of an instructor is to construct and deliver content-rich lectures that transmit content clearly and in an organized way. Moreover, lectures should engage and interest students. Judy also thought that an instructor has the responsibility to provide opportunities outside of class for students to get help. This assistance should be available to all students. Another role of an instructor that Judy identified was the responsibility to treat students with respect and to create course policies that insure the fair treatment of students. Finally, Judy believed that instructors should teach at a reasonably high level in order to challenge students.

Teaching: Student Engagement and Instructional Strategies

As course coordinator, Judy had considerable autonomy over aspects of teaching the course such as syllabus development, course schedule, and grading schemes. Although she elicited feedback from the instructors with whom she would be teaching, the structure of the course did not change much from semester to semester. The course was always lecture format, weekly discussion sections were taught by one instructor and one TA, and students were required to complete weekly problem sets. With the exception of the implementation of clicker technology, thinker questions, and the reading questions assignment, this was the format of the course during the study. And the instructors, for the most part, taught the same topics in the same order.

Judy gave her lectures while projecting very detailed lecture notes on the front screen in HTML. She liked the ease with which she could scroll through the notes as she presented the information. She started each new topic by drawing students' attention to the two lists at the top of the HTML notes, one of learning objectives and one of key concepts. Embedded in the HTML notes were active links to Jmol structures of proteins, and tables and diagrams from textbooks. She used a combination of bold-face, underlining, italicizing, font size, and color to emphasize points. Many hours were spent editing, updating, and formatting the lecture notes to make them as comprehensive and clear as possible. She believed that this would maximize student engagement during lectures.

> "This seems pretty trivial a way to spend instructor time I guess. [sic] Sometimes it sounds like I'm trying to publish a book, which I'm not. [I try] to make it as visually good for information transfer, I guess, as I can make it." I2J-FA05-73

In interviews, however, students gave mixed reviews of the lecture notes. Some students liked them because they alleviated the pressure to take notes during class and enabled them to sit and listen. Others found them to be visually confusing or hard to follow. Yet other students noted that, due to their detailed nature, they were excellent study aids for exams but that they rendered the textbook virtually obsolete and a waste of money.

Judy also embedded questions in her lecture notes and colored them red. This was one of her strategies for engaging the students in class. When she would scroll to one of these questions, Judy would read it aloud. She hoped that the question would not only encourage student participation, but also entice students to think about the concept at hand.

> "So we don't spend a lot of time, maybe we should spend more time discussing in class but hoping that at least when there's a question in front of them and I'm posing it orally too that hopefully they will wake up and think about it even if they are too shy to volunteer to answer or even if they don't know the answer that that it will at least make their gears turn in their brain in a way that they wouldn't if it was just listening, listening, listening to me tell them how it is." I1J-FA05-332

In practice, they were not always utilized in this way. On some occasions, after reading the question, Judy would not allow enough wait time for students to answer. Disappointed by lack of response or in a hurry to cover everything in time, she would answer the question herself. And sometimes she would not take any class time for them, instead telling the students to read and try and answer the questions on their own.

> "I've got questions that are already in there in red as sort of student thought questions whether we actually deal with them in class or not. I used to always sort of deal with them in class. I mean, we would answer those questions before we would go on in the lecture. But now we sometime even just skim through them and I figure fine, the information has been transferred, the students ought to be able to answer those and if they can't that's something they can ask in office hours or in you know help session or something." I2J-FA05-88

Judy's strategies for engaging students were not limited to using only the red questions embedded in her lecture notes. Taking a colleague's advice, she made a conscious effort to pause periodically and ask students if they had any questions. She said that in her endeavor to get through all the material she would forget to do that. She also tried to slip other types of questions in when appropriate. For example, she might describe a particular phenomenon and then ask the students to predict the mechanism causing it. Although her wait time was not always optimal, occasionally a student or two would pipe up to offer an explanation. It was also not uncommon for a student to interrupt the lecture to pose a question or ask for clarification.

> "Every 10 minutes or whatever in the lecture throw a question in, I don't know if it's effective or not but at least it indicates an expectation on my part that that they're thinking about this. And if I pause long enough to wait for an answer, but that really is about the only way that I can think of in the past that I've engaged students in class." I1J-SP06-150

With the implementation of clicker technology, Judy had a new way of posing questions during lecture. During the first semester of using them, Judy worried that the clicker questions she asked were not particularly thought-provoking. She and the other instructors sometimes found it difficult to create clicker questions for each lecture because the content did not always lend itself well to clicker-style questions. At a minimum, Judy hoped that the clicker questions were at least getting students to think about biochemistry on a daily basis. In general, this was the rationale behind Judy's use of any question as an instructional strategy; she wanted students to engage with the material.

Yet Judy's desire to get students to think about biochemistry in class was in direct conflict with her objective of covering a large amount of material in lecture. Before teaching biochemistry in this department, Judy had been assigned to teach in one of the courses at the medical school. The use of case studies and other strategies in that course was more learner-centered than Judy had previously encountered. From her experience teaching the medical course, Judy received a small taste of learner-centered teaching. She noted that in some instances students learned a lot of biochemistry. Yet she thought that many of the instructional strategies employed worked best for review or deepening student understanding, not as a primary way to encourage student learning.

Although acquainted with alternative instructional strategies such as case studies, in her own teaching Judy chose to adopt a lecture format. She wondered how using case studies in her own teaching would impact the amount of material she could cover in a semester. For Judy this became a question of how to strike a balance between content coverage and time. She identified lecture as the most efficient way of covering large amounts information in the allotted time. Judy was sometimes reluctant to take time away from lecturing because she did not want to sacrifice content coverage.

> "It's really, you give up an awful lot of content, I think, in order to spend a lot of time engaging students in an active way like in small group discussions." I1J-SP06-158

In addition to time constraints, Judy's decisions about instructional strategies were influenced by her perceptions of student capabilities. Consistent with her thoughts about the role of an instructor, Judy was interested in teaching strategies that she anticipated would challenge students. In particular, she worried that if she challenged the "good" students in the class, the end result would be leaving other students behind. On the other hand, if she targeted her teaching at students achieving at or below the class average, she worried that the top students would be bored. Judy worked hard to balance these two situations, although in general she tended to choose options that would challenge top students. She also noted that this variety in students' capabilities makes it difficult to adopt teaching strategies other than lecture.

> "I don't think you can deliver it all by altering your presentation in class to try to include say 80% of the class if only 50% of them are really good students and you are going to just bore the 50% or at least the upper 20% incredibly by trying to reach the 30% that are below the mean." I1J-FA05-155

> "Maybe we could do a lot more participatory stuff, but it is so hard with the breadth of student preparation and abilities to have expectations like that." I1J-SP06-166

Judy prepared for teaching with certain expectations. She expected students to come to class prepared, listen attentively to lecture, pose clarification questions, and to take notes. As a result, her thoughts about instruction mostly focused on how to explain things and what to emphasize. She thought about how to contextualize concepts by describing actual biochemical or medical examples. Finding real-life biochemistry examples was a priority for use in her teaching. Judy believed that a combination of good examples and repeat exposure to the content represented in those examples should result in student learning.

> "I'm sort of a little bit cynical or defeatist after a while when I hear that students get to the second semester of this course [that] they still don't remember even what a free energy change is or what the general principles are of, in thermodynamics, is a little discouraging. That may be saying that even in a lecture format with what we think are brilliant explanations we're obviously not as brilliant as we think for it's not staying with the students after multiple applications of problems." I1J-FA05-436

During the study, the instructors tried new instructional strategies: in-class clicker and discussion questions, reading questions, and thinker problems. Trying something new impacted Judy's thoughts about student engagement and instructional strategies both in lecture and in discussion sections. After receiving feedback about her wait time being too short, Judy focused on waiting longer and not answering her own questions. She also spent more time thinking about what types of questions to pose in class. Judy's clicker questions became less focused on recall and more on application. And she incorporated more questions that could stimulate small discussions in class between students. In the

discussion sections, Judy valued the new thinker problems because they also facilitated discussion and greater student-student interactions. She liked that the students seemed to be engaged and talking about biochemistry. In general, Judy's thoughts changed after trying the new instructional strategies. Instead of considering how best to explain concepts to students, she began to think about how to create opportunities for students to talk about and explain biochemical phenomena.

> "I would like to think more interactively with the students, to try and involve them more in discussions. I'm not ready to totally abandon the whole talking head thing." I3J-FA06-415

> "But I would like to kind of keep easing myself and just, it's a little bit like pulling a something with a lot of resistance through molasses or something after this many years of teaching, you know, to change. So, I mean, I'm changing, I think I am changing a little bit by degrees. And that business about trying to get more reaction from the students, get more participation, get more discussion and so on is easier in 462A than in 460, partly because it's a smaller class, partly because the students are more interested in being engaged" I3J-FA06-419

In summary, when thinking about student engagement and instructional strategies, Judy devoted considerable time thinking about how best to present information to her students. This included creating clear, well-organized, and content-rich lecture notes, developing embedded questions in the notes for students to consider during or after lecture, and finding illustrative examples of key biochemical concepts. Judy was interested in engaging and challenging her students, especially the high-achieving students. After trying them out, Judy believed that clicker, discussion, and thinker questions were instructional tools she could use to accomplish this. Finally, many of Judy's thoughts about teaching were impacted by her struggle to find a balance between content coverage and time.

Teaching: Assessment

In addition to dedicating significant amounts of time tweaking lecture notes and thinking about how to explain concepts to students, Judy also spent a lot of time developing assessments such as problem sets, exams, and quizzes. Problems sets were created with the intent of encouraging students to grapple with biochemistry and to give them practice at applying content covered in lecture. Quizzes were administered 10 days prior to every hour exam to encourage students to begin reviewing exam material further in advance. Exams were used to determine the level to which students understood the concepts and, in some cases, as an opportunity to teach the students something new. All three forms of assessment were used as tools in the assignment of letter grades to students. Judy found it difficult to create new questions for problem sets, quizzes, and exams each semester. She did not like re-using questions, since answer keys posted on the web the previous semester might be available to current students. As a result, much of her time was spent writing new questions or editing old ones.

In writing the questions for assessments, Judy was sometimes frustrated. She believed that questions requiring students to apply concepts in novel situations were a good way to assess student understanding of a concept. These were the types of questions she ultimately wanted on the exams. But she found it difficult to write questions like this. She was also curious about how effective these questions were at uncovering students' true understanding of the material.

> "But, the other way I can tell when a student understands something is either talking to them one-on-one, which you can't do in a big lecture

> class, or asking an exam question. And even then, as we all know, sometimes that doesn't, they may get points on an exam question when they didn't understand it or they may miss the question when they understood most of it." I3J-FA05-76

With the exception of exams, none of the instructors participated in the grading of assessments. The instructors interacted with students in discussion sections as they worked on problem sets, thereby gaining some insights into student difficulties on some problems. For this reason, Judy valued her interactions with students during discussion section. But without grading the problem sets, they generally lacked a clear picture of the range or extent of student difficulties. There was little communication between TAs and instructors. This contributed to a general lack of understanding on the part of the instructors of the level at which most students understood the material. Judy had been teaching the course for many semesters, and therefore had knowledge of common stumbling blocks for students. Yet she lacked an awareness of her students' understanding. Often it was only after an exam that she learned where her students were having difficulties when it is too late to correct them.

Before using the clicker technology during lecture, Judy had no real mechanism for making students' thinking visible. She was limited to reading students' facial expressions as an indicator of whether or not students understood the material and to asking questions in class. Yet Judy was unsatisfied with both of these forms of assessing student understanding. She was skeptical of facial expressions as anything more than an indicator of students being awake. And she was hesitant to rely on student answers to her questions, since the students who volunteer to speak up in class may not be representative of the entire class. Judy viewed using clickers as an alternative way to uncover student

understanding. Although she sometimes found it difficult to write "good" clicker questions that formatively assessed her students, she thought they were more useful than relying on facial expressions and volunteered student responses.

> "But I guess I'm not very creative but other than facial expressions which lie and um, and just asking the class questions as a whole and calling on someone, which is not very indicative of really of you know how much the class understands, I can't think of anything other than the clickers to answer that. Right in class as you go, as opposed to waiting until an exam where it's a little late if they don't understand it." I3J-FA05-127

In addition to using clickers for formative assessment, during the second semester reading questions provided insights into student thinking. After the first reading question submissions by students, Judy was intrigued by what she learned by reading them. Although she had a general idea of common student difficulties from years of teaching experience, she was surprised at some of the concepts with which students were struggling. Judy was excited by the new understanding she had acquired about her students and thought that it might impact her teaching. She noted early on that reading the student questions was time consuming, but initially found them so valuable that she sent an e-mail out to other instructors in the department describing her experiences and the positive effects. She ended the e-mail by recommending that other instructors try reading questions themselves.

> "And certainly they've brought up stuff I wouldn't have realized they'd get hung up on, that are actually very good points. From that point of view I'm getting a lot out of it, and it's very useful, will actually inform my teaching on Mon. and maybe Wed. But it's been a LOT of time -- " J-email-8-26-06

By midterm, Judy's excitement about the reading questions had dwindled. She still contended that some aspects of the student questions were valuable to the instructors

because they provided valuable insights into student thinking. She also believed that the reading questions assignment was beneficial to students because it encouraged students to read the textbook more carefully and prior to coming to lecture. But she was concerned with the amount of time she was spending reading and responding to the questions. Judy was spending upwards of 8 hours on her 20-25 student questions. She was also worried about students' negative perceptions of the grading of the reading questions. Judy's concerns were not unique; the other instructors felt similarly. By the end of the semester, Judy decided that the benefits of the reading questions did not outweigh the costs and eliminated them in future semesters.

Whether through clicker questions, reading questions, or discussion sections, Judy valued learning more about her students' understanding of biochemistry. She liked the smaller review sessions and discussion sections because she believed that there were more instructor-student interactions. She felt that these interactions allowed her to learn about student reasoning difficulties. Yet one key instance caused Judy to question how much she learned from these interactions. Judy had been working with a student on some of the problem sets. After their meeting, she felt like the student had a respectable understanding of the basics encompassed in the problem sets. A few weeks later, Brian spent 90 minutes working with that same student, covering many of the concepts that Judy had thought the student understood. He discovered that the student did not have a firm understanding of basic concepts from chemistry and organic chemistry. After sharing this information with Judy, she was shocked that she had not uncovered the student's deficits. She wondered if she assumed background knowledge that the student

did not have and therefore did not think to ask probing questions to uncover weaknesses in student understanding. This was an important event for Judy because it caused her to re-evaluate the nature of her instructor-student interactions and their effectiveness at uncovering student difficulties.

In summary, Judy employed mostly summative assessment measures such as problems sets, quizzes, and exams in her teaching. On these assessments, Judy strived to create questions that required students to apply or extend their knowledge. Through her use of clicker technology and the reading questions assignment, Judy experimented with formative means for uncovering student understanding. She came to value what she learned about her students from these formative measures. In addition to clickers and reading questions, Judy valued instructor-student interactions as a way of learning about her students' conceptual understanding. Yet she also came to question the effectiveness of these interactions at helping her identify student reasoning difficulties.

Students and Learning

Judy has mostly taught junior- and senior- level science courses. Although some courses were geared for biochemistry majors and others for non-majors, the courses were similar in that they were not introductory courses for non-science majors. Many of her thoughts about this population of students and learning have been shaped by these prior teaching experiences. However, Judy's thoughts have also been influenced by her own personal experiences with learning. The result is a well-formed conceptualization of the

roles and capabilities of students, student backgrounds and how these factors relate to student success in biochemistry.

Judy was a successful student, not just in science but all of her classes. She identified several characteristics that contributed to her success. First, Judy noted that she has always been adept at memorizing information, whether from textbooks or lectures. This was to her advantage since the courses she attended were taught in a lecture format. Her instructors did not provide lecture notes; rather it was expected that students would take detailed notes during lecture. Judy prided herself on her ability to take "rapid-fire notes". In fact, she was so proficient at note taking that she could often teach from the notes that she had created while watching someone else lecture. But more than just being good at memorizing and taking notes, Judy said that she studied very hard, capitalizing on study skills that she thought she had acquired in high school. She also felt that she learned a lot through lecture, so as a student she was diligent about attending all of her classes. For example, Judy recalled one occasion when a graduate school interview prevented her from attending class. Although she borrowed notes from a classmate and read the textbook, she clearly remembers missing the question on the exam addressing the content covered during her missed class. She was disappointed that she "just didn't understand the stuff even though [she'd] tried to study it but hadn't been in class."

It is not surprising that, an instructor, Judy's ideas about the role of students align with her experiences as a learner. To her, the responsibility of the student is to "prepare for class by at least skimming the assigned reading and to pay close attention in lecture"

and to “take good notes”. She felt strongly that students should attend class and discussion section, perhaps because attending classes had been so valuable to her. Judy also thought that students should review their notes after class. Although she did not articulate a set number of hours, Judy expected students to dedicate significant out-of-class time preparing and studying for the course. Yet she doubted most students met this expectation.

> “I feel as if for the last 30 years I’ve been telling students you will get more out of class if you prepare before you come so you’re not just hearing it cold, in which case you’re probably going to walk out not remembering any of it, if you walk in cold. And then unless you go away and study it right away you might as well almost not have come to class because it just won’t have stuck with you, zoom it goes by you at the end of class. But, I’ve been telling students for years how I think they should be studying.” I3J-FA05-145

> “I bet it wasn’t half, even in 462A, who were really studying conscientiously almost everyday.” I1J-SP06-93

Judy is responsible for teaching two biochemistry courses in the department, one for biochemistry majors and one for other life science majors. She perceived that students in the course for biochemistry majors are more interested, and therefore more dedicated, to learning biochemistry. Yet she understood that they entered her course with varied capabilities and backgrounds. She characterized students roughly into three groups, the very good students, the mid-range students who could be successful if they dedicated enough time to biochemistry, and the lost students who may never be successful at biochemistry. Judy had high expectations for all the students in her course, regardless of background, because she believed that students will strive to meet expectations placed on them and that “people work harder when they’re not complacent.”

These expectations, she felt, were much higher than students would have encountered in many of their lower- division courses.

Judy believed that students' capabilities and backgrounds differentially impacted their chances of meeting her high expectations. For example, although there are rigorous math pre-requisites for enrollment in the course, Judy noted that many students are "math-challenged", which caused them to get hung up on the mechanics of some problems and miss the underlying biochemical concept. Furthermore, Judy felt that students' differential levels of conceptual understanding of chemistry, organic chemistry, and biology often impacted their performance on problem sets, quizzes and exams. She believed that deficits in any of these areas could be remedied in some students by more one-on-one interactions with students. Yet she thought that for some students these difficulties might be too great to overcome, thereby preventing success for them in any science major.

> "And I think there are students who, with a little one on one time can actually kind of get back up to speed and join the upper mode, even if they're on the lower fringes of the upper mode. [sic] Some of them, don't really belong in a science major maybe, you know, the students, usually the students who would be in that lower mode. If you were to go and look at their records, you find that this is not an anomaly in this course. They just are having, they struggle with math and science courses if you look at the rest of their records." I1J-FA06-201

In developing her understanding of student capabilities, Judy often examined student transcripts, taking note of performance in previous classes and where students had completed prior science classes. Yet she evaluated students' abilities differently depending on the nature of the transcript. For example, if a student received high marks in a pre-requisite course such as organic chemistry, she expected a certain level of

competency from the student. But if the student earning the high marks received them through a community college, she was less likely to expect as high a competency as a student completing a course at the university. Furthermore, independent of where a student took his previous coursework, Judy correlated a student's previous grades with that student's capability. She did not, however, credit all of a student's ability to prior education. Judy also considered that some students may have innate strengths in math and science.

> "And I tend to attribute it either to differences in innate ability in the students or more likely to differences in the kind of education they've had coming up to this course, like whether they've gotten you know easy As and Bs at a community college but never really learned the chemistry or never really learned how to learn to study or whatever." I1J-FA06-164

An innate strength that Judy thought a student might have is the ability to memorize information. She noted that many, if not all, of her students are skilled at memorizing. But Judy thought that not all students have the ability to relate this information or apply it. She anticipated that these were the students earning scores in the 50s on exams. This was of concern to Judy because she was unsure how to assist these students' transition from memorization to application.

> "And those may be the students who, you know, clustered around 50 in a bimodal distribution. And I don't know how to deal, I mean, you almost have to deal with them separately from the other students. You can't sort of take class time to deal with that lower mode, I don't think. I don't think it's fair to the other students to kind of go back and pick up and spend longer explaining things and so on for that lower mode." I1J-FA06-198

In summary, Judy perceived the role of students in her class to be similar to the one played by her as a student. Yet her experiences teaching this population of students also influenced her beliefs about student roles and capabilities. Specifically, Judy

characterized her students as having varied capabilities and backgrounds in biochemistry. Some of these variations are due to innate qualities of the student whereas others are due to previous education and experiences of the students. Judy believed that these variations can result in differential success in biochemistry, and that some of these variations can be compensated for through one-on-one interactions between instructors and students. Although Judy recognized the diversity of her student population, she is not always certain how to adjust her teaching to address it.

	Fall 2005	Fall 2006
Role of Instructor	• Deliver content-rich, clear, and organized lectures • Foster engagement and interest in students • Provide opportunities for students to get help outside of class • Treat students fairly and with respect • Challenge students	
Student Engagement & Instructional Strategies	• Lectures are important for presenting information to students • Embedding questions and illustrative examples in lecture notes will engage students with material • High-achieving students need to be engaged	• Clicker, discussion, and thinker questions are instructional strategies that can engage students • Integration of learner-centered strategies impacted by struggle to balance content coverage and time
Assessment	• Problem sets, quizzes, and tests are the primary form of assessment • Questions on assessments written for students to apply or extend knowledge • Instructor-student interactions valued as a mechanism to learn about students	• Formative assessments such as clickers valued as a way to learn about students • Instructor-student interactions questioned as a means for identifying student reasoning difficulties
Students and Learning	• Personal experiences as a student shape thinking about roles of students and student learning • Biochemistry students have varied capabilities and backgrounds due to (1) innate student qualities and/or (2) previous education and experiences • Differences in students can result in differential success in biochemistry • Students from community colleges generally have insufficient background content knowledge	

Table 5: Summary of the Case of Judy

Case Study of Brian

After more than 30 years as an academic scientist, Brian's experiences with teaching were not dissimilar to other faculty members. As a graduate student, he held a teaching assistant position for just one year. Following graduate school, he accepted a post-doctoral position which entailed minimal teaching responsibilities. And as a new faculty member, Brian learned how to teach through trial and error and by watching his colleagues. But his first teaching experience was influenced by a departmental document that he called a teaching philosophy. It was a packet distributed to the faculty containing departmental expectations with regard to teaching, grading, and course objectives. Brian noted that this document facilitated some level of consistency in teaching within the department and was useful to him as junior faculty.

After his first academic position, Brian worked at another prominent university before accepting his current position of department chair. He described the department there as one that lacked a culture of teaching. Discussions of teaching never occurred in faculty meetings. Professional development experiences in teaching for faculty were not offered. And although faculty members observed each other's teaching, they limited their feedback to comments about lecture style or organization. His impression was that teaching was not taken very seriously and that excellence in teaching was not a priority. In contrast, Brian noted that the administration for which he currently works is interested in high quality teaching.

At the beginning of this study, Brian had been department head for five years. As such, Brian experienced opportunities to think about teaching that were unique in

comparison to other faculty members. Brian noted that whereas he primarily would have been concerned with his own teaching, he is now obliged to think about the teaching practices of everyone in the department. In many ways, therefore, he has the power to influence the culture of teaching within his department. For example, he promotes the scholarly activities of one of his faculty members that focus on the teaching and learning of biochemistry. He considers her expertise an asset to the department and encourages members of the faculty to include her in their discussions about teaching. Furthermore, Brian endorsed the research presented here. Graduate students in science departments investigating issues in the teaching and learning of science are still unusual, and this research is the first of its type approved within this department. By advocating this research, Brian demonstrated support and interest in the teaching and learning of biochemistry. His actions are conducive to an environment where conversations about the teaching and learning of biochemistry are commonplace.

Brian's interest in discussions about teaching and learning was also made apparent by his allocation of time in staff retreats and biochemistry advisory board meetings. In the spring of 2006, Brian not only reserved time in the annual staff retreat for discussions about teaching, but he also created a document describing what he hoped could become a departmental teaching philosophy. He distributed the document to the faculty and invited conversation about its contents. Although it did stimulate discussion, to date the department still does not have an articulated teaching philosophy. The following spring, Brian again set aside time at the departmental staff retreat during which I was invited to share the instructional strategies we had been implementing in the

biochemistry course. This sparked lively dialogue amongst faculty members, some of whom shared their own experiences with similar strategies in their courses. In both cases, faculty discussion ran over the time allotted.

A board of advisors for the biochemistry department meets annually to hear news about the department and to discuss ways of enriching and extending the program. Each year, Brian invites select faculty members, graduate students, and undergraduates to speak about their research and scholarly projects. I was invited to this meeting twice to talk about research in science education. This was an opportunity to not only communicate my research to members of the faculty, but also to instigate discussion between Brian, the faculty, and the board members. In general, the audience was engaged and attentive, posing various questions and demonstrating interest in the research aspects of science education.

During the study, Brian also collaborated on multiple grant proposals for science education research projects. The projects ranged from the implementation and evaluation of learner-centered teaching strategies to the creation of new courses focusing on the integration of mathematics and biochemistry. In writing these proposals, Brian engaged in conversations about course objectives, curricula, teaching, and student learning. Not only was I included in most of these discussions, but so were other science education researchers, biochemistry faculty members, and colleagues within the math department.

Finally, Brian's participation in the study, particularly interviews and reflective journaling, had two noteworthy effects that provide a critical contextual backdrop. First, as department head, Brian's time is infinitely divided between the duties of his position.

His participation in interviews and reflective journaling necessitated setting time aside in his schedule. Although inherently thoughtful about his teaching, Brian's duties had not previously afforded him chunks of time specifically for thinking about teaching. Second, Brian noted on multiple occasions that the nature of the questions posed in interviews and as reflective journal prompts were novel to him. They caused him to think about aspects of his teaching he had not thought about before. This increased reflection, both in terms of time and quality, underpins many changes in Brian's thinking about teaching, as will be elucidated in his case.

As illustrated by the examples above, Brian participated in several unique opportunities which had the potential to impact his thoughts about teaching during the study. Furthermore, they highlight the fact that Brian has the means to strongly influence the culture of teaching in his department. Supporting research in science education, dedicating time to discussions about teaching and learning, and actively seeking funding for science education research projects all contribute to a culture of awareness about teaching and learning issues. Moreover, Brian often speaks of the department's reputation for teaching both within the university and outside the university. He believed that the responsibility of a university is to teach the leaders of the next generation. And, after two years in this study, he posed the following questions:

> "For me over the last couple of years, I really have, I think it's a to a large extent your fault, I really have been thinking a lot more about, are we really doing that which we are taking the king's gold to do? Are we doing it right? Are we really doing it the way that our students are going to be stronger for it?" I3B-FA06-381

Teaching: Role of Instructor

After many years of teaching, and several in the supervisory position of department head, Brian's well-defined ideas about the roles and responsibilities of biochemistry instructors were teacher-centered. At the most basic level, he believed that the responsibility of an instructor is to present material in a clear and organized manner, to tell students what it is they need to know, and to assign grades to student work. He viewed the role of the instructor to be more of the "sage on the stage", where the instructor transmits knowledge to the student.

> "I must say all my life, all my teaching career I have viewed my responsibility of being one of conveying factoids. You know, I just, here's how it is folks, that's what I've done." I3B-FA05-290

More than just giving the students lists of facts to know, Brian believed that instructors should demonstrate the experimental and mathematical underpinnings of key concepts. Furthermore, he thought an instructor should show students how the facts or concepts are connected to one another. He did not describe the act of making connections as an activity in which students would engage, rather the instructor's responsibility is to make connections for the students and then present those connections to them.

> "Uh, my responsibility is to try to de-convolute some of the really complex issues and draw connections to help students see connections between bits of information so that they're not like sort of hanging out there in a vacuum, that they are really tied together tied down related to some bedrock that's easy to understand." I1B-F05-85

> "…spoon feeding the students stuff that's completely all the connections are made and it's just a matter of here it is, memorize it." I3B-FA06-230

Beyond teaching students biochemistry concepts, Brian felt passionately that instructors have the responsibility to develop students' efficacy in biochemistry. He often spoke of one aspect of an instructor's job, "to encourage students, not to demoralize them." An instructor's responsibility is to encourage, motivate, and empower all students to be successful, to maintain their sense of "can do".

> "How, are we all on the teaching staff right now really recognizing our responsibility to be encouraging to the students, even the poor students?
>
> "I think it's very important for anyone who's engaged in the teaching enterprise to realize that at the end of the day we have to encourage students. It's hard work that they're going through and um a lot of stuff that they need to learn and they need to be encouraged. It makes it easier to want to work hard when you are being encouraged." I1B-FA06-286

While reflecting on previous teaching experiences, Brian said that he could only think of one instance when another faculty member had come to observe his teaching. And in that case, the faculty member's only comment was that he had enjoyed the lecture. Yet, throughout the study, questions were posed of Brian about his thoughts on teaching, the decisions he made in class, and how his students learn. He felt that the process of answering these questions, receiving feedback, and reflecting on it all could influence one's thoughts about teaching and learning. For example, when asked to identify one way in which he had grown as an instructor over the course of the study he described a new role for instructors.

> "I think I'm becoming more comfortable with the idea that what we're really trying to do here is to give the students some brains and exercise in thinking like a biochemist. [sic] But if we can give them the tools they need to learn it, then we will have been successful. So it's helping the students realize how you go about doing this, this stuff. [sic] If they have got the tools then they can go on and continue learning for the rest of their lives, then that will be success. Not a matter of just cramming it all into

> their heads and tamping it down there and putting a plug in it. You know, that's, which is what I think a lot of people, and I certainly in my past you could have seen me trying to do that." I3B-FA06-400

The language Brian used when talking about the roles of instructors and students also became less teacher-centered. Instead of describing what the instructor should be doing, he talked about how instructors could facilitate the activities and participation of students.

> "I think if a student is trying to make a connection and they just don't see it, then perhaps you need to give them a stepping stone. Sometimes a stepping stone is just to ask the question a different way. Or if a student is asking you a question, ask them a question… That may be like giving them a stepping stone. You know, giving them some intermediate piece of information from which they can say, aha. If you do that, I think the student might be making a connection." I3B-FA06-238

> "And I think if we can figure out how to really engage the students in teaching each other and we … can step back instead of wanting to jump in there you know, and tell them, oh no, you guys got it all wrong, which is our natural tendency." I3B-FA06-202

Brian's interactions with other faculty members also changed. He began to pose questions to his colleagues, asking them to explain their goals for a lecture, activity, or problem set. He became an advocate for activities which deviated from a transmissionist model of instruction, activities that encouraged students to grapple with material such as thinker problems in discussion section (as opposed to traditional problem sets). In preparing for his own lectures, he spent more time constructing clicker questions and discussion prompts that would facilitate student discussions and connection making.

In summary, Brian initially considered the role of the instructor to be more teacher-centered. He believed that instructors should present clear and organized material, demonstrate experimental underpinnings and the connections between concepts

to students, and assign grades to student work. He also perceived the role of an instructor as one who develops student efficacy in biochemistry. His instructor thinking about the role of the instructor changed to be more learner-centered. He focused less on the activities of the instructor, and more on the activities of the students. Furthermore, as possibly demonstrated by his questioning of other faculty members, Brian also enacted a new instructor role by instigating discussions and reflections about teaching.

Teaching: Student Engagement and Instructional Strategies

Brian was not new to teaching this biochemistry course. As department head, his teaching load was a little lighter than the other two instructors with which he taught. Yet he typically taught one course a semester on average. Due to the many demands on his time, he sometimes did not have time to write his own lecture notes or to modify the ones that Judy, as course coordinator, had constructed for him. Despite this, he spent a significant portion of time thinking about how to engage his students.

Brian believed that if he set high standards for the students, they would rise to achieve them. Complementary to his initial characterization of the role of an instructor to be one who transmits information to students, he considered lecturing to be a useful instructional strategy. He believed that lecturing is most effective when done in small groups because the likelihood of interactions occurring between students and the instructor would be greater. Yet he did not believe that lecture should be used only to convey factoids, rather he believed that it could be used to engage students and to give them the necessary tools for approaching biochemical problems.

> "how we can give the students the tools that they need to learn the material themselves as opposed to trying to implant in their brain every little factoid on the, you know, that we can't do that, but we can give them the tools that they need." I2B-FA05-83

Instead of using lecture primarily to convey factoids, Brian thought that lectures should provide a roadmap for students to help them see how the concepts in the course relate to one another. "What you can cover in class is giving students an outline of those things that they need to learn on their own. Clear roadmap (I1B-F05-219)." When preparing for class, he thought about how to tie information to previous lectures and tried to anticipate how it should flow into future lectures. "I try to in lecture refer to material that was already covered and to anticipate material that is going to come (I1B-FA05-157)." He seldom considered how to get students to make the connections for themselves, focusing more on how and what to present to the students.

In contrast to factoids, Brian placed value on presenting the experimental and mathematical underpinnings of biochemistry to students. He believed that showing students where equations are derived from and what experiments led to the modern understanding of concepts would result in greater student understanding of those concepts. In addition to exhibiting foundational underpinnings, Brian also contemplated in-class demonstrations as a strategy for engaging students. Although he never actually implemented them, Brian thought that demonstrations might make some of the more abstract ideas become clearer to students.

Although the instructional strategy employed by Brian most often was lecture, he believed that questioning during lecture had some utility. Early on, Brian talked about using questioning as a way to keep students awake during lecture. When preparing for

lecture, he considered when the best time for posing a question might be. He believed that keeping students "fresh" would help them maximize their in-class learning.

> "Doing something (during lecture) to maintain their mental focus (like breaking for a story or a clicker question) will actually allow you to convey more knowledge in a lecture than other ways." I1B-F05-225

> "Because I think that 20 minutes into the lecture is probably a pretty good time to put a clicker question. 'Cause by then, I can see the lights going dim in the eyes. Um, and so a clicker question at that point would, might get their pulse going again." I2B-FA05-153

Brian also regarded questions to be useful in inspiring or motivating student interest in key concepts. He believed that if students became excited about a concept, they would be enticed to think about it more.

> "I can ask questions that are basically "are you awake" kinds of questions and I don't think that they find those to be particularly interesting and a couple of times I've managed to hit I think questions that really excite the students' imaginations and get them really thinking about the material. And if I can just get a better feeling for what makes a good question of that type, then I think I will have learned something pretty important. " I2B-FA05-106

Brian's thoughts about using questions as an instructional strategy changed from one semester to the next. Rather than using questions as a way to wake students up or to increase interest, he began to consider questioning as a tool for actively engaging students with the material. In particular, he recognized that asking students questions requiring application of what they have learned to novel situations can result in students making connections that they would not have otherwise. For him, questions served as a mechanism for challenging students to extend their thinking in new ways. Furthermore, he saw that some questions could be used to encourage student-to-student interactions.

As he evolved to value these interactions as an effective way to help students learn, he became increasingly concerned with designing questions that would result in this type of interaction.

> "I've gotta spend some more time thinking about how to pose good clicker questions. 'Cause I do think that that is a mechanism to engage students in talking to each other and again it would be good if the students would be sitting in sort of clusters already in the classroom where they would be able to talk to each other easily." I3B-FA05-198

By the end of the second semester, Brian had shifted his beliefs along the continuum from teacher-centered to more student-centered. He grew to think that actively engaging students, particularly through cleverly composed in-class questions, might lead to increased student learning.

> "But over the last two years or so I think I have come to appreciate the idea that perhaps um, setting up, um a situation and asking the students to think about it, getting them engaged in it, actually they may walk away with a clearer understanding." I3B-FA06-53

In summary, Brian's preliminary instructor thinking with regard to student engagement and instructional strategies can be characterized as more teacher-centered. The primary instructional strategies he used were lecturing and questioning. Initially he conceived of lecturing to be a mechanism by which experimental underpinnings and connections between biochemical concepts could be conveyed to students. He viewed questioning as a way to maintain student attention and focus during class and to motivate student interest. Later, he considered questioning to be an effective strategy at fostering student engagement in class. He also came to see questions as a strategy for engendering discussion between students about biochemical topics in class and extending student learning.

Teaching: Assessment

Like so many university instructors, Brian's ideas about assessment were limited to summative measures such as tests, quizzes, and problem sets designed for the primary purpose of assigning grades. He viewed these tools, especially exams, as an opportunity to teach students something new. He seldom paid attention to identifying ways to investigate the level to which his students were learning or uncovering student thinking.

During class, Brian relied on visual cues from his students to gauge whether or not they were "getting it." He thought that this was a valuable form of feedback to receive from students, one that helped him determine if the lecture was aimed too high or too low for the students.

> "I get from looking at the eyes of the students in the classroom. I get an enormous amount of feedback from the students in class. And I think I manage, at least I try pretty hard to pay attention to whether students are with me and if they're not with me I try to figure out how to go back and scoop them up." I2B-FA06-48

In discussion sections, office hours, and informal conversations Brian gained insights into student learning through one-on-one interactions with some of his students. He listened carefully to students, and valued their input greatly. On more than one occasion, a student comment or question caused Brian to re-think aspects of his teaching or logistics of the course. During his first semester using the clicker questions, Brian was able for the first time to confirm that this somewhat anecdotal feedback from one of his students was representative of a more widespread conceptual misunderstanding.

> "I think for example just most recently the kinds of responses I've been getting on the clicker questions in kinetics sort of underscore what I was

> worried about from the conversations of last Thursday's discussion sections." I2B-FA05-243

This was an important realization for Brian. His increased use of clicker questions was designed to not only encourage student discussions, but to help reveal aspects of the students' thinking. In addition to in-class questions, he tried to imagine other mechanisms for revealing student understanding. He proposed several ideas including interviews with students, anonymous student questionnaires, and on-line feedback forms. None of these ideas, however, explore mechanisms for gathering this kind of information during class.

In the second semester, two new elements had been added to the course: reading questions and undergraduate tutors. Although reading questions had initially been proposed and adopted as a way to encourage student preparation before lecture, after the first few weeks Brian noted that they could be used for another purpose. The reading questions submitted by students were a useful way to learn about the things with which students were struggling. In instructional staff meetings, he often shared what he had learned about his students through the reading questions. He encouraged brainstorming amongst the staff on how to address student difficulties. Occasionally he would go to the white board to sketch an alternative way for explaining a concept. Of the three instructors, he was also the one who insisted that undergraduate tutors give a weekly report of student difficulties encountered in tutoring sessions. He enjoyed the increased knowledge about his students, and dedicated personal and staff time to thinking about how to alleviate the problems faced by students.

In sum, Brian's initial ideas about assessment were characteristic of many faculty members: assessment is a tool to assign grades to students and is therefore used summatively, rather than formatively, to learn about students. His strategies for learning about his students' understanding were limited. Experimenting with clicker questions during lecture created an opportunity for Brian to consider more effective ways to gather information about his students' thinking. As a result, his ideas about assessment began to include using it formatively.

Students and Learning

Brian had not only taught this course before, but had also taught the next course in the sequence. Consequently, he had well-developed ideas about this population of students in particular and about students in general. These ideas about and expectations of students were shaped by his prior experiences teaching this sequence of biochemistry courses, his experience teaching other biochemistry courses here and at other universities, and by his own personal experiences as a learner.

When reflecting on his own experiences as a learner, Brian shared that acquiring new understanding is not always an easy process for him. He credited much of his success as a student to a strong will and work ethic. For him, it took more than just reading the text or listening to a lecture on a topic to learn it. Hearing an explanation more than once and in different words helped things "soak in." In his science courses, he read the textbook and worked problems, not just those that were assigned but as many as he could find. He spent long hours at the library reading other textbooks to find an

alternate explanation for concepts covered in his course textbook. He recognized that learning these things can be easier for some people than others. He often spoke admiringly of his wife's ability to hear or read things once and remember them. But for Brian repetition was the key to much of his learning because it provided him opportunities to test his understanding.

Brian was a motivated student, and usually came to science classes well-prepared. It was important for him to have thought about the material ahead of time so he could have a contextual framework from which to work. As a result, he had mostly positive learning experiences. However, on a few occasions he was frustrated by instructors who left too much to abstraction. These were some of the few times where Brian felt lost and unsuccessful as a student. He needed to see how equations were derived, or what experiments had been done, in order to understand what was being taught.

> "And, you know, you would see an equation and you would say, what the hell does that have to do with anything in the real world? And for me I've gotta see someplace where something, you know, there's gotta be a stake in the ground somewhere that I can take off from. I guess that's the way my brain works, I tend to think of things in pretty concrete terms, if you know what I mean." I2B-FA06-139

Perhaps related to his own role as a student, but certainly aligning with his teacher-centered thoughts about instruction, Brian believed that the primary responsibility of students is to pay attention to what the instructor says is important to learn, and then to learn it. At the beginning of each semester he communicated his expectation that students spend several hours a week reading and working problems. He imagined that successful students would read the chapter, solve problems, and discuss biochemistry with peers. As a result, he worked hard to create novel, data-driven problems on weekly

problem sets. And, like the other instructors, he believed that there is little one can do to inhibit the learning of a "good" student. But he had little knowledge of how any students, "good" or otherwise, approached their learning. He had ideas about what students should do in class to enhance learning, like keeping their minds crisp. This was one of his initial reasons for introducing more in-class questions as an instructional strategy; they would help students maintain focus during lecture. He believed that attending lecture well-prepared and taking careful notes contributes significantly to student learning. Yet, with the exception of a handful of highly motivated students each semester, Brian had little knowledge about the nature of the work that the majority of his students did outside of class.

Independent of what students are doing in or outside of class, Brian believed that his students' self-confidence in biochemistry influences whether or not they will learn something, "their mind set was not should we say 'right' for learning after that period of time; they were aggravated." He thought that once students become discouraged or overly frustrated, they will no longer be able to succeed in learning the content. This motivated one of his beliefs about the role of an instructor, that they must maintain the sense of "can do" in the students, even though he believed that not all of them can.

> "Students start feeling their feet slipping out from underneath them and they start losing their confidence that they can learn the material, they're dead, they may as well go find something else to do because they're not going to be successful. The only way a student's really going to be successful is if they maintain a feeling in their deep down in their gut that this is something they can do and if they just put in the effort they will do it." I1B-F05-189

In his own learning, Brian values questions as a way to develop understanding. When learning new things, Brian asks himself how they fit into what he already knows about the world, or what the implications of that piece of information might be in the broader context. He wondered if some students lacked the ability to ask themselves similar questions. On occasion, Brian would pose questions to his students to push their understanding. Other times, he asked questions with the intent of helping students make a connection or see the next step. As a student himself, one instructor stuck out in his mind as being particularly skilled at posing questions to promote understanding. When Brian would come to his office, this instructor would listen to Brian's question and, "his normal response was to come out and ask me a question. And quite often from the question he asked me, I could see the answer." Brian tried to model his questioning on this instructor when working with students individually.

In general, Brian thought that the students that take this biochemistry course are mostly motivated students who "want [the instructors] to be throwing the hardball at them pretty fast." He believed that a proportion of students is capable of, and requires, being challenged. But he believed that challenging these students at the level they could most benefit from would cause the average student to perform more poorly than if the course were taught at a normal pace. Regardless of the situation, Brian considered a small portion of the class as students who "just should not be there." These students Brian identified as lacking the background to be successful and being beyond the instructors' reach to help.

Many students enrolled in this particular class are biochemistry majors, and Brian felt that one responsibility of students is to adopt the manner of thinking and analyzing data of a biochemist. This included not only learning how to speak and use discipline-specific vocabulary like a biochemist, but also attending departmental seminars and thinking about biochemical research. In particular, students should understand the tools and techniques applied when investigating biochemical phenomena. Students could demonstrate this understanding by explaining the experiments and findings from biochemistry journals or seminars to someone else. Brian also thought students should appreciate the interdisciplinary nature of biochemistry and how it fits together with other disciplines.

Yet Brian also recognized that the students in the course represented a wide range of backgrounds. Not only did he believe that students enter the course with differing depths of understanding of chemistry, biology, and physics, but he also noted that students enter with different skills and abilities for thinking about scientific problems.

> "There are, as with any class it is a mixed bag. There are some students who are I think pretty smart, who are not doing so well. There are some students who are doing pretty well who are not so smart. There are some students who are doing pretty well who have no interest in understanding the material. There are some students who are struggling to understand the material who want to understand the material who are not getting it. " I2B-FA05-176

He believed that most students have difficulty making connections between concepts, especially when encountering those concepts for the first time. But he sometimes wondered if students in his class struggled more because of a lack of background in a particular content area, or if students had not learned good study and reasoning skills

prior to the course. Brian believed that whatever strengths and weaknesses students have, they vary from student to student, and therefore students can benefit from working together and learning from each other. This tied into his expectation that expected students to interact with one another in the classroom as they would if working in a research laboratory.

> "It is the students' responsibility to challenge each other. The students need to engage in the act of dialogue, just like what goes on in a laboratory. Everybody in a laboratory has their own research problem, but they all have each other. They share knowledge, they share understanding, they share victories, defeat, everything else. The same dynamic kind of dynamic needs to go on in a classroom. If there's someone who gets it, they need to share that with other students. And if there are students who are struggling and having trouble, they need to feel comfortable in talking with other students as well as instructors. It really needs to be a, a group effort." IB-F05-95

In summary, some of Brian's personal experiences with learning seem to parallel his thoughts about students and student learning. For instance, as a student, Brian valued derivations and demonstrative experiments for their contributions to his understanding. This complements Brian's description of the role of an instructor as being one who should communicate experimental underpinnings. Furthermore, Brian's personal experiences with an instructor who used questioning to push Brian's thinking forward might have contributed to Brian's adoption of questioning as an instructional strategy for increasing student engagement. Yet other thoughts about such as the capabilities of biochemistry students are built upon prior years of teaching. Encompassed in these thoughts was the expectation that students should strive to adopt the habits of mind and language of biochemists. And, although he identified most of his students as highly motivated, he recognized that they possessed diverse backgrounds in terms of science

content and skills which would result in varying degrees of success in understanding biochemistry.

	Fall 2005	Fall 2006
Role of Instructor	• Present clear and organized material • Demonstrate experimental underpinnings • Demonstrate connections between concepts to students • Assign grades to student work	• Facilitate the activities and participation of students • Helping students become life-long learners • Initiate discussions about teaching with colleagues
Student Engagement & Instructional Strategies	• Lecturing is effective for conveying information to students • Questioning is a tool for maintaining student attention and motivating student interest	• Questioning is an effective strategy for fostering student engagement • Questioning can be used to create student discussion and extend student learning
Assessment	• Assessments are used for assigning grades • Quizzes, tests, and homework sets are examples of assessment • Assessments such as tests can be used to teach something new • Assessment is a summative activity • Limited strategies used to make students' thinking visible	• Alternative assessment strategies such as reading or clicker questions can reveal student thinking • Increased information about student thinking can lead to productive discussions about teaching
Students & Learning	• Personal experiences with learning shape thoughts about students and learning • Repetition is useful for student learning • Students learn from derivations and experimental underpinnings • Biochemistry students are generally highly-motivated • Posing questions helps students make connections and models metacognitive thinking • Students have diverse backgrounds in science content and skills that impact their ability to learn • Students have difficulty connecting information into a larger conceptual framework	

Table 6: Summary of the Case of Brian

Cross-Case Analysis

In an effort to understand more about university teaching, the first objective of this research was to characterize the nature of "instructor thinking" for biochemistry faculty members engaged in teaching an upper-level, large-lecture biochemistry course. For the purposes of this study, "instructor thinking" was defined as an instructor's thoughts, beliefs, and attitudes about teaching, students, and learning. The second objective was to characterize factors contributing to changes in instructor thinking. Finally, the last objective was to identify instances in which changes in thinking were associated with altered teaching practices.

All three of the faculty members in this study were similar in that they had received no formal training in teaching. Instead, their own personal experiences as students and instructors heavily influenced their thoughts about teaching. For example, when talking about their experiences as students, they described didactic lectures where the instructor was viewed as a content expert. It may not be surprising to note, then, that initial thinking for all three instructors was teacher-centered. They commonly equated good lecturing with good teaching. For all three, their instructor thinking shifted away from a teacher-centered paradigm toward a learner-centered one throughout the study. But what factors were associated with these changes? The following cross-case findings serve as an answer to this question.

Finding #1: Pedagogical dissatisfaction can motivate changes in instructor thinking.

All three instructors demonstrated instances of pedagogical dissatisfaction. As defined by Gess-Newsome et al. (2003), pedagogical dissatisfaction is a "mismatch between stated teaching beliefs, goals, instructional practices, and student learning outcomes" (p. 762). In some instances, this dissatisfaction created an entry point for the exploration or enactment of changes in teaching practice. The nature of dissatisfaction was similar from instructor to instructor. For example, all three instructors expressed dissatisfaction with less-than-optimal outcomes in student learning. But each of their responses to dissatisfaction differed. Moreover, each *individual* instructor's reactions varied depending on the nature of the dissatisfaction.

Both Mari and Judy were dissatisfied with the level to which students learned the material. They noted that many students not only failed to achieve deep understanding of the content, but often did not retain even cursory information for very long. Judy's dissatisfaction resulted in her consideration of alternate instructional strategies. She questioned whether or not the use of real-life biochemistry examples and repeat exposure to content in lecture were sufficient for students to retain the information. As a result, Judy was open to suggestions about trying new strategies such as clicker and discussion questions in class. She observed that students seemed to be engaged and talking about biochemistry more often after using the clicker and discussion questions. She grew to spend less time thinking about how to explain concepts to students, and more time considering ways to create opportunities for students to interact with the material and each other.

In contrast, Mari's dissatisfaction led her to question the process and conditions necessary for achieving deep understanding. She drew upon her own experiences as a learner to propose that deep learning results from the process of making connections between concepts. As a result, Mari contemplated ways to foster connection making in her students. She recalled the concept mapping exercise students had completed in one of the discussion sections. Mari viewed it as an effective means for increasing students' capacity to make connections. In discussions of her plans for future semesters she explored ideas about how to integrate aspects of this exercise to foster connection making with the goal of achieving deeper student understanding.

Mari also expressed dissatisfaction with the instructional strategies she was using. Yet her response to this dissatisfaction was different than her reaction to dissatisfaction with student learning. Mari felt that the instructional strategies she used often failed to promote student engagement during class. Mari welcomed suggestions and contemplated how to increase student engagement. She also changed aspects of her teaching in the second semester. Most notably, Mari exhibited a greater capacity for risk-taking in the classroom. She was more apt to relinquish control and allow students' questions to guide portions of the lecture. In this case, dissatisfaction was associated with a change in Mari's teaching, not just her thinking.

In summary, in each of the individual case studies pedagogical dissatisfaction was evident for the instructors. It was a motivating factor for revised thinking about teaching and, in some cases, teaching practice. However, instructor reactions to dissatisfaction varied amongst the faculty members. Additionally, an individual instructor's reaction to

his or her dissatisfaction was different depending on the situation. This raises further questions about the nature of pedagogical dissatisfaction in motivating changes in instructor thinking.

Finding #2: Instructors' thoughts about what constitutes good teaching align with the types of evidence collected to evaluate and think about their own teaching.

Instructors in the biochemistry department are required to distribute end-of-semester evaluations to their students. There is not a standard departmental teaching evaluation. With the exception of a few questions that must appear on the evaluation to inform annual performance reviews and promotion and tenure decisions, the questions used on evaluations vary from course to course. As course coordinator, the final decision about the nature of the course evaluation was Judy's. She generally divided the evaluation into sections. One section probed student perceptions of the course as a whole (i.e. amount of material covered, fairness of exams); the second section inquired about the instructors (i.e. clarity of their lectures, willingness to answer questions); and the third asked about the quality of course materials (i.e. textbook, website). Results from these evaluations were considered by the instructors, although to varying degrees, when making decisions about their teaching effectiveness.

Both Mari and Judy were reflective about their student evaluations. In our first discussion, Mari shared that she had received the poorest evaluations in the department the previous semester. Similarly, Judy revealed that her evaluations were consistently below average. Both Mari and Judy had negative feelings about how they had been

evaluated by the students. Worried about her effectiveness as an instructor, Mari questioned what other instructors did or what qualities they possessed that she did not. She wondered what aspects of her teaching she could change to improve her evaluations. Judy, on the other hand, paid less attention to the evaluations. She noted that someone has to be below average and that both the average and her own scores had been rising a little each semester. Judy did not dismiss her evaluations entirely, and continued to think carefully each semester about the questions that should be included in the evaluation. In contrast, Brian seldom talked about his teaching evaluations. Both Judy and Mari spoke highly of Brian's teaching abilities. Although he personally didn't believe he was the most effective teacher, he generally placed less emphasis on his evaluations than Mari or Judy when making judgments about his effectiveness as an instructor. However as department head, he was limited to end-of-semester and peer evaluation to make promotion and tenure decisions. He was skeptical that these data were sufficient to make decisions about teaching effectiveness.

In addition to end-of-semester student evaluations, the instructors considered other forms of evidence in evaluating their teaching effectiveness. For example, when discussing how well they had taught a particular concept, they would cite unsolicited feedback from students as an indicator of teaching effectiveness. This feedback was collected informally through interactions in office hours, discussion section, and casual conversations before or after class or in the hallway. But the weight they placed on student feedback varied with the perceived ability of the student. If a "good" student indicated that she had troubles with a concept presented in lecture or discussion section,

the instructors would reevaluate how they had taught the concept and brainstorm alternate ways to present it. But if a "poor" student provided the same feedback, the instructors were less likely to reevaluate their teaching. Instead, they might question whether or not the student had prepared prior to class, had worked the problems sets, or spent enough time working with the material. Similarly, if a student who had completed his previous course work at a community college performed poorly in the class, the instructors were more likely to attribute his achievement to the community college's inability to adequately prepare the student rather than to examine their own instruction. In short, the instructors were more responsive to certain student feedback and drew upon it differentially when self-evaluating their effectiveness as teachers.

Beyond end-of-semester student evaluations and informal feedback from students, these instructors collected no other evidence to inform decisions about the effectiveness of their teaching. Their descriptions of good instructors depicted colleagues who presented clever, well-organized, and content-rich lectures while fostering the engagement and excitement of students. In other words, they equated good lecturing with good teaching. The end-of-semester evaluations asked questions about aspects of teaching that aligned with their criteria for good instructors. The student testimonies served a similar role by attesting to an instructor's ability to engage students.

In summary, these three instructors collected limited evidence to make decisions about their teaching effectiveness. Yet the evidence they considered was reasonably aligned with their ideas about what defines good teaching. This leads one to question the

relationship between beliefs about effective teaching and the types of evidence considered in evaluating one's own teaching.

Finding #3: Instructors' experimentation with assessment strategies is associated with expanded, but not fully developed, thinking about assessment. Expanded thinking about assessment may not subsequently be accompanied by revised teaching practices.

All three instructors' initial thoughts about assessment were similar. To them, the primary purpose of assessment was to gather information for the assignment of grades and for providing students opportunities for practice through working biochemistry problems. They did not think about assessment as a way to uncover student understanding, rather they viewed assessment as a distinct process only loosely connected to teaching and learning. This is in contrast to a learner-centered approach consistent with assessment for learning, where assessments are embedded in the teaching process and are used to diagnose and enhance student understanding by providing feedback for both instructors and students.

> "But to be completely honest with you, over my career I have really not paid that much attention to the issue of how do you best determine whether the students have learned the material. Because of all aspects of teaching that's the one that I really don't like. I don't like the business of giving grades." (I3-B-FA05-72)

Although they did not view the purpose of assessment to yield information about their students' understanding, Mari, Judy, and Brian were curious about student learning. They relied on informal means to gather information about their students. For example,

they paid attention to student responses during a lecture. Brian relied on visual cues from his students during class to gauge whether or not they were "getting it." He valued this type of feedback from students, and used it to decide if the lecture was aimed too high or too low.

> "I get from looking at the eyes of the students in the classroom. I get an enormous amount of feedback from the students in class. And I think I manage, at least I try pretty hard to pay attention to whether students are with me and if they're not with me I try to figure out how to go back and scoop them up." I2B-FA06-48

The instructors also interpreted students' lack of participation in class or "glazed over" eyes as evidence that students were either bored or having difficulty understanding content in the lecture.

The instructors noted that the large-lecture format of the course made it difficult to interact directly with students during class. One-on-one interactions were limited to before or after class, office hours and discussion sections. Yet the instructors relied heavily on these interactions to learn about their students. For example, Mari valued discussion sections because they helped her identify the concepts with which students struggled. Many of these concepts Mari had assumed would be obvious to the students or easy to understand. Confronted by students' difficulties, Mari re-evaluated the assumptions she made about the basic level of students' knowledge in her course.

At the beginning of the study, Mari, Judy, and Brian relied on unplanned and informal methods for uncovering their students' understanding about biochemistry. Their extensive experience in teaching biochemistry afforded them a general idea of students' common conceptual stumbling blocks. But, due to the predominantly summative nature

of their assessment practices, the instructors were largely unaware of the range or extent of students' reasoning difficulties.

All three instructors grew to like the clicker technology in their teaching. Although none had any prior experience using the technology, they were interested in trying it because they had heard it helps students learn. Yet the underlying purpose for implementing clicker questions differed from instructor to instructor. For one instructor, the clicker questions were viewed as a way to break up the lecture, thereby maintaining student focus. For another, they were seen as an effective stimulus for discussion between students. And for yet another, they were used for the purpose of seeing whether or not students were "getting it". But all three instructors identified that, when constructed properly, clicker questions had the potential to tell them something about their students. Moreover, the nature of the clicker questions themselves changed throughout the study. Whereas questions were initially lower-level and often targeted declarative knowledge, the instructors soon began to experiment with more cognitively demanding questions. And although they were not required to pose clicker questions the second semester, they often did. Although not explicitly stated, the instructors came to believe that clicker questions could be used as a formative assessment strategy to uncover student understanding.

> "I mean I do try to ask them things and hope that the answers that I get back will be representative of maybe that ¾ of the class still didn't get it, but I think they [all] did because of the ¼ that are nodding and participating. But I think that the clicker questions have the potential of, if we use them a little bit more even, of letting us know that." I3J-FA05-24

> "I think for example just most recently the kinds of responses I've been getting on the clicker questions in kinetics sort of underscore what I was worried about from the conversations of last Thursday's discussion sections." I2B-FA05-243

Mari, Judy, and Brian also valued the reading questions. They increased student-instructor interactions (albeit asynchronously), yielded information about what and how students were thinking, and served as a student incentive for reading prior to class. Yet after experimenting with them for a semester, the reading questions were not valued as highly as clickers for formative assessment. It is interesting to note that clicker questions continue to be used by the instructors, while the reading questions were discontinued after one semester. Mari and Judy advocated this decision because they felt that grading and responding to the reading questions was too time consuming and therefore difficult. Despite being reminded that reading questions could be used to illuminate student difficulties, they focused on crafting responses to students rather than identifying reoccurring themes in the questions. The instructors had inadvertently turned the reading questions assignment into another opportunity to judge student learning, not to diagnose common problems and ways to alter instruction to address them.

In contrast, Brian noted the utility of reading questions in telling him about the students. He advocated that they be used again, although implemented differently. In addition to instructors learning about students, Brian believed that students could learn from each other through their questions. He envisioned multiple situations in which the reading questions could be utilized to stimulate greater interaction between students. One suggestion was to create an online learning environment where students could post and

respond to each other's questions. The instructors' role in the new system would be to read the students' posts and interject only when students got stuck. In this manner, instructors could learn about students' reasoning difficulties while simultaneously being freed of the responsibility of grading the quality of questions. Furthermore, the online environment would be student-driven, which Brian thought would be beneficial to the students.

Prior to experimenting with either of these assessment strategies, the three instructors seldom considered assessment as a tool to gather information about their students' thinking. Instead, they used assessment for the assignment of grades and to give students practice working biochemical problems. Through their experimentation with new assessment strategies such as clicker and reading questions, they expanded the ways in which they thought about assessment. Although they initially used clicker questions for purposes such as breaking up lecture or maintaining student focus, all three instructors grew to value them for their potential to reveal more about their students. Interestingly, although the reading questions assignment had similar potential, it was not uniformly thought to be fruitful for this purpose. Rather, the reading questions assignment was an assessment strategy used in alignment with their initial beliefs, most often as a way to judge student learning. Regardless of the limited perception of reading questions as a formative assessment tool, by the end of the study the instructors were actively using clicker questions to this end.

After experimenting with alternative assessment strategies, these instructors' thinking about the purposes of assessment broadened to include using assessment

formatively to gather data about students. Yet they seldom used these data to alter their teaching practice in the classroom. Moreover, the instructional decisions made by Mari, Judy, and Brian in response to these data were variable. For example, when there was a large discrepancy in the distribution of student responses to a clicker question, Brian might tell the students to "talk to their neighbor" for a few minutes about the question. He would then follow up by re-polling the class. On the other hand, Judy might simply ask for a volunteer to explain the logic behind the correct response. Or on some occasions, Mari would look at the varied distribution of student responses, talk generally about the problem, and move on to the next slide without making it clear to the students which answer was correct.

In general, the instructors used information gained through formative assessment to congratulate the students on arriving at the right answer, explain or have a student explain the correct answer, or instruct students to re-visit the topic on their own time. They rarely drew upon the new information about their students to alter the direction of the lecture. With the exception of a few minutes of student discussion about the clicker question posed, instructors generally followed the sequence of lecture notes as planned.

Occasionally the instructors used formative assessment data to inform the development of questions for more summative assessments such as problem sets, quizzes, and exams. These questions were not developed to create another mechanism for feedback for instructors and students. Instead, the purpose of these questions was either to give students more practice or to test their understanding, not to gather information for students and instructors to use for diagnosing student learning.

In summary, experimentation with assessment strategies resulted in the expansion of these instructors' thinking about assessment. More learner-centered teaching approaches often embed assessments in the teaching process. The information gathered can then be used to diagnose student learning and alter instruction to enhance student learning. Mari, Judy, and Brian's thinking about assessment did not grow to fully align with these learner-centered conceptions. Most notably, they did not consider using assessments as a way to gather information they could use to inform instructional decisions. Yet in some cases the assessment data were used in the revision of student tasks such as problem sets. This causes one to question how instructors' thinking about assessment develops and how it is related to teaching practice.

Finding #4: Interactions with a knowledgeable other may result in the creation of productive spaces for developing thoughts about teaching. This may be especially important in departments without well-developed teaching cultures.

Mari, Judy, and Brian were similar in that none of them had received formal training in how to teach. Furthermore, a well-developed culture of teaching within the department of biochemistry was absent. Faculty discussions about textbook selection, course objectives, and general teaching strategies were not uncommon. But discussions of appropriate pedagogies, assessment, or student learning were generally lacking. Consequently, there were limited opportunities within the department for these three instructors to develop their thinking about teaching. Interactions with a knowledgeable other, one well-acquainted with science education literature and alternative teaching

techniques, presented opportunities that had not previously existed. These opportunities created productive spaces in which the instructors could discuss, think about, and reflect on issues in teaching and learning.

Viewed as a specialist in science education, I was perceived by the instructors as a knowledgeable other. As such, I was frequently consulted for my opinion on all aspects of the instructors' teaching, both in person and via email. For example, I was sometimes asked whether or not I approved of something they were going to try in the classroom or on an assessment. At other times the instructors questioned me about how to improve aspects of their teaching. As a knowledgeable other, I was included in discussions as if I were an instructor myself. Especially during the second year of the study, I offered a combination of critical feedback, connections to the science education literature, and alternative teaching strategies. These interactions resulted in further discussion with and reflection by the instructors. On more than one occasion the instructors noted that these interactions were causing them to think about new aspects of their teaching. For example, in a discussion about end-of-semester course evaluations, Mari and Judy advocated that questions be added inquiring about the number of hours students dedicated to studying biochemistry. I asked them how they would use this information. Would they use it to inform their teaching? My questions instigated a discussion between Mary and Judy about the purpose of evaluations and how, if at all, evaluation results could be used to inform instruction.

Simply through participating in the study, Mari, Judy and Brian experienced new opportunities to discuss and reflect on their teaching. For example, participation in three

thirty-minute interviews with me amounted to a minimum of one and a half hours each semester formally dedicated to considerations of teaching and learning. Moreover, this time focused less on surficial aspects of teaching and learning, such as course logistics, and more on pedagogical issues. Often the ideas discussed in interviews were further considered in reflective journal entries or in informal conversations with me, the other instructors, or colleagues within the department.

For Brian, the questions posed in interviews and reflective journals caused him to reflect more on his own teaching. Although inherently reflective, Brian had not previously considered some of the questions posed to him in the interviews or reflective journals. In later conversations, it became apparent that Brian's thinking about these questions continued beyond the interviews or journaling events. For example, a series of interview questions were designed to uncover the ways in which instructors thought about formatively assessing student understanding. In that interview, Brian remarked that he had never considered how best to learn if students are "getting it" in class or not. He had difficulty describing a way to accomplish that. But Brian's thinking about the question did not stop with the end of the interview. The following semester, he expressed interest in capitalizing on instructional staff meetings as a venue for discussions about student learning. As a result, undergraduate tutors were encouraged to give weekly reports about student reasoning difficulties they encountered. And now, two years after the initial interview, Brian is still curious about how to uncover student understanding in class. Based on a suggestion elicited by Brian from the undergraduate tutors, he

implemented a new instructional strategy in class to collect questions from students that he uses to guide the direction of the lecture.

In a few of the interviews, the instructors were presented with scenarios that were developed from interviews with their students. After reading each scenario, they were asked to respond to a set of questions. The scenarios were designed to probe their thoughts about topics such as assessment, student learning, and student engagement. Responding to the scenarios provided another opportunity for instructors to think about teaching at a deeper level. For example, in her responses to a scenario about how to help students make connections between concepts in a course, Mari hypothesized about the nature of how people learn and brainstormed ways to alter her instruction to capitalize on her students' natural tendencies. The scenario created an opportunity for her to extend her thinking beyond how to lecture effectively to how to actively engage students in their learning.

When presented with the scenarios in her interviews, Judy described not only how she would respond, but also the thoughts that would inform her decisions. Descriptions of her decision-making process often included the solicitation of the opinions of the instructors with whom she was teaching. On more than one occasion she remarked that it would be interesting to have my opinion on the issues raised in the scenario. Her comment is illustrative of the value Judy places on being able to discuss teaching with others. Judy, more than Mari and Brian, sought others' opinions when making decisions about her teaching. She frequently caught people in the departmental hallways or sent e-mails to the instructional staff eliciting their ideas. For Judy, fruitful opportunities for

thinking and reflecting on teaching would likely include interactions with other faculty members.

In sum, interactions with a knowledgeable other resulted in the creation of productive spaces for thinking about teaching that did not previously exist. These spaces presented unique opportunities for these instructors to develop their thinking about teaching. From the perspective of the professional development of faculty, understanding the range of ways in which these spaces are created and sustained within a department will be a fruitful line of inquiry.

The purposes of this study were to describe the nature of "instructor thinking" for these biochemistry faculty, to characterize conditions for change in this thinking, and identify instances in which changes in thinking and altered practice were associated. In generally, these instructors' initial thinking about teaching could best be described as teacher-centered. However, there were a number of conditions which supported changes in their thinking along a continuum toward more learner-centered. The most notable of these were pedagogical dissatisfaction, experimentation with assessment strategies, and the creation of productive spaces for thinking about teaching. Although these conditions often fostered expanded thinking about teaching, in some cases it was still incomplete. Furthermore, changes in thinking were sometimes associated with only small changes in instructional practice.

DISCUSSION

Case Study Findings

The individual case studies report on a formal investigation of three biochemistry instructors which lasted for two years and followed their teaching for two full semesters. During that time, Mari, Judy and Brian experimented with a variety of new instructional and assessment strategies. Not surprisingly, their thoughts about teaching were initially very teacher-centered. Two years later, they demonstrated expanded thinking about teaching. In many cases, this expansion was small. And in other instances instructor thinking, although expanded, was not uniformly sophisticated (i.e. the instructors did not fully consider the multiple purposes of assessment). Finally, these expanded thoughts were not necessarily accompanied by revised classroom teaching practice. In other words, changes in thinking and practice happened slowly. If the paradigm in higher education really is changing from a focus on teaching to a focus on learning (Barr & Tagg, 1995, Huba & Freed, 2000), then it is important to understand the timescales over which it is reasonable to expect changes in faculty members' thinking and teaching practice.

These findings are particularly significant when considering funding opportunities provided to support science education reform at the undergraduate level. As demonstrated by Gess-Newsome et al. (2003), granting agencies can facilitate reform by reducing financial or institutional barriers. However, their model suggests that removal of these barriers is an insufficient condition for change. If changes in thinking and teaching practice occur slowly, over multiple years, perhaps funding should be provided

for more long-term faculty professional development efforts. In contrast, most funding opportunities only provide short-term, start-up funding. For example, the Arizona Board of Regents (ABOR) in conjunction with the National Center for Academic Transformation (NCAT) sponsored the Learner-Centered Education Course Redesign Initiative (LCE CRI), an initiative providing up to $50,000 for each three-year course redesign effort. The focus of the initiative is on improving student learning outcomes through course redesign and technology integration. It does provide support for the training or professional development of faculty in support of these changes. On the national scene, the National Science Foundation (NSF) sponsors the Course, Curriculum, and Laboratory Improvement (CCLI) program (http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5741), which "supports efforts to create new learning materials and teaching strategies, develop faculty expertise, implement educational innovations, assess learning and evaluate innovations, and conduct research on STEM teaching and learning." Three types of awards are funded: 1-3 year projects (up to $150,000/project), 2-4 year projects (up to $500,000/project), and 3-5 year projects ($2 million/project). If success of these projects is measured by the degree to which faculty demonstrate reformed teaching practice, they may falsely be determined ineffective if progress reports are provided after only two years.

The individual case studies of Mari, Judy, and Brian reveal many similarities between the instructors. Again, it is not surprising to find that these instructors, with exception to the single workshop on active learning attended by Mari, received no formal training in teaching. Their instructor thinking developed from their personal experiences

as students and through their "time in the trenches" as university teachers. This aligns with the findings of McAlpine et al. (2000) in their comparison of university instructors who had received formal pedagogical training versus those who had not. They found that instructors without formal training more frequently drew on personal experiences to construct knowledge about teaching. The experiences of Mari, Judy, and Brian experiences had been limited to lecture-style teaching. It seems reasonable to suggest that either (1) exposure to new teaching experiences and/or (2) access to formal professional development opportunities will be important for supporting university instructors in transitioning to the implementation of more learner-centered instructional strategies.

This study also employed cross-case analysis to provide interpretation across the individual case studies. A discussion of each of the four cross-case findings follows.

Pedagogical Dissatisfaction

Dissatisfaction was found to be a driver for change in thinking about teaching and, in some cases, teaching practice. These results are consistent with previous studies on teacher beliefs and practices suggesting that dissatisfaction plays a critical role in initiating and supporting changes in teaching practice (Feldman, 2000; Gess-Newsome et al. 2003). Gess-Newsome et al. (2003) argue that pedagogical dissatisfaction is required for changes in instructional practices to occur. The current results contribute to the literature because they bring to light instances in which instructor responses to dissatisfaction are variable, not only *between* individuals but also *within* an individual. It

is unclear what factors influence an instructor's response to the dissatisfaction. Perhaps there is a range of dissatisfaction which is acceptable to an instructor. This leads one to question what factors impact this range. At what point does dissatisfaction become unacceptable and lead to a change in thinking or practice? Characterizing what instructors pay attention to in situations of dissatisfaction will be important for understanding the conditions under which dissatisfaction serves as a driver for change in thinking.

Gess-Newsome et al. (2003) identified dissatisfaction as a fruitful entry point for the professional development of faculty in teaching. They postulated that this dissatisfaction may be internally motivated, through a long-term and personally recognized mismatch between beliefs and practice, or externally motivated, through an intervention or knowledgeable other. However, they failed to correlate motivations for dissatisfaction with subsequent instructor reactions. Are internally and externally motivated dissatisfaction equally useful entry points for professional development? Would an instructor be more responsive to internally motivated than to externally motivated dissatisfaction? Although not a specific focus of this research, these instructors were responsive to both types of dissatisfaction. But the data do not indicate whether the responses were equivalent or not. This raises further questions about the nature of pedagogical dissatisfaction in motivating changes in instructor thinking as well as subsequent practice. Clearly, further research is needed to better understand dissatisfaction as a potential entry point for professional development.

Evidence for Evaluating Teaching Effectiveness

In their descriptions of good teaching, Mari, Judy, and Brian focused on what good instructors do in the classroom. But they did not explicitly talk about the students of good instructors or about student learning. Independent of their descriptions of good teaching, the instructors would often talk about what students should be able to do at the end of the course. For example, as a result of taking the course they expected students to be able to explain experiments and findings to someone else after having attended a departmental seminar. But they would talk about student learning separate from their considerations of good teaching. If these instructors' definitions of good teaching were to include their ideas about student learning, would the nature of the evidence collected to evaluate good teaching be different? If in thinking about good teaching they also thought about clearly defined learning objectives, would they seek evidence of meeting those objectives?

Let's say, for example, that these instructors extended their description of good teaching beyond clever, well-organized, and content-rich lectures that foster engagement and excitement in students. What if good teaching also included the goal of encouraging students to seek and value alternative modes of investigation? What new evidence would these instructors look for as an indicator of effective teaching? Perhaps they would assign and collect student projects designed to showcase students' abilities to employ alternative modes of investigation. This type of evidence is in stark contrast to the traditional course evaluations that often focus on measuring student satisfaction instead of student learning.

It seems reasonable to propose that incorporating these instructors' well-established ideas about students and learning into their beliefs about what constitutes good teaching could lead to their consideration of a greater variety of evidence when evaluating teaching effectiveness. It is easier to design measures of clearly defined objectives. Consequently if instructors were to become more curious about student learning in evaluating their own teaching, it could result in more carefully crafted course objectives and agreement among instructors about what specifically students should be taking away from particular courses.

Each of the three instructors questioned end-of-semester evaluations as an adequate measure of teaching effectiveness. As department head, Brian's skepticism was related to his frustration with the evidence available to him for evaluating teaching in his department. He was limited to using only end-of-semester evaluation and peer evaluations to make inform promotion and tenure decisions. Although the end-of-semester evaluation is the department and university standard, as department head Brian could advocate for collection of additional evidence to evaluate teaching. But what other forms of evidence would seem reasonable to the department as a whole? What changes within the departmental culture would need to occur before other forms of evidence would be valued? Would good teaching need to be redefined at the department level? During the study, Brian presented a rough draft of a departmental teaching philosophy to share and discuss at the faculty retreat. One might imagine that discussions about something such as a teaching philosophy might also involve discussions about course goals, what constitutes effective teaching, and student learning. By allocating time

during faculty meetings, a department head can create ways for faculty to extend their thinking about evidence of good teaching and teaching effectiveness.

Experimentation with Alternative Assessment Strategies

Much of the literature into teacher cognition makes the assumption that revised teaching practice must be preceded by a change in teaching beliefs (Dall'Alba, 1991; Devine, 2006). In order for instructors to adopt formative assessment practices, they must first have beliefs about assessment that view it as a useful tool for student learning. In their investigation of science education reform in higher education, Gess-Newsome et al. (2003) suggest a cyclical relationship between beliefs and practice, where beliefs inform practice and vice versa. Kane et al. (2002) and Devlin (2006) point out that there have been only a few studies that empirically investigate the relationship between teacher beliefs and teaching practice, and fewer still that investigate the directionality of this relationship. Mary, Judy, and Brian's views of assessment changed *after* trying something new in the classroom. They initially conceived of assessment as a summative activity separate from the teaching process used to judge student learning and assign grades. After experimenting with alternative assessment strategies, they considered more formal ways to gather information about their students. Therefore, the relationship between beliefs and practice may not be unidirectional as previously proposed; change in beliefs may not necessarily precede changes in teaching. But then one might ask if these instructors would have permanently adopted clickers had they not developed their thinking about assessment. That is to say, had the instructors not come to view

assessment as useful for learning about their students, would they have continued to use formative assessment strategies after the study as they currently are? In which case, one might argue that a change in belief must precede changes in *sustained* practice.

Like the clicker questions, the reading questions had the potential to provide insights into students' reasoning about biochemistry. But the instructors chose not to use them as a formative assessment tool in subsequent semesters. Why did they choose one strategy over the other as a formative assessment tool? The reading questions did reveal student reasoning difficulties and misconceptions. Yet the instructors focused more on grading and responding to the questions than using them to diagnose student learning. These instructors initially had very teacher-centered ideas about the role of an instructor. They defined a good instructor as one who transmits information to students in a clear and organized manner. Perhaps their ideas about the role of an instructor prevented them from viewing the reading questions as anything more than an opportunity for transmitting content in the form of instructor-generated responses to student questions.

Alternatively, perhaps their thinking about assessment had not been revised in a manner fully consistent with assessment for student learning. The reading questions, unlike the clicker questions were assigned points. They were used to help make summative judgments about students' performance in the form of a final grade. Despite contributing to a very small portion of the grade, perhaps the simple fact that the reading questions would ultimately be used in a summative judgment impacted the instructors' decisions about what can serve as a formative assessment tool. Although there is no "one size fits all" assessment, a single assessment instrument can serve more than one purpose

(NRC, 2001). Perhaps instructors with fully-revised assessment thinking are those that can identify and employ assessments flexibly and for different purposes.

The literature investigating instructor thinking in higher education most commonly depicts growth in thinking as a progression from less sophisticated to more sophisticated ideas about teaching and learning (Kember, 1997, Kugel, 1993, Ramsden, 2003). In general, these less sophisticated ideas are characterized by a focus on the instructor and the transmission of information to students. More sophisticated ideas are those that focus on students and learning. The findings from this study suggest that assessment thinking may develop similarly. Initially, these instructors' thinking about assessment focused on the activities of the instructor. Assessment was used by the instructor to measure student progress; it was teacher-focused. However, as they experimented with formative assessment strategies, the instructors' thinking grew to consider assessment as a way to understand student learning. The focus was less on the instructor and more on the student. Fully-developed thinking consistent with assessment for learning would likely shift the focus even further toward the student. When used to its greatest capacity, formative assessment provides feedback for the students and the instructors to diagnose and promote learning. Based on the progression of these instructors' thinking, it seems reasonable to suggest that assessment thinking can be characterized as a continuum from less to more sophisticated conceptions.

Knowledgeable Other

Although opportunities for discussion and reflection had previously existed in the department, many only invited exploration of logistical aspects of teaching such as textbook selection and syllabus development, not teaching techniques or pedagogy. Interactions with a knowledgeable other created productive spaces in which the instructors discussed and thought about teaching. These spaces were often further expanded by the instructors as they personally reflected on aspects of their teaching. Reflection has been identified in the literature as an essential mechanism for making sense of experiences with and developing one's knowledge about teaching (Eley, 2006; McAlpine, 1999). It seems reasonable to propose, therefore, that increasing the number and quality of productive spaces for thinking and reflecting about teaching might drive changes in thinking, and might also be beneficial for the professional development of faculty.

How might such spaces be created within the context of an entire department? Those discussed above were instigated by a knowledgeable other, an individual inside the department with content knowledge of the discipline taught in addition to expertise in teaching and learning in science. This suggests that productive spaces can be created in which faculty members can develop their ideas about teaching even if a departmental culture for doing so does not exist. This leads to questions about the role of a knowledgeable other in professional development. Who can serve as a knowledgeable other? Would the results have been different if this role were played by someone outside

the department? Does a knowledgeable other need to have mastery of the content, or will expertise in teaching and learning issues suffice?

It is feasible that, within a department, faculty interested in issues of teaching and learning could construct their own productive spaces for discussing and reflecting, independent of the involvement of a knowledgeable other. A supportive department head could facilitate these interactions by establishing a committee for teaching and learning or creating a system for interested faculty to identify each other. Or a department head could elicit the assistance of campus resources for teaching, such as a university teaching center. In this instance the role of knowledgeable other would be served by an outside individual with expertise in teaching. Either way, these spaces might be utilized to foster a departmental culture of teaching.

Within the context of this particular department, the infrastructure might already exist for the creation of opportunities by the faculty members themselves. For example, this course, and many others in the department, is described as being "team-taught". The instructors met weekly and were present for each other's lectures. Yet they seldom gave feedback to each other about what was happening in the classroom. Occasionally a member of the team would remark on a typo in the lecture notes, offer suggestion on to how explain a figure more clearly, or recommend a real-world example to include in the following year's lecture. The instructors seldom engaged in active discussions about teaching and learning or in posing questions of each other about teaching. Although thought of as being members of a team of instructors, they functioned mostly independently. During weekly instructional staff meetings, they consulted each other

primarily for the purpose of developing assessments such as problem sets, quizzes, and exams. However, these instructors could alter the team dynamic to create productive spaces for thinking and reflecting about teaching. They could use a portion of their weekly meeting to discuss student learning issues uncovered in discussion section and office hours, propose new strategies for future lectures, and discuss the outcomes of trying new things in the classroom.

From the perspective of the professional development of university faculty, understanding the range of ways in which productive spaces are created and sustained within a department will be a fruitful line of inquiry. The findings from this study suggest that a knowledgeable other provides a personalized experience for instructors to develop their thinking.

IMPLICATIONS

In light of the literature on teaching in higher education, the findings from this study have implications for the professional development of university instructors as well as science education reform efforts at the undergraduate level.

Currently, the majority of professional development opportunities aimed at developing faculty thinking about teaching take the form of full- or half-day workshops. Research into the efficacy of such interventions is scarce (Emerson & Mosteller, 2000). Given that changes in thinking happen slowly, it seems reasonable to suggest that such short-term interventions would be unlikely to instigate significant changes in thinking about teaching because they fail to generate long-term opportunities for discussion and reflection. In contrast, it was demonstrated here that a knowledgeable other can create spaces for faculty to extend their thinking about teaching. Professional development efforts that utilize a knowledgeable other will create an environment in which faculty engage in ongoing discussions and reflection that builds on and challenges previous thinking. These types of interactions are essential for encouraging evolution of thought about teaching, and potentially teaching practice. The interactions between an instructor and a knowledgeable other are personal, stemming from the instructor's interests or concerns. Consequently, the instructor explores issues in which he or she is personally invested. In this manner the knowledgeable other best serves as a sounding board, a resource, and a guide to further the exploration. This creates a highly customized professional development experience for the faculty member. Moreover, such

experiences support instructors in a way that encourages deep, long-term reflection of personal approaches to teaching

This research contributes to a broader picture of faculty professional development in teaching, one in which productive spaces for the development of thinking about teaching are created and sustained over long periods of time. These productive spaces can be created within departments that lack a well-developed culture of teaching. Furthermore, results from this research suggest that productive spaces may provide the impetus for departmental discussions and changes that begin to support such a culture. For example, instructors involved in teaching teams could grow to serve the role of knowledgeable other for their colleagues. Or, as was the case with Brian, personal growth in thinking about teaching could be incorporated in larger-scale discussions at the departmental level.

Beyond professional development opportunities for university instructors, this research has implications for the training of *future* instructors. Despite a strong interest in teaching in academic-bound graduate students (Golde and Dore, 2001), opportunities for graduate students in science to learn about teaching and students are limited (Austin, 2001). Tanner & Allen (2006) report on recent efforts to integrate pedagogical training into graduate science programs with the purpose developing future science faculty as instructors. Given the findings reported here that instructor thinking develops slowly over time, it is imperative to provide opportunities for development early on. The demands on junior faculty are numerous in the pre-tenure years. Training future faculty

as instructors will help alleviate worries about teaching and possibly create more time for focusing on establishing a research program.

In conclusion, this research has significant implications for science education reform efforts as well as future research. National and state funding opportunities have been created with the goal of improving teaching and learning at the collegiate level. However, most provide only short-term, start up funding for projects. Given the time required for changes in instructor thinking to occur, these funding opportunities appear insufficient. Some of these reform efforts focus on the professional development of faculty in teaching. This research has implications for how to create personalized experiences for university science faculty that create productive spaces for professional development. Future research endeavors could extend from the findings of this research. In particular, more focused research into the relationships between teaching and practice and between teaching practice and student learning might serve to inform ways to develop instructor thinking. Perhaps the most important implication resulting from this research is that relating to faculty members' thinking about assessment. With current efforts focused on developing more learner-centered education at the undergraduate level, it seems reasonable to suggest further investigations in how to expand faculty thinking to align with learner-centered conceptions of purposes of assessment.

APPENDIX A

Human Subjects Protection Program
http://www.irb.arizona.edu

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11 August 2005

Erika Offerdahl, Ph.D. candidate
Advisor: Lisa Elfring, Ph.D.
Steward Observatory
933 Cherry Ave
P.O. Box 210065

RE: BSC B05.183 IMPLICATIONS OF LEARNER-CENTERED TEACHING STRATEGIES IN LARGE-LECTURE BIOCHEMISTRY COURSES

Dear Ms. Offerdahl:

We received your research proposal as cited above. The procedures to be followed in this study pose no more than minimal risk to participating subjects and have been reviewed by the Institutional Review Board (IRB) through an Expedited Review procedure as cited in the regulations issued by the U.S. Department of Health and Human Services [45 CFR Part 46.110(b)(1)] based on their inclusion under research categories 6 and 7. As this is not a treatment intervention study, the IRB has waived the statement of Alternative Treatments in the consent form as allowed by 45 CFR 46.116(d) and the need for signed informed consent has been waived for the surveys, as the research involves no risks or procedures for which consent is normally required outside of the research context as stated in 45 CFR 46.117(c)(2). Although full Committee review is not required, a brief summary of the project procedures is submitted to the Committee for their endorsement and/or comment, if any, after administrative approval is granted. This project is approved with an **expiration date of 11 August 2006.** Please make copies of the attached IRB stamped consent documents to consent your subjects.

The Human Subjects Committee (Institutional Review Board) of the University of Arizona has a current Federal Wide Assurance of compliance, number FWA00004218, which is on file with the Department of Health and Human Services and covers this activity.

Approval is granted with the understanding that no further changes or additions will be made either to the procedures followed or to the consent form(s) used (copies of which we have on file) without the knowledge and approval of the Human Subjects Committee and your College or Departmental Review Committee. Any research related physical or psychological harm to any subject must also be reported to each committee.

A university policy requires that all signed subject consent forms be kept in a permanent file in an area designated for that purpose by the Department Head or comparable authority. This will assure their accessibility in the event that university officials require the information and the principal investigator is unavailable for some reason.

Sincerely yours,

Theodore J Glattke, Ph.D.
Chair, Social and Behavioral Sciences Human Subjects Committee

TJG:pm

cc: Departmental/College Review Committee

REFERENCES

Åkerlind, G. S. (2003). Growing and developing as a university teacher – variation in meaning. *Studies in Higher Education, 28*(4), 375-390.

Åkerlind, G.S. (2007). Constraints on academics' potential for developing as a teacher. *Studies in Higher Education, 32*(1), 21-37.

Amundsen, C., Gryspeerdt, D., & Moxness, K. (1993) Practice-centred inquiry: Developing more effective teaching. *Review of Higher Education, 16*(3), 329-353.

Amundsen, C., Saroyan, A., & Frankman, M. (1996). Changing methods and metaphors: A case study of growth in university teaching. *Journal on Excellence in College Teaching, 7*(3), 3-42.

Austin, A. E. (2002). Preparing the next generation of faculty: Graduate school as socialization to the academic career. *The Journal of Higher Education, 73*(1), 94-122.

Barr, R. B., & Tagg, J. (1995). From teaching to learning: A new paradigm for undergraduate education. *Change, 27*(6), 13–25.

Berg, B. (2004). *Qualitative Research Methods for the Social Sciences, 5th Ed.* Boston, MA: Pearson Education, Inc.

Berman, J. & Skeff, K.M. (1988) Developing the motivation for improving university teaching. *Innovative Higher Education, 12*(2), 114-125.

Biggs, J. (1999). *Teaching for quality learning at university.* Buckingham, England: Open University Press.

Calderhead, J. (1996). Teachers: Beliefs and knowledge. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 709-725). New York: Macmillan.

Clark, C.M. & Petersom, P.L. (1986). Teachers' though processes. In Wittrock, M.C. (Ed), *Handbook of research on teaching* (pp. 255-296). New York: Macmillan.

Dall'Alba, G. (1991). Foreshadowing conceptions of teaching. Research and Development in Higher Education, 13, 293-297.

Devlin, M. (2006). Challenging accepted wisdom about the place of conceptions of teaching in university teaching improvement. *International Journal of Teaching and Learning in Higher Education, 18*(2), 112-119.

Eley, M.G. (2006). Teachers' conceptions of teaching, and the making of specific decisions in planning to teach. *Higher Education, 51*, 191-214.

Emerson, J.D., & Mosteller, F. (2000). Development programs for college faculty: Preparing for the twenty-first century. In R.M. Branch & M. A. Fitzgerald (Eds.) *Educational Media and Technology Yearbook: 2000 Volume 25,* (pp. 26-42). Englewood: Libraries Unlimited, Inc.

Entwistle, N., & Walker, P. (2000). Strategic alertness and expanded awareness within sophisticated conceptions of teaching. *Instructional Science, 28,* 335-361.

Fang, Z. (1996). A review of research on teacher beliefs and practices. *Educational Research, 38*(1), 47-64.

Feldman, A. (2000). Decision making in the practical domain: A model of practical conceptual change. *Science Education, 84*(5), 606-623.

Fernandez-Balboa, J. & Stiehl, J. (1995). The generic nature of pedagogical content knowledge among college professors. *Teaching and Teacher Education, 11*(3), 293-306.

Gess-Newsome, J., Southerland, S.A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. *American Educational Research Journal, 40*(3), 731-767.

Gibbs, G. & Coffey, M. (2004). The impact of training of university teachers on their teaching skills, their approach to teaching, and the approach to learning of their students. *Active Learning in Higher Education, 5*(1), 87-100.

Golde, C. M. & Dore, T. M. (2001). At cross purposes: What the experiences of doctoral students reveal about doctoral education, Philadelphia, PA: Pew Charitable Trusts. www.phd-survey.org (accessed December 30, 2007).

Gow, L. & Kember, D. (1993). Conceptions of teaching and their relationship to student learning. *British Journal of Educational Psychology, 63,* 20-33.

Guskey, T.R. (1986). Staff development and the process of teacher change. *Educational Researcher, 15*(5), 5-12.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S.M., & Wood, W.B. (2004). Scientific teaching. *Science, 304,* 521-522.

Hativa, N. (2000). Teacher thinking, beliefs, and knowledge in higher education: An introduction. *Instructional Science, 28*, 331-334.

Henderson, C. & Dancy, M. (2007, April). *Reform barriers for university faculty*. Paper presented at the American Educational Research Association Conference, Chicago, IL.

Henderson, H. & Rosenthal, A. (2006). Reaching questions: Encouraging students to read the text before coming to class. *Journal of College Science Teaching, (35)*7, 46-50.

Huba, M.E. & Freed, E.J. (2000). Learner-centered assessment on college campuses: Shifting the focus from teaching to learning. Needham Heights, MA: Allyn & Bacon

Kagan, D. M. (1990). Ways of evaluating teacher cognition: Inferences concerning the Goldilocks principle. *Review of Educational Research, 60*(3), 419-469.

Kagan, D.M. (1992). Implications of research on teacher belief. *Educational Psychologist, 27*(1), 65-90.

Kane, R., Sandretto, S., & Heath, C. (2002). Telling half the story: A critical review of research on the teaching beliefs and practices of university academics. *Review of Educational Research, 72*(2), 177-228.

Kane, R., Sandretto, S., & Heath, C. (2004). An investigation into excellent tertiary teaching: Emphasising reflective practice. *Higher Education, 47*, 283-310.

Kember, D. (1997). A reconceptualisation of the research into university academics' conceptions of teaching. *Learning and Instruction, 7*(3) 255-275.

Kember, D. & Gow, L. (1994). Orientations to teaching and their effect on the quality of student learning. *Journal of Higher Education, 65*, 58-74.

Kember, D. & Kwan, K. (2000). Lecturers' approaches to teaching and their relationship to conceptions of good teaching. *Instructional Science, 28,* 469-490.

King, K.P. & Lawler, P.A. (2003). Best practices in faculty professional development in North American higher education: Distinctions and dilemmas. *Journal of Faculty Development, 19*(1), 29-36.

Kugel, P. (1993). How professors develop. *Studies in Higher Education, 18*(3), 315-328.

Lam, B. & Kember, D. (2006). The relationships between conceptions of teaching and approaches to teaching, *Teachers and Teaching: Theory and Practice, 12*(6), 693-713.

Marshall, C., & Rossman, G.B. (2006). *Designing Qualitative Research, 4th Ed.* Thousand Oaks, CA: Sage Publications.

Martin, E. & Balla, M. (1991). Conceptions of teaching and implications for learning. *Research and development in higher education, 13*, 298-304.

McAlpine, L., Weston, C., Beauchamp, J., Wiseman, C., & Beauchamp, C. (1999). Building a metacognitive model of reflection. *Higher Education, 37*, 105-131.

McAlpine, L. & Weston, C. (2000). Reflection: Issues related to improving professors' teaching and students' learning. *Instructional Science, 28,* 363-385.

McAlpine, L., Weston, C., Berthiaume, D., Fairbank-Roch, G., & Owen, M. (2004). Reflection on teaching: Types and goals of reflection. *Educational Research and Evaluation, 10*(4-6), 337-363.

McAlpine, L., Weston, C., Timmermans, J., Berthiaume, D., & Fairbank-Roch, G. (2006). Zones: Reconceptualizing teacher thinking in relation to action. *Studies in Higher Education, 31*(5), 601-615.

Menges, R. J. & Austin, A.E. (2001). Teaching in higher education. In V. Richardson (Ed.), *Handbook of research on teaching, 4th Ed.* (pp 1122-1156). Washington, D.C.: American Educational Research Association.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook.* Beverly Hills, CA: Sage Publications.

Morse, J.M., Barrett, M., Mayan, M., Olson, K., & Spiers, J. (2002). Verification strategies for establishing reliability and validity in qualitative research. *International Journal of Qualitative Methods, 1*(2), 1-19.

Munby, H. Russell, T. and Martin, A.K. (2001). Teachers' knowledge and how it develops. In V. Richardson (Ed.), *Handbook of research on teaching, 4th Ed.* (pp 1122-1156). Washington, D.C.: American Educational Research Association.

National Research Council. (2000). *How people learn: Brain, mind, experience, and school, expanded edition.* Washington, D.C.: National Academy Press.

National Research Council (NRC). (2001). *Knowing what students know: The science and design of educational assessment.* Washington DC: National Academy Press.

National Research Council. (2003). *Evaluating and improving undergraduate teaching in science, technology, engineering, and mathematics.* Washington, D.C.: National Academy Press.

Norton, L., Richardson, J.T.E., Hartley, J., Newstead, S. & Mayes, J. (2005). Teachers' beliefs and intentions concerning teaching in higher education. *Higher Education, 50,* 537-571.

Pajares, M.F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*(3), 307-332.

Phillips, D. C. (Ed.) (2000). *Constructivism in education: Opinions and second opinions on controversial issues*, Chicago, IL: University of Chicago Press.

Piburn, M., Sawada, D., Falconer, K., Turley, J. Benford, R., Bloom, I. (2000). Reformed Teaching Observation Protocol (RTOP). ACEPT IN-003 (available at http://PhysicsEd.BuffaloState.Edu/AZTEC/rtop/RTOP_full/PDF)

Pickering, A.M. (2006). Learning about university teaching: Reflections on a research study investigating influences for change. *Teaching in Higher Education, 11*(3), 319-335.

Posner, G. J., Strike, K. A., Hewson, P. W. & Gertzog, W.A. (1982). Accommodation of a science conception: Toward a theory of conceptual change. *Science Education, 66,* 211-227.

Pratt, D.D. (1992). Conception of teaching. *Adult Education Quarterly*, *42*(4), 203-220.

Prosser, M., Trigwell, K., & Taylor, P. (1994). A phenomenographic study of academics' conceptions of science learning and teaching. *Learning and Instruction, 4,* 217-231.

Ramsden, P. (2003). *Learning to Teach in Higher Education, 2nd Ed.* London: Routledge.

Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of teacher education* (pp. 102-119). New York: Macmillan.

Samuelowicz, K. & Bain, J.D. (1992). Conceptions of teaching held by academic teachers. *Higher Education, 24,* 93-111.

Samuelowicz, K. & Bain, J.D. (2001). Revisiting academics' beliefs about teaching and learning. *Higher Education, 41,* 299-325.

Shavelson, R.J., & Stern, P. (1981). Research on teachers' pedagogical thoughts, judgments, decisions, and behavior. *Review of Educational Research, 51*(4), 455-498.

Sherman, T.M., Armistead, L.P., Fowler, F., Barksdale, M.A., & Reif, G. (1987). The quest for excellence in university teaching. *The Journal of Higher Education, 58*(1), 66-84.

Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Stake, R.E. (1995). The art of case study research. Thousand Oaks, CA: Sage Publications.

Stake, R.E. (2006). *Multiple case study analysis.* New York: Guilford Press.

Tanner, K. & Allen, D. (2006). Approaches to biology teaching and learning: On integrating pedagogical training into the graduate experiences of future science faculty. *Cell Biology Education, 5*, 1-6.

Taylor, S.J., & Bogdan, R. (1984). *Introduction to qualitative research methods: The search for meanings, 2nd Ed.* New York: John Wiley & Sons, Inc.

Trigwell, K., Prosser, M., & Taylor, P. (1994). Qualitative differences in approaches to teaching first year university science. *Higher Education, 27,* 75-84.

van Driel, J.H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching, 38*(2), 137-158.

Verloop, N., van Driel, J., & Meijer, P. (2001). Teacher knowledge and the knowledge base of teaching. *International Journal of Educational Research, 35,* 441-461.

Woodbury, S. & Gess-Newsome, J. (2002). Overcoming the paradox of change without difference: A model of change in the arena of fundamental school reform. *Educational Policy, 16*(5), 763-78

Yin, R.K. (1994). *Case study research: Design and methods, 2nd Ed.* Thousand Oaks, CA: Sage Publications.