The Effect of University Science Faculty Beliefs on Teaching Practices across Contexts

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Abstract

As a central component in efforts toward increasing student interest in scientific studies and careers, the milieu of university science teaching is an important current focus of study; teaching reform efforts that include the level of higher education are of key importance if secondary and elementary science teachers, products of the higher education system, are expected to implement such reforms in their own teaching. The goals of this research were to describe the extent to which university science instructors employ student-centered, inquiry-oriented teaching methods in their courses for undergraduates and in-service teachers, and investigate what factors impact their ability or willingness to implement such reforms in these differing contexts. We addressed these questions using a mixed methods approach which resulted in a multiple case study interpretive study. Patterns in the instructors' responses provided insight into individual attributes and institutional structures that are favorable and unfavorable toward effective science teaching at the higher education level.

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Introduction

In recent years, STEM (Science, Technology, Engineering, and Mathematics) education has come under serious scrutiny in terms of its ability to recruit and retain sufficient numbers of students in STEM fields of study. Since peaking in 1985, the number of engineering degrees awarded in the United States has decreased by 20 percent (Business Roundtable, 2005). Retention rates for science and engineering students from the moment they enter college to successful completion of their degree are approximately 25-30 percent (National Science Foundation, 2002). It is expected that by the year 2014, computer and mathematics occupations will add nearly one million jobs to the market (Hecker, 2004), but declining enrollments in the STEM fields of education are unlikely to fill this demand. In recent publications, influential organizations such as the National Science Foundation (2006), the Business Roundtable (2005), and Partnerships for 21st Century Learning (2004) have discussed strategies for reforming K-12 education and teacher preparation in order to reverse the negative STEM education enrollment trends. However, few of these recent publications have examined another important area for research and educational reform: the culture and practices of university science faculty and classrooms. As Fullan (2003) suggests, the kind of change or reform needed to address the complex issue of increasing numbers in the STEM pipeline requires the examination and organization of multiple levels of constituents. Thus, reform efforts that move beyond the jurisdiction and responsibility of K-12 education to include influences at the level of higher education merit serious consideration.

This study examines the extent to which university science faculty change their teaching practices due to participation in new teaching contexts and availability of professional development, and the structural and psychological barriers that preclude them from doing so. We followed university science faculty members as they participated in an NSF-funded Math Science Partnership (MSP) project designed to assist in-service secondary science teachers in developing a robust background in science content and pedagogy. Apart from the overarching project goals for teacher participants, there are additional goals for faculty who teach in the program in terms of improving teaching practice. First, through engagement with contemporary educational theory and discussion of the instructors' beliefs about teaching during regular faculty meetings, the Institute aims to bring about a research-based and reform-oriented change in how Institute courses are taught. A secondary program goal is to support and promote the use of the faculty's new pedagogical knowledge in their university undergraduate courses. Given the framework of these program goals, this study seeks to measure the faculty's use of student-centered and inquiry-oriented teaching practices in two teaching contexts, and to understand and categorize the types of beliefs the instructors hold that impact their willingness and ability to reform their teaching practices using available pedagogical knowledge.

Literature Review

Attracting and Retaining Students in STEM Fields

Previous research on recruitment and retention of students in STEM fields of study has identified several critical conditions, involving both pedagogical practices and institutional culture that influence the success of students in STEM education. Research has shown that more than one-third of college undergraduates who leave science and engineering cite poor teaching as

the predominant reason for leaving the field (Seymour & Hewitt, 1997). Students' self-perceptions and self-efficacy about ability and fit with the academic science culture have also been revealed as important predictors of academic and career success (Pajares, 1996; Zeldin & Pajares, 2000). Furthermore, factors found within the institutional culture of university science courses, including competition rather than collaboration (Anderson et al., 1999; Armstrong & Thompson, 2003; Busch-Vishniac & Jarosz, 2004; Zhao et al., 2005), lack of inclusive curriculum and teaching (Reddick et al., 2005; Rosser & Kelly, 1994), and the presence of gate-keeping or weeder courses (Busch-Vishniac & Jarosz, 2004), have seriously hampered efforts in recruitment and retention of students in STEM higher education. It is generally understood within the K-12 science education literature that teachers' personal and epistemological beliefs strongly impact pedagogical practices, curriculum development and delivery, and the construction of the educational culture (Brickhouse, 1990; Lederman, 1999; Pajares, 1992). It may be hypothesized then that concerns regarding recruitment and retention of students in STEM fields can in likewise be attributed to the teaching beliefs held by university STEM faculty.

This study is based on the following hypotheses: 1) the teaching styles or approaches used in higher education influence the interest and achievement level of students; and 2) when students are (or will become) teachers themselves, they tend to propagate the teaching styles or approaches that they experienced in their own coursework. Our hypotheses are empirically supported in part by a body of research arising from the NSF-funded Collaboratives for Excellence in Teacher Preparation. These studies give empirical support to the belief that university students who learn science in student-centered, inquiry-oriented courses have larger achievement gains than students in traditional classes (Falconer et al., 2001; Sawada et al., 2002). It appears, in fact, to matter how university instructors teach, particularly when working

with current or future teachers. In classes where instructors have an approach to teaching focused on student learning over content coverage, significant positive effects have been shown on student conceptual knowledge (Falconer et al., 2001) and in the students' own use of such an approach in their own teaching (Adamson et al., 2003). Given the link between learning-centered teaching and student achievement and teaching style, it becomes crucial to more clearly understand the reasons or factors that play into an instructors' adoption of such an approach.

University Faculty Beliefs and Practices

Previous work has provided some insight into the important role that university instructors' beliefs about teaching and learning have in defining their teaching practices. Kember and Kwan (2000) approached this question using a previously developed theoretical model where an instructor's approach to teaching is impacted by their conceptions of teaching as well as curriculum design, department and institutional pressures, and the nature of the students (Kember, 1997). In this model, however, contextual factors (i.e., institutional pressures and the nature of the students) were believed to have little or no impact on the instructor's conceptions of teaching. The study used interview transcripts to study 17 university lecturers' approaches to and conceptions of teaching. Based on ratings along six continua, the subjects were categorized as either content-centered or learning-centered in their approach to teaching. Then, using separate sections of the transcripts, they were then placed into one of four categories regarding their conceptions of good teaching: transmissive conceptions included teaching as passing information, and teaching as making it easier for students to understand, while facilitative conceptions included teaching as meeting students learning needs and as facilitating students to become independent learners. Not surprisingly, the researchers found that instructors' approaches to teaching and conceptions of teaching were very closely aligned (content-centered with

transmissive and learning-centered with facilitative); furthermore, they did not observe any significant changes in approach to teaching depending on context, even though they taught both traditional full-time undergraduates and part-time adult students. They concluded that approaches to teaching may be comprised of a preferred aspect (based on deep-seated beliefs about teaching) and a relational aspect, which allows adaptation of the preferred approach to the teaching context. However, they did not find evidence that the relational aspect could cause major shifts in an instructors' approach to teaching, which implies that teaching context was a relatively unimportant factor in these instructors' decisions about how to teach.

Martin *et al.* (2000) also investigated the links between instructors' intended and actual teaching practices and their conceptions of the "object of study," which could also be described as the intended purpose of instruction. Their categories for object of study included learning about a specific subject matter topic, learning about a subject as a whole, learning about how disciplinary knowledge was developed, learning a subject in relation to professional practice, and learning lifelong analytical skills. This study based its conclusions on a combination of interview and class observation evidence, analyzed qualitatively. However, it is not clear how they assigned instructors into categories of conception and approach. Furthermore, they did not constitute these categories of description independently of one another; therefore, it is not surprising that, like Kember, the authors found close correlation between object of study and approach to teaching. In a subsequent study, these findings were extended by relating instructors' understanding of the field of subject matter to their object of study and approach to teaching (Prosser *et al.*, 2005). The researchers found that instructors with an integrated and holistic understanding of the subject matter being taught also tended to teach in a more student-focused manner and to aim for more integrated student understanding. They concluded that efforts to

improve university teaching and learning must focus in part on helping instructors think about how what they are teaching "relates to and coheres with the field as a whole," and might require purposeful engagement in inquiry on their own teaching (Prosser *et al.*, 2005, pg 153). These recommendations point out the important metacognitive aspect of the teaching endeavor, and conceptually link instructors' content knowledge with their understanding of how to teach.

In contrast to the empirical connection developed in the previously mentioned research between instructors' conceptions of subject matter and teaching and their approaches to teaching, Murray and MacDonald (1997) reported the existence of a disconnect between conceptions of teaching and self-reported teaching practices. They divided conceptions of teaching into four categories: knowledge imparting, motivating, facilitating, or supporting students. Their model allowed for instructors to simultaneously hold more than one of these conceptions, and did not impose a hierarchical structure on these categories. In the context of a School of Business, open-ended survey responses were utilized to identify instructors' teaching methods and strategies, the reasons for their instructional choices, and their beliefs about assessment, instruction and student academic success. The authors argue that the participants' conceptions of teaching and their role as an instructor were not always congruent with the teaching methods or approaches they use. They hypothesize several possible reasons for this disconnect, which as been referred to as a 'mystery of higher education' since the 1970s (Marton & Saljo, 1984). Of particular relevance to our study, they discussed the impact that resource shortage or large class size could have on the ability of lecturers to teach according to their preferred model: 32 of 39 respondents to their survey reported that the number of students in a class affected the teaching methods utilized. From a more theoretical perspective, the authors also note that there is likely a distinction between espoused theory and theory-in-use. In light of this idea, one limitation of the study may

be that it depended on self-reported data regarding both beliefs and practice, in a way similar to the study by Kember and Kwan (2000) discussed above.

Addressing a specific type of science instructor beliefs in higher education, Brown et al. (2006) interviewed science faculty members regarding their beliefs about classroom inquiry and their teaching practices in laboratory-based courses. They found that the majority of instructors understood student inquiry as an open, unstructured process, and therefore inappropriate for introductory courses or those for non-majors. These beliefs were determined to be more influential in the instructors' approaches to teaching than other factors such as class size, facilities, or student knowledge or ability. This study points out the importance of instructor beliefs with regard to inquiry-oriented teaching, but again relies a single interview for data on both beliefs and practices.

Science Teacher Beliefs and Practices

While the above studies shed some light into the beliefs and practices of higher education faculty, much can be learned from the significant literature on science teaching beliefs and practices in other contexts. Using a case study approach, Kang and Wallace (2005) investigated the link between secondary science teachers' epistemological beliefs and their relation to the use of laboratory experiences in their teaching. Their findings indicated that a naive epistemology was associated with a transmissive approach to teaching wherein labs were utilized to verify previously presented concepts rather than facilitate students' construction of new knowledge. On the other hand, a sophisticated epistemology was not sufficient to ensure facilitative teaching; teachers' perceptions of the goals of instruction, student needs, and external curricular constraints also played a major role in determining teaching style. The role of perceived external constraints was also the focus of Tobin and McRobbie (1996), who used in-depth observation of a secondary

science classroom to develop four cultural myths that acted as constraints to reform: transmission of knowledge, efficiency, rigor, and exam preparation. They argue that these pervasive beliefs were reinforced by a positivist understanding of science on the part of the teacher, which was consistent with a transmissive approach to teaching. The cultural myths were also underpinned by a distribution of power in which the teacher, as the source of knowledge in the classroom, had control over the students' learning environment but was disempowered with regard to decisions about disciplinary content and assessment strategies. The links between beliefs and practice illustrated by Tobin and McRobbie are thus very much in line with several of those previously described (Kember & Kwan, 2000; Martin et al., 2000; Prosser et al., 2005). Their analysis goes further by examining the psychological reason for certain beliefs, by indicating that much of what teachers perceive as external constraint is at least in part self-imposed; "in common parlance a restraint is akin to an excuse" (Tobin & McRobbie, 1995, p. 226).

The research presented here seeks to link previous work on the beliefs of higher education faculty (both within and outside of science disciplines) with the body of both theoretical and empirical work in STEM fields at other levels of the educational system, and extend previous findings by identifying factors that influence both beliefs and practices of STEM instructors. We hope this study provides a link between the areas of research in higher education teaching and faculty development, and science teacher beliefs and practices. Cross-fertilization between these bodies of research would likely benefit both, given the interdependent nature of secondary and higher education. In contrast with much of the previous work in the area of higher education teacher beliefs and practices, however, we utilized classroom observation instead of self-reported description to measure classroom practice separately from the instructors' stated

beliefs. We believe this approach will allow for a more methodologically rigorous analysis of the areas of congruence and/or discrepancy between what instructors say and what they do.

Research Questions

This study seeks to address the following set of related questions:

1. To what extent do university science faculty utilize student-centered, inquiry-oriented teaching strategies in their teaching?
2. Do the teaching strategies utilized in science courses for undergraduates differ from those used in courses designed for practicing science teachers?
3. How do faculty beliefs about students, instructional setting, and teaching and learning impact their teaching practices in the two contexts (undergraduate vs. practicing teachers)?

To invoke instructor beliefs and examine their relationship to teaching practice, we must define the term "belief"; researchers have interpreted this construct in different ways, and used other terms with similar meanings (Pajares, 1992). Our working definition of instructor beliefs is congruent with that of Rokeach (1968), in that we conceptualize beliefs to include cognitive, affective, and behavioral components. That is, knowledge about a situation is a part of one's beliefs, as are emotions and behaviors surrounding that situation. In addition, we recognize that beliefs are abstract concepts that cannot be directly observed. In this study, instructors' beliefs about education are inferred from what they report in interviews, and compared against their observed teaching practices (which may also be an imperfect measurement of their "typical" approach to teaching). Our conception of instructor beliefs also draws on the notions of the

instructors' "conception of teaching" as referred to by Kember & Kwan (2000), as well as the "object of study" discussed by Martin *et al*. (2000).

The analysis presented here is based on an understanding of the imperfect relationship between theoretical constructs (instructor beliefs and general teaching practices) and observables (instructor statements and RTOP scores). These relationships are depicted in Figure 1. We propose that while there does exist a relationship between the theoretical constructs of teacher beliefs and teacher practice, we can only observe their proxies, and the relationship between these observables. It is important to realize that there is a difference between a planned or remembered lesson and the lesson as it was actually enacted, just as there is a difference between espoused beliefs (or theory) and beliefs-in-use (Marton & Saljo, 1984). Our conclusions were made with these sometimes subtle distinctions in mind.

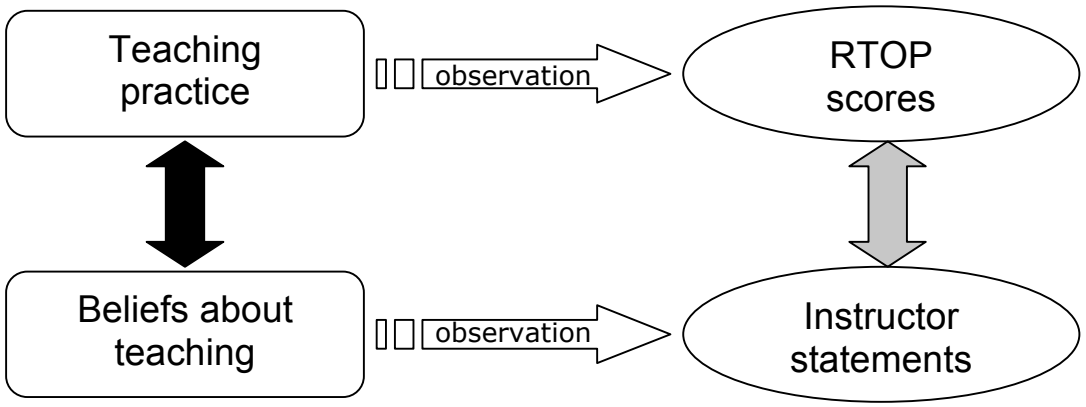

Figure 1. Relationships between practices (top row) and beliefs (bottom row), and theoretical constructs (rectangles) and observables (ovals)

Methodology

The Context

The project that serves as the context of this study is an NSF-funded Institute that offers two Masters degree-granting programs for in-service secondary science teachers. Both programs

span 26 months and include 10 courses, 8 of which are focused on science content and taught by University science faculty. Average class size for Institute courses is less than 20 students. The University itself is a private, highly-selective research institution located in the Eastern United States, and offers undergraduate majors in traditional science disciplines. The Institute draws its applicant pool from the population of in-service science teachers in the surrounding region, and does not have the same high level of entrance requirements as other science or education graduate programs at the University (e.g., applicants do not take the GRE and there is no minimum college GPA requirement).

Institute courses met either during an eight-week summer session, or once a month during the academic year. These courses were designed collaboratively by the Institute faculty and staff to address two of the goals of the Institute: 1) to increase science teachers' content knowledge, and 2) to model research-based pedagogical practices that are effective to improve science teaching and learning.

Study Participants

Institute science instructors included University professors (four active, one emeritus) and University lecturers (three). As part of their participation in the program, instructors attended monthly program faculty meetings during the academic year. The purposes for these meetings included review of student progress, sharing of course information, development of program components, and professional development around progressive pedagogical theories and practices. School of Education faculty also occasionally attended these meetings in order to support the pedagogical aspects of science faculty members' professional development.

Four of the Institute's seven active University science professors and lecturers were chosen as case study participants. The selection of these participants produced a sample that

represented a range of teaching strategies from very traditional to very student-centered, within both Institute and non-Institute teaching contexts. Selected participants (3 males and 1 female) were members of three science departments at the University. They included both tenured professors and non-tenure track staff members. Their length of service at the University ranged from 6 to nearly 40 years, and the length of their association with the Institute ranged from one to six years. All participants had attended at least one year of faculty development meetings prior to participating in this study. The participants are referred to by pseudonyms in this paper (Drs. A, B, C and D).

Data Sources and Analytical Techniques

The goals of this study were to investigate teacher beliefs and teaching practices independently of one another, and to understand the links between them. As discussed above, Institute instructors taught in both Institute and non-Institute undergraduate contexts. In order to investigate the extent to which student-centered, inquiry-oriented practices were used in all of their teaching experiences, we visited Institute and non-Institute classrooms. Teaching practice data were quantitatively evaluated using the Reformed Teaching Observation Protocol (RTOP, Piburn et al., 2000), described in more detail below. Analysis of faculty professional development meetings and individual interviews provided data regarding the participant instructors' beliefs that were likely to impact their teaching. A constant comparative method (Strauss & Corbin, 1990) was used to identify cross-cutting themes in these data sources, each related to a different category of belief that instructors brought to their teaching. The resulting themes then informed a multiple case study, which looked at the individual instructors in greater depth, and drew connections between inferences about teaching practice (drawn from RTOP

data) with inferences about beliefs (drawn from video and audio data sources). Each data source is described in more detail below.

Measurement of teaching practices using the Reformed Teaching Observation Protocol. Teaching practices were evaluated quantitatively using the Reformed Teaching Observation Protocol (RTOP). The RTOP instrument was developed for use in investigating teachers' approaches to teaching in mathematics and science classrooms, and can be generally described to value equitable and student-centered social construction of knowledge and represent an inquiry-oriented nature of science (Piburn et al., 2000). The type of science teaching valued by the RTOP instrument will be referred to generally as "reformed" throughout this paper, and is in contrast with more traditional, didactic and teacher-centered instruction. It has been validated for

Table 1
Summary of RTOP Instrument

Sub-scale name (abbreviation)	Items[a]
Lesson Design and Implementation (LDI)	1. Respects students' prior knowledge and preconceptions.
	2. Engages students in learning community.
	3. Student exploration precedes formal presentation.
	4. Values alternative modes of investigation or problem solving.
	5. Students determine focus of lesson.
Propositional Knowledge (PropK)	6. Lesson involves fundamental concepts of the subject.
	7. Lesson promotes strongly coherent conceptual understanding.
	8. Teacher has a solid grasp of subject matter.
	9. Elements of abstraction are encouraged.
	10. Explores and values connections with other disciplines and/or real world.
Procedural Knowledge (ProcK)	11. Students use various means to represent phenomena.
	12. Students make predictions or hypotheses, and devised means to test them.
	13. Thought-provoking activity involves critical assessment of procedures.
	14. Students are reflective about their learning.
	15. Values intellectual rigor, constructive criticism and challenging of ideas.

Communicative Interactions (Comm)	16. Students communicate ideas using a variety of means and media.
	17. Teacher questions trigger divergent thinking.
	18. High proportion of student talk, including between students.
	19. Student questions and comments determine focus of discourse.
	20. Teacher fosters climate of respect.
Student-Teacher Relationships (STR)	21. Active participation of students valued.
	22. Students generate alternative solutions and ways of interpreting evidence.
	23. Teacher is patient with students.
	24. Teacher is resource for student investigations.
	25. Teacher listens to students.

[a] Item descriptions are paraphrased from the original instrument.

evaluation of teaching in middle school, high school, and college classes (Sawada et al., 2002). The instrument contains 20 items divided into five sub-scales (Table 1), and each item is evaluated using a 0-4 point scale for a maximum score of 100. We have found that RTOP score is sensitive not only to the extent of the use of reformed teaching strategies, but also to the implementation quality of a specific teaching style. The program evaluators involved in use of the RTOP had been previously trained to use the RTOP instrument and had established an inter-rater reliability of 0.91 based on seven observations.

All Institute faculty members' classes were observed as a matter of course for the purposes of Institute program evaluation. The primary purpose of these observations was to determine the extent to which a key project goal was being met, i.e., modeling of progressive pedagogical practices by Institute instructors. Institute courses were observed multiple times (two to four visits) over the course of two sequential summers. A subset of these observed Institute classes were evaluated by two researchers independently (using video footage of the lesson), and both evaluator's scores were compared to ensure continuing inter-rater reliability

during the course of the study. Faculty were also observed while teaching their non-Institute undergraduate courses; in this context, two researchers attended a single meeting of each course and evaluated the class independently using the RTOP instrument. Results from non-Institute class observations are reported as averages of the two evaluators' scores. Statistical comparisons between the instructors' RTOP scores for Institute and non-Institute courses were made using paired t-tests.

Analysis of faculty meeting video. During the academic year over which this study was conducted, three faculty meetings from one of the Institute degree programs were videotaped and transcribed, providing one source of qualitative data. These meetings had been planned by one of the authors to involve discussion of important ideas related to reformed teaching, including the use of inquiry-oriented techniques and course design based on the attributes and needs of the student population. Two of the case study instructors attended these meetings, as well as a number of other instructors that were not part of this study.

The transcripts from these meetings were analyzed using a constant comparative method. Two evaluators independently identified sections of the transcripts that provided insight into the instructors' philosophies, beliefs about students and teaching, and reasons for their instructional choices. After combining the segments identified by each evaluator, the process of categorizing these statements in terms of the underlying issue began. Selected statements were coded collaboratively and iteratively using a grounded theory approach wherein quotations with relevance to the stated research questions were coded as themes emerged (Strauss & Corbin, 1990). The unit of analysis for the purposes of this study was defined to include as much of the instructor's transcript turn as needed to fully illustrate the point being made, and units sometimes also included questions or comments from other speakers, if needed to provide context. If an

instructor returned to a similar idea in later transcript turns, those subsequent statements were treated as separate units. As a result of this coding process, four themes emerged from the data; each theme spoke to a particular factor that was identified as something that impacted the teaching of the instructors. The themes are listed in Table 2, along with short descriptions and examples of types of statements that fell under each code.

Analysis of faculty interview audio. Each of the four case study participants were interviewed using a semi-structured interview protocol. The questions were designed to provide insights into the instructors' past teaching experiences, beliefs and philosophies of teaching and learning, and perceived problems and successes in their own teaching. For example, instructors were asked, “Can you describe your personal philosophy or theories about teaching and learning?” and, “Do your instructional choices depend on the level or type of student?” Each interview lasted approximately 45-60 minutes.

Table 2
Factors affecting Institute instructors' teaching practices

Category	Definition and example
Beliefs about student attributes	Instructor's statement describes or mentions attributes of his or her students, and uses these attributes to explain or rationalize teaching methods or instructional decisions. Example: "Since these students are working adults, I don't think I need to spend as much time motivating them to do their work as I do with undergraduates. If they weren't motivated, they wouldn't be here."
Beliefs about institutional factors	Instructor's statement describes aspects of the institutional context that impact teaching methods or instructional decisions. Example: "As an intro-level instructor, I'm really on my own. They give you a textbook and tell you when and where to show up for class, but I've never gotten any mentoring or help with how to be an effective teacher."

Category	Definition and example
Beliefs about teaching and learning	Instructor's statement describes their beliefs about knowledge, learning, and teaching Example: "I really think that the number one thing an instructor can do is keep students interested by being interactive and even maybe entertaining in his or her delivery of material."
Beliefs about personal characteristics	Instructor's statement describes their own personal characteristics and experiences, as pertaining to their teaching style or instruction-related decision making. Example: "It's hard for me to facilitate collaborative learning in my class because I am not a social person and work best alone."

Themes and codes emerging from these transcripts were identified by the two study researchers. For validity and reliability purposes, a coding manual was generated and tested by an external reviewer using a small data set (10 items). Minor changes were made to the manual based on feedback from this testing, and then used to train two additional raters. Three training sets were used (27 total items), and after each set was rated, the external raters discussed their coding with the researchers and suggested clarifications that could be made to the coding manual. Finally, the two researchers and the two trained raters independently coded 20% (40 of 200) of the total items which had been randomly selected from the total data set (excluding items that had already been discussed as part of the training sets). An interclass correlation test for four raters produced an alpha score of 0.70.

Quantitative Data

Classroom Evaluation

The average RTOP scores of Institute faculty members for both Institute and non-Institute classes are given in Table 3. Three major patterns emerged from these data. First, the average RTOP score for Institute courses was higher than for non-Institute courses ($d = 2.1$, $p = 0.011$, one-tailed). Second, there was a wide range in the RTOP scores for Institute courses, reflecting differing extents of the use of student-centered, inquiry-oriented teaching. Finally, instructors adjusted their non-Institute teaching practices according to the teaching context as well; two instructors (Drs. A and B) were observed teaching two different non-Institute courses, and their use of reformed teaching practices varied across these contexts. In general, higher RTOP scores were generated in teaching contexts for less technically advanced courses.

Table 3
RTOP Scores of Institute Faculty

	Average RTOP scores	
Instructor	Institute class (# observations)	Non-Institute classes (type)
Dr. A	77 (4)	23 (400 level) 40 (100 level)
Dr. B	47 (4)	19 (100 level) 34 (general studies)
Dr. C	52 (4)	35 (100 level)
Dr. D	56 (2)	46 (general studies)
Average	**57.8**	**32.7**

Note. For Institute classes, the average score is reported along with the number of observations. Non-Institute courses were observed once by two evaluators, whose scores were averaged.

The data from course observations can be broken down further into RTOP sub-scores. Table 4 shows average scores in each sub-scale for all instructors in Institute and non-Institute courses. There were large and statistically significant differences between Institute and non-Institute instruction in all sub-scales except for "Propositional Knowledge" (PropK), the category associated with delivery of content. These results will be discussed in more detail in the following case studies.

Semi-Quantitative Analysis of Instructor Belief Profiles

Instructors' statements regarding factors that impacted their teaching practices were coded according to the categories described in Table 2. For each instructor, the frequency of statements or items for each category were calculated as a percentage of their total number of coded items. The results of this frequency analysis are given in Table 5; frequency was taken as a rough indicator of the relative importance or emphasis the instructors placed on each category.

We noted that Dr. C's belief profile showed a relatively equal distribution among the four categories. Drs. A and D talked about their beliefs about teaching and learning more often than the other instructors, while Dr. B discussed institutional factors more often than the other instructors by a factor of two or more. Dr. A put very little emphasis on the influence of personal characteristics on teaching approach, while Dr. D did not weight institutional factors very heavily. These patterns will be referenced in the case studies that follow, in order to provide a general picture of the instructors' beliefs where possible.

Table 4

RTOP Sub-Scale Scores for Institute Faculty in Institute and Non-Institute Courses

	Dr. C			Dr. A					Dr. B					Dr. D			Average		
Sub-scale	Inst[a]	100-level	*t* (*DF*=3)	Inst	100-level	*t* (*DF*=3)	400-level	*t* (*DF*=3)	Inst	GS[b]	*t* (*DF*=3)	100-level	*t* (*DF*=3)	Inst	GS	*t* (*DF*=1)	Inst	Non-Inst	*t* (*DF*=8)
LDI	7.5	5.8	1.81	13.4	3.0	9.07**	2.0	9.95***	6.8	3.5	1.40	0.5	2.69	9.0	4.5	N/A	9.2	3.2	3.95*
PropK	17.9	18.0	0.16	16.8	18.0	1.35**	14.3	2.71***	15.8	16.5	1.19	14.0	2.78	15.0	17.0	2.00	16.5	16.3	0.07
ProcK	7.4	3.8	2.30	14.1	5.5	7.21**	2.3	9.92***	5.1	2.5	3.99*	1.5	5.51*	9.0	4.8	2.13	8.9	3.4	3.22*
Comm	9.9	3.3	3.24*	14.5	6.0	10.75**	2.5	15.18***	8.9	6.8	1.06	1.8	3.54*	12.0	10.3	1.75	11.2	5.1	3.25*
STR	9.0	4.7	3.18*	17.8	7.3	9.27**	1.5	14.41***	10.0	5.0	2.45	0.8	4.53*	10.5	9.3	0.48	12.0	4.7	3.06*
Total	51.7	35.6	2.75	76.6	39.8	8.72**	22.6	12.82***	46.6	34.3	1.69	18.6	3.87*	55.5	45.9	19.50*	57.8	32.7	3.34*

[a] Inst = Institute course average.
[b] GS = General studies course.
* $p < 0.05$. ** $p < 0.01$. *** $p < 0.005$.

Table 5
Frequency of Statement Category by Instructor

	Dr. A	Dr. B	Dr. C	Dr. D
Beliefs about student attributes	18%	15%	24%	24%
Beliefs about institutional factors	28%	46%	21%	7%
Beliefs about teaching and learning	48%	26%	38%	56%
Beliefs about personal characteristics	6%	13%	18%	12%

Participant Instructor Case Study Analysis

In this section, qualitative data obtained from faculty professional development meetings and individual interviews, as well as the frequency analysis presented in the above section, were used to develop a more in-depth understanding of the previously described patterns in RTOP scores. For each case, themes were identified in terms of factors described by the instructor that influenced their teaching and whether these factors were positive or negative influences on their ability or desire to enact reformed teaching approaches. Some comparisons between instructors are also included, although a more thorough multiple case analysis follows in a later section of the paper.

Dr. A Case Study

Dr. A is unique among the four case study instructors in several ways: this instructor had the highest average RTOP score for Institute courses, particularly on the sub-scales of "Lesson design and implementation" (LDI), "Procedural knowledge" (ProcK), and "Student-teacher relationships" (STR). Dr. A's strengths in these areas can be at least partially explained in light of the beliefs expressed in interview segments. We would argue that the LDI and ProcK sub-scales contain the items most central to true adoption of learning- and student-centered, inquiry

oriented science teaching. Therefore, repeated high RTOP scores in these areas should reflect a commitment to and deep understanding of the principles of reformed teaching. University teaching environments are not generally conducive to development of such understandings; constraints such as large class size and prioritization of research "work against the reform of undergraduate science education" (Brown et al., 2006, p. 785). However, Dr. A described how a departmental leader provided the opportunity to "experiment" with teaching reforms during a summer program:

> I was encouraged by the current chair at that time to, if I wanted, explore what might be done for teaching as something outside of the traditional mold. It was "If you're interested in it, and you want to put some intellectual effort into it, then, you know, you should come up with your own model for how to do it and see how it works… it did sort of spark in me the inspiration that we could use that one month in August [of a pre-freshman program] as a laboratory for teaching. So we could try different things there and then what we thought might be able to move into the regular semester would at least already have a pretrial, where we understand some things about the logistics and understand some things about how the students respond and we have a way of more or less explaining to your faculty what kind of experiments you want to do. (Dr. A, interview)

However, the impetus for learning more about science education research and innovative teaching practices came from within for Dr. A, although the departmental environment made it possible:

> We tried, I think, pretty much every permutation of the things that… were considered and are still considered best practices – so peer instruction, just-in-time teaching, an all-

> laboratory experience,… you know, pretty much every variation - working in groups, the whole thing…. [I learned about these ideas] mostly reading on my own. But, I mean, I did talk to people like [educational researchers in the discipline]. You know, I met with them, interviewed them, tried to find out what the pitfalls were, and of course, since all of their stuff is in the literature you can read about it beforehand and more or less try and reflect what you think the problems with applying it to a situation or environment like [the University] might be. (Dr. A, interview)

In addition to becoming acquainted with student-centered techniques such as those mentioned in the above quote, Dr. A's statements also gave evidence of internalization of some of the key understandings about student construction of knowledge. For example:

> So, without that personal experience [with individual students], you lose a lot of the "What have they internalized from what I've just done?" because most of it's right, but not all of it is.… When people are listening to you, what you think you're explaining quite clearly, explicitly, and correctly, they're not hearing in exactly that same way. So that, if you don't have any personal connection with them, you never get the reflection back except through the exams, which are very, very imperfect for determining what students are actually understanding and what they believe. (Dr. A, interview)

Dr. A's willingness and ability to reflect on and learn from each teaching experience also likely played a major role in the high RTOP scores reported here:

> [I was reminded] that of course we have to also be reflective on how we approach things. And so, if you really believe the philosophy that the best learning experiences only take place when both parties are learning, then we have to go back and rethink how we've done things…. So part of the change is just we have to evaluate how well we really think

> we are doing, and we can't do that if we continue to do the same things in the same ways, independent of the feedback that we've gotten. (Dr. A, interview)

Thus, aided by departmental support and the opportunity to experiment with and reflect on teaching, Dr. A developed a strong commitment to student-centered teaching over time, prior to becoming affiliated with the Institute.

Dr. A also exhibited the largest difference in teaching practices between Institute and non-Institute courses, which was accordingly pronounced in the LDI and ProcK sub-scale data. Although these two contexts are different in several ways, one of the most obvious is in the type of students involved. Dr. A pointed out that the goals of the two groups are different, and therefore the purpose of the knowledge they are attaining also differs:

> For the teachers, what you're really hoping is that they'll change their expectations for themselves and their students. So I don't really, I don't really think the content that we teach in [the Institute] is really as important as the experience of, "This is how you learn and [also] how your students learn. So all these things that you're telling them, that you can't imagine why it's so hard for them to get, you can now see personally yourself why it's so difficult."… I think at the beginning the [program] philosophy is really more about changing the way that you approach learning science and math, as opposed to "Here's the base that you build on." Whereas for the [undergraduate] students, they really do have to take this and have it be the foundation for the later courses. (Dr. A, interview)

The belief that introductory courses for undergraduate science majors play an important role in building a foundation for later learning (which straddles the "student attributes" and "teaching and learning" belief categories) explains in part Dr. A's reversion to a greater attention to content coverage and less use of student-centered approaches in introductory courses for undergraduates.

This is in contrast to his belief about the relative unimportance of any given piece of content knowledge for teachers in the Institute. In addition to this important philosophical reason for approaching the two groups of students differently, Dr. A also pointed out a practical reason for differing approaches to teaching in the two contexts:

> But, in point of fact… students like lectures because they have relatively low expectations on them.... They really feel as though they're being taught when you're explaining things to them and you're being humorous at the front of the classroom and trying to sort of pull them into answering questions.... So, for a number of reasons, the feedback the students give me is that the more of these active learning things I do, the less comfortable they are and the less they feel they've achieved by the end of the semester. (Dr. A, interview)

Clearly, student resistance to new modes of teaching and learning are an obstacle, although Dr. A did not appear to have given up completely in attempting to move in this direction in lower level courses, according to the RTOP evidence for Dr. A's three evaluated courses. The obstacle of student expectations was not specifically addressed with regard to the Institute course, but course evaluation responses from Dr. A's Institute students suggested that the Institute students prefer inquiry-oriented approaches to learning and are accepting of and enthusiastic about the student-centered, open-ended approach to the course syllabus.

Although these differences in Dr. A's beliefs about groups of students appear consistent with the large difference between Institute and non-Institute RTOP scores, Dr. A also discussed some relevant similarities among students that should be considered when formulating a model of the relationship between beliefs and teaching practices. While student expectations of an instructor may vary based on their prior experiences and beliefs about learning, what does not vary is the difficulty in trying to change those expectations:

> My overall experiences between... middle school and high school students… [and] college freshmen… is that it's very hard to change the expectation of the students, no matter how much the classroom changes. (Dr. A, interview)

Another similarity mentioned by Dr. A was the students' relationship to the content:

> I don't know that they [Institute and non-Institute students] are different. They share a lot of characteristics. The first happens to be... [that science]... is one of the subjects where people come into it and they feel, for whatever reason - it's very strange to me – that, "I'm behind. Everybody else is doing better than I am. They know the stuff, they had prior experience with it, they're ahead of me, and I can't catch up." And no matter how much you try and reassure them that that's not the case... they really feel as though they're at some big disadvantage. And that's something that it takes a while to overcome. So it's a constant struggle right at the beginning of a class to make sure that they stay enthusiastic enough to get past it. And that seems to be true for adults as it is for seventh graders as it is for college students - that a third of the class really feels lost. (Dr. A, interview)

This similarity between students helps to explain why Dr. A's introductory course rated higher than the 400-level course in the areas of "Communicative interactions" (Comm) and "Student-teacher relationships" (STR), although both scores were still lower than for the Institute course.

The overall picture we gained regarding Dr. A's teaching is one of a reflective practitioner who has a strong sense of agency to investigate and attempt teaching reforms. Dr. A is aware of but not totally subservient to the demands of the students; realizing that it is difficult to change student expectations, Dr. A still believes that active learning, rather than passive absorption of lectures, is the best way to develop scientific knowledge and reasoning skills. These attributes as a whole appear to help to explain Dr. A's success in implementing reformed

teaching practices in the Institute course, and to a much lesser extent in the introductory undergraduate courses.

Dr. B Case Study

Compared to the other case study instructors, Dr. B's Institute RTOP average was fairly low (Table 3). One pattern that emerged in Dr. B's statements in the interview and meetings was that many of the barriers he perceives to improving his teaching are situated externally. He appears to believe that forces outside of his control limit what he can achieve in his classroom. Accordingly, a very high percentage (46%) of this instructor's statements were coded as "beliefs about institutional practices and structures" (Table 5). One example of such a statement, that helps to explain Dr. B's low RTOP scores in the LDI category, follows:

> I don't really, in any [Institute] class, I've never really had much information about prior knowledge, what anybody knew coming in.… Because I don't think, in my case, I certainly don't know what they already know, or what they might not know. (Dr. B, interview)

This statement was made in the context of a discussion about RTOP item 1. While the intent of the item is that instructors seek out information about what knowledge and preconceptions students bring to the classroom, most commonly by using formative and pre-assessments to help design their instruction, Dr. B seems to believe that such information is unattainable unless presented from an outside source (such as a previous instructor), and that information presented by the instructor is transmitted directly into knowledge held by students.

In a similar vein, Dr. B discussed an area of the Institute course that was perceived as relatively ineffective, as a result of external problems beyond the instructor's control:

> And it's been kind of a frustrating experience because we are relying on stuff to work for us - working [field equipment] and that has been almost at least a partial failure almost every time we try to do it. And it's gotten to be really frustrating, because I don't think we have the equipment or the time during the summer to really really develop this into something that makes sense. (Dr. B, interview)

Dr. B made other similar statements about both Institute and non-Institute courses, effectively relinquishing agency to improve his students' learning conditions. Dr. B also reported feeling little departmental support for teaching reform and improvement. In a response to interview questions about previous training or professional development, and about the departmental teaching environment, Dr. B responded:

> Never had any... I had to figure out by myself and, so there really has been nothing. I've been given a book, and nowadays I get some CDs… it certainly wasn't a formal process in which somebody said, "OK, this is what we do and this is how, what we have, these are the resources available, these are the things we've got for demonstrations." [The instructors for the introductory course] don't even talk to each other for the most part, which is pretty bizarre... It's been kind of frustrating at times, because some of these things could work a lot better and a lot smoother *if there were some guidance* of some kind…. It's really hard [to improve one's teaching], especially in a place like this because there's no reward for it, at all.. Your students might like you if you're a good teacher, but that doesn't pay the rent. (Dr. B, interview, emphasis added)

When student attributes were mentioned by Dr. B, they were often perceived as externally imposed and uncontrollable limitations, rather than as parts of the teaching

environment that could be shaped by the instructor. For example, during a discussion about using group work in Institute courses, Dr. B said:

> It's definitely true… the class has a personality, there isn't any question about that. And in my experience, what you are able to do with that collective personality is really good some years and in other years it's not so good. And there have been times when I have just wondered exactly what we were going to accomplish… the community idea… is going to work if the students are willing. But if they can't, they just won't do it. (Dr. B, faculty meeting)

While student willingness to participate in group work is relevant to effective student-centered instruction, the intent of the corresponding RTOP items is that instructors will facilitate and scaffold the group learning process in order to improve student buy-in (Piburn et al., 2002). Dr. B, in contrast, reported feeling unable to influence the students' behavior, and simply conceded to pressures originating from the students.

On the other hand, through participation in the Institute, Dr. B reported developing some new understandings about teaching and learning. Dr. B described an approach to teaching the Institute course being based in the idea of teaching how to learn, rather than teaching a certain body of content:

> I've always told them [Institute students] that we can't teach them everything. But we can tell them, or try to teach them how to ask questions or what are the right questions or the right direction to go and ask. (Dr. B, faculty meeting)

Dr. B equated good teaching with instruction that is grounded in explaining real-world phenomena, and that involves facilitating student understanding of the representations of the discipline, such as commonly used graphs.

> [That unit] one of the better developed parts of the course. Because you can, there are visual things [graphical representations of data] that people can work toward understanding and then they have an application [from the real world] that is perfect. (Dr. B, interview)

Dr. B also reported that Institute meetings helped in developing a better understanding of student learning:

> So there are things that I learn from being in [the Institute] about what people are thinking, what they're experiences are, that I have a much better handle on than I do in any other course that I'm teaching, and I think it does have an effect on other courses in the undergraduate program, and that's especially true in [the general studies course] because that's also in a small group. (Dr. B, interview)

Interestingly, in the above quote, Dr. B claimed that some of the ideas learned through participation in the Institute have carried over into non-Institute courses, especially the general studies course which overlaps with the Institute course in both the content area and small class size. On the other hand, the 100-level introductory course had less in common with the Institute context, since it enrolled about five times as many students and covered different material.

Another perceived difference between the teaching contexts, which explains the higher level of feedback and interaction provided in the Institute course as evidenced by Comm and STR sub-scores, is referenced in the following quote:

> [Institute students] needed a different level of involvement than undergraduates usually get or are interested in. I think undergraduates here, you can for the most part give them an assignment and they just run off and do it. And they're quite good about that, most of them. Some struggle with it, some don't do it, but those numbers are pretty small among

> the undergraduates. In [the Institute], there's a different perception or a different need, and you can't rely quite so much on them taking off and just doing this stuff that you assign to them. (Dr. B, interview)

In contrast to Dr. A, Dr. B's statements as a whole describe an instructor who feels very little support from the department outside of the structure of the Institute. The lack of agency Dr. B feels with respect to improving the learning experience provided to students is likely linked to that disconnect with the department. However, Dr. B has clearly benefited from interactions with Institute faculty and staff, and is beginning to internalize some of the central ideas of reformed teaching. Unlike Dr. A, who came to the Institute with a well-developed identity as a teacher, Dr. A has acted more as a consumer of pedagogical knowledge from other Institute faculty and staff, rather than a contributor of knowledge, skills and strategies about teaching and learning.

Dr. C Case Study

Dr. C exhibited a much smaller difference in RTOP scores for Institute and non-Institute courses than Dr. A, and the highest RTOP score for an introductory undergraduate course of all the participants (including several Institute instructors not included in this study). We hypothesized that Dr. C's beliefs about students and teaching strongly influenced the approach taken to teaching in both contexts. However these beliefs were not entirely consonant with the description of reformed teaching embodied in the RTOP instrument. As previously mentioned, Dr. C's statements were the most evenly split (compared to the other instructors) between the four categories of beliefs described previously (Table 5); no one factor dominated Dr. C's thinking about how to teach, or why to teach in a certain way.

Like Dr. A, Dr. C developed and internalized over time a strong sense of what it means to be a good teacher:

> I've had a pretty clear idea of how I like to do things, in my style, which is very interactive… just in terms of quote a lecture, I never was back to the audience sort of lecturer.… A really engaging lecturer for whatever it takes to do that, there is a certain amount of, if not entertainment, at least… you need to engage people, otherwise they could go read the book on their own…. If you're saying something a little bit differently or in other way, not just spoon-feeding, I mean not just saying something again... (Dr. C, interview)

This description of Dr. C's teaching fits the "sage on the stage" mold that has traditionally been common in both secondary and higher education. This instructor feels a responsibility to clarify difficult concepts for students, to keep them interested, and to give them more than what the textbook presents. In contrast to Dr. A, Dr. C described an approach to teaching that is primarily transmissive in nature. However, the importance of information flowing back to the instructor during class was also mentioned:

> Even with a group of a hundred, I am fairly Socratic, I am interacting with individuals or pointing to someone asking them, moving on to some other individual. That's the style that attracted ME more when I was an undergraduate or a graduate, even big classes…. By interacting with people, you begin to figure out where they are understanding it and where they are not. This is only a couple of individuals, but you can get a sense if you're paying attention to the class, body language, it's very hard from the perspective up in front… what everyone is seeing, thinking, responding, or how to read those blank stares. Is it the "I'm bored" or the "I'm lost"? So you ask them, and you know after a while they'll begin to trust you enough to respond. (Dr. C, interview)

Dr. C's personal teaching style has been influenced to some extent by participation in the Institute, due to being exposed to new teaching methods, and discussing pedagogy as a group:

> I always at some level have viewed teaching as very important and had a pretty clear-cut idea of what I was doing and why, but this [Institute] course, this program exposed me to, well, certainly the possibility of using other methods besides more traditional lecture and Socratic… There were just enough discussions, roundtable discussions, seminar discussions that required exchange of views about how you do things, and occasionally just the ability to defend what I do. Not necessarily change it, but to at least put into words why I do things the way I do in response to comments or questions…. You cannot be unaffected by spending time thinking about your teaching. Even if you decide not to change something… by having thought about it, you've changed. It is good for you, you are at least aware there are other possibilities. (Dr. C, interview)

However, according to both the RTOP data and the instructor's own statements, these benefits appear to have made only a minor impact on Dr. C's teaching, even if they did result in some reconsideration of beliefs:

> I can't tell you, I honestly do not know, how much of my style has evolved because of doing [the Institute course]… I would imagine that I am even more, I've decided that I'm even more interactive in my, if you want, lecture style because probably of [the Institute], but I'm not sure... (Dr. C, interview)

Like Dr. A, Dr. C described several ways in which student attributes impact the approach taken to teaching in the two contexts. The undergraduates Dr. C frequently teaches are chemistry majors, for whom external constraints were identified that don't exist within the Institute:

> There is the factual information that a chemistry major in a good program is expected to know coming out. ACS has standards on these things… there is stuff that, a body of knowledge you expect majors to know when they get their Bachelors degree. There is also the issue that you are preparing them to some extent for other courses that they might take. (Dr. C, interview)

Additionally, as in Dr. B's case, larger class size in undergraduate courses was identified as a factor affecting instruction, although Dr. C was not explicit in how teaching was affected:

> I usually get to teach the [undergraduate] science majors [in the introductory course], which is a group of forty or so but is more than double the size of a typical [Institute] cohort, that does affect how you do things. (Dr. C, interview)

These differences, especially the decreased class size, might explain why Dr. C's teaching varied the most in ways reflected by the Comm and STR sub-scales of RTOP, that deal with interactions among students and between student and teacher.

One unique aspect of Dr. C's teaching in the Institute context was the high importance placed on understanding the Institute participants' role as teachers; Dr. C reported spending class time learning from them about secondary curriculum and teaching methods, and explicitly addressed the links between high school chemistry and more advanced understandings of chemical topics:

> I've always tried to be in tune with [what the Institute participants teach their own students]… it acts like a feedback. What do they understand, what's there context, what do they teach, what do they need to teach? Are we talking about having people understand things above the level which they teach it? But if you don't know the level at which they teach it how do you answer that question… So that [Institute course activity]

> was an attempt to consciously explore that aspect of what they where teaching and whether or not we had any impact on them. (Dr. C, interview)
>
> [Certain topics in high school] are taught in an algorithmic way, where there are rules and certain rules they're told not to violate... and we just try to open it up to, "Yes, this is a simplification. Not everything falls in categories, but these rules are still pretty good most of the time. Why is that?" (Dr. C, faculty meeting discussion)

In summary, Dr. C, had already developed an teaching style perceived (by the instructor and colleagues) to be interactive and engaging prior to becoming affiliated with the Institute. Therefore, it is not surprising that Dr. C's RTOP scores in both undergraduate and Institute teaching contexts are relatively high when compared to lecture-based classrooms, but still lower than expected for an student-centered, inquiry-oriented classroom. By way of possible explanation for Dr. C's unwillingness to make that leap into a new teaching style, we offer the following quote:

> "Is this more work for me?" I ask that question before I ask, "Is this good for the students?" I'm already doing a lot of good things for the students... I am willing to do more within reason but I am going to ask that question first: "Is this ultimately going to be more work for me or not?" (Dr. C, interview)

This statement seems to be an acknowledgment of the fact that student-centered teaching and reflective practice consume large amounts of time and energy that many professors at research universities, including perhaps Dr. C, are not willing to spend.

Dr. D Case Study

Much like Dr. C, Dr. D's RTOP scores were intermediate, and the approaches to teaching both Institute and non-Institute courses were quite similar. Only in the LDI sub-scale was there a

statistically significant difference between the two scores, and Dr. D's total score difference was the smallest of all four instructors. In part, this may be due to the fact that this instructor's non-Institute course was a general studies course with a similar class size, and assumed little to no background knowledge or plans for future study on the part of the students, like the Institute course. Dr. D's statements as a whole portrayed an instructor with a large body of experience, like other instructors, and in this case resulted in a fairly well-developed and stable teaching style that still has been influenced in minor ways by Institute participation.

Dr. D's statements illustrate beliefs about teaching and learning that have several traditional or non-reformed aspects. One such aspect that is central to Dr. D's approach to teaching the Institute course is the importance placed on content coverage, even higher than for non-Institute courses:

> So, for example, when I teach the non-majors [undergraduates] about [a certain topic], I'm not at all complete about the [all the details and examples possible], just the ones that we're going to actually talk about in the course… Whereas, for the [Institute] teachers, they basically *have to know* about all these different [details and examples].... I would say the bigger difference is that a significant part of the [upper division undergraduate] course depends on their input. And a lot of the emphasis is on analysis more than specific content…. [Institute teacher-participants] *DO need to know some basic [science] when they're finished*. (Dr. D, interview, emphasis added)

This emphasis on content coverage is associated with a teacher-centered, lecture-based approach to teaching, where the instructor serves as the source of well-organized and clearly explained knowledge, rather than as a facilitator of student exploration.

Dr. D's position as the source of knowledge was not due solely to beliefs about teaching, but also to the students' need for the certainty provided by that model of instruction. Dr. D described how it is hard to skip topics that students expect to cover because, "it makes them nervous if you don't mention them" (Dr. D, interview). Unlike Dr. A, who at least partially resisted the students' desires for teacher-centered instruction, Dr. D felt that an instructor must give students what they want, even in cases where their demands might be counter-productive to learning science authentically:

> [Dr. D]: The need [of the Institute students] for explicit, step-by-step [explanations], I just hadn't anticipated.
>
> [Interviewer]: Is that something that you think you have to work with, or something you want to try to change about them?
>
> [Dr. D]: You have to work with it, I think. (interview)

Dr. D's philosophy about motivating students could also be characterized as non-reformed:

> So, one of my principles, I guess, is that you have to… think about what will actually motivate [the students] to do what you want them to do…. An example is in a seminar course it's really crucial that they have done the reading before class so you can actually have an informed discussion. So, in a seminar course I did pop quizzes that aren't a huge amount of credit but they have a certain amount of credit assigned that, you know, motivates them to do the reading. And it's really fascinating to me how few points you need to actually motivate the behavior! (Dr. D, interview)

The underlying theory about the nature of learning that this statement implies is based on a behaviorist model of extrinsic motivation, and could be considered incompatible with the

learning-centered notion of the teacher guiding students to develop their own intrinsic motivation based on interest and confidence. When the reward for the "desired" behavior (here, reading in order to pass a quiz) is tied to a proxy for learning, rather than learning itself, students are unlikely to ever move past a shallow performance expectation.

Considering the largely traditional nature of Dr. D's teaching described above, RTOP scores (Table 3) were relatively high. In some ways, Dr. D held understandings of teaching and learning that *were* consonant with the philosophy of student-centered, inquiry-oriented teaching and had been gained through experience and reflection. Dr. D placed a high degree of importance on student engagement during class, and had sought out ways to address this issue in classes of various sizes:

> I've found it easier to keep students engaged in classes that serve 25 and smaller, because… you can be more interactive…. About 15 years ago I was having trouble keeping the interest in the really big lecture, and that's when I sort of tried a lot of things that didn't work that well…. And finally… I came across the ConcepQuestion idea. And that was a way to bring some of the dynamic of the smaller class into the larger class. (Dr. D, interview)

The ConcepQuestion teaching method, also mentioned and used by Dr. A, is an example of peer instruction and was developed by Mazur (1997). This technique requires all students to respond to questions and provide formative feedback to the instructor about the level of understanding in the class. This strategy, then, supports both active student learning and formative assessment practices in a lecture-based course; it was used by Dr. D in both Institute and non-Institute classes, but in the Institute classes, the discussion that followed the question was centered on clarifying the concept for students who had answered incorrectly, while in the non-Institute class,

Dr. D acknowledged the students who had answered correctly, and then moved on. This strategy, while meeting the stated goal of increasing student involvement in the lecture in both contexts, was therefore used to greater effect in the Institute course, where it also served as a means of pre-assessment and informed the flow of the lecture and discussion. The technique also supported development of the class as a learning community where knowledge was developed and clarified by the group instead of only by the instructor.

In addition to beliefs and practices developed over the course of a long teaching career (prior to becoming involved with the Institute), Dr. D described having been affected by the Institute in two ways. As already mentioned, Dr. D chose to work with a co-instructor who had expertise in middle-school teaching and knowledge of educational theory and reform efforts. Dr. D described how this collaboration had resulted in a greater understanding of student learning:

> At the end of [a certain] lecture that I gave, I could see that they weren't asking questions. So then I was going even faster. And when I got home, I knew they hadn't understood it. You know, it wasn't like I'd all of the sudden become so clear that they could grasp everything instantaneously! And so I sent out this email saying, "OK, we're going to redo this lecture, don't worry about it until next week." And that was partly helped by [my co-instructor's] remarks. So, [my co-instructor has] already helped to communicate some of the difficulties that some of them were having…. My goal will be to make sure the less knowledgeable students will also get a good grasp of the basics. (Dr. D, interview)

Here, Dr. D describes a growing understanding that coverage of content by the teacher does not directly translate into student learning, and credits the course co-instructor for helping to reach that understanding by bridging the gap between students and instructors. This may be an

important next step leading to a further evolution away from a behaviorist and content-centered approach to teaching.

Another way in which Dr. D credited the Institute with supporting an improvement in teaching was a direct outcome of a faculty meeting activity. Instructors were asked to develop and discuss "Enduring Understandings" (Wiggins & McTighe, 1998) for their course, which would set out their key conceptual student learning goals. Dr. D identified this exercise as useful for both the Institute and non-Institute courses:

> I have to admit, I was a big grumbler about having to develop the Enduring Understandings. And actually, I think they've been a really good part of our [science] course, and this year… they'll be even a bigger part, because I really thing that's very helpful. And… that's one thing I've a little bit brought into the non-majors courses - not much, but a little bit. (Dr. D, interview)

In fact, when asked for an opinion about the faculty meetings as professional development, the Enduring Understandings exercise was the only thing mentioned by Dr. D as useful. In general, Dr. D felt that personal experience and independent investigations into teaching strategies had been most beneficial, and there was little need for organized faculty development offerings:

> I don't find them [faculty meetings] all that useful…. In my own case, I've sought out a lot of input, and as I've said I've been teaching for nearly 40 years so, [but] I understand that maybe other people's needs are different. (Dr. D, interview)

To summarize, Dr. D provides another example of an accomplished instructor whose beliefs and practices have been shaped by a large body of prior experience, and also impacted in some ways by the interactions and support provided by the Institute. Although Dr. D understands the value of active student participation and formative assessment, it appears that like Dr. C, Dr.

D has not yet made the philosophical shift to a truly facilitative and reformed teaching practice. We posit that, in the absence of such a shift in fundamental beliefs, the maximum authentic student learning attainable (and, as a result, the maximum attainable RTOP score) is limited.

Multiple Case Analysis

The cases presented above represent four instructors with a range of personalities, beliefs and experiences; this section will illuminate commonalities and important differences between instructors, in terms of beliefs and the practices that are supported by those beliefs. Our analysis was aided by our ability to examine teaching and beliefs around two very different teaching contexts (undergraduate University teaching and in-service teacher professional development through the Institute).

In comparing the two instructors with the highest (Dr. A) and lowest (Dr. B) RTOP scores for their Institute courses, we noted that both internal and external factors were relevant to the differences between them. Dr. A, as the highest scoring instructor, expressed views on teaching and learning that were nearly all congruent with the reforms espoused by the RTOP instrument and the Institute mission; furthermore, Dr. A felt supported by the department in terms of both resources and philosophy. In contrast, the correspondence between Dr. B's beliefs and RTOP was not as complete, and there was no perception of similar departmental support for teaching improvement. The other two instructors, Dr. C and Dr. D, whose RTOP scores were intermediate, did not put much emphasis on institutional or departmental support as either a supporting or limiting factor in their development as teachers. Both also expressed beliefs about teaching and learning that were at least in part conflicting with the beliefs encoded by the RTOP instrument. From these observations, we conclude that reformed teaching requires an instructor

to have internalized the importance of student-centered, equitable, inquiry-oriented teaching, AND to have developed a sense of agency with regard to their teaching practice.

All four instructors described differences between Institute students (adult practicing teachers) and non-Institute students (full-time undergraduates). However, looking at differences between Institute and non-Institute RTOP scores, we noted that the two instructors with the largest score differences (Dr. A and to a lesser extent Dr. B) described student differences, and their responses to these differences, differently than the two instructors with smaller RTOP score differences (Dr. C and Dr. D). Both Dr. A and Dr. B described how their approach to teaching was adapted for the Institute context in order to best align with important learning goals of the Institute: appreciation of the process of science and development of lifelong learning skills and habits. On the other hand, many of Dr. C's comments about student differences centered on a deficit model view based on the perceived academic ability of the Institute participants compared with a typical University undergraduate. These contrasts did not appear to directly affect Dr. C's conscious approach to teaching. In Dr. D's case, the major difference described between student groups was based on a conception of teaching that requires possession of as much content knowledge as possible. This did have a direct and consciously mediated affect on Dr. D's approach to teaching, resulting in a more detailed treatment of topics, but not in a manner that would be reflected in RTOP scores. In fact, the spirit of this "adaptation" is contrary to that of the RTOP instrument, which rewards depth of student understanding over breadth of topics covered.

Finally, in analyzing the instructors' stated views on faculty meetings, we noted that there are two different roles instructors play with respect to these opportunities for professional development. Instructors can act as contributors or producers of professional knowledge to the

community of Institute faculty and staff; they can also act as users or consumers of this community knowledge. Of course, instructors do both interchangeably, but to different extents. We found that more experienced faculty members tended to describe the usefulness of faculty meetings more in terms of being able to share their ideas and experiences with one another, while the less experienced faculty members put more emphasis on what they took away from the meetings. This pattern was also supported by evaluators' observations regarding participation in faculty meetings, including who talked most often and who played a more passive role.

Discussion and Conclusions

Our findings largely support those from previous work: in most cases, instructors practices were correlated with and explained by their stated beliefs. The instructor with the highest RTOP score also described the most consistently student-centered and inquiry oriented conceptions of teaching and learning, and the instructor with the lowest RTOP score expressed confusion and unfamiliarity with several key concepts of reformed teaching. However, we also found that contextual factors (including changing course goals, institutional support and student attributes) were also important in determining how instructors taught, and that courses taught in different contexts resulted significantly different teaching styles or approaches (as measured by RTOP score). This context dependence did vary by instructor, however. We explain our results using a model in which an instructor draws on a different subset of beliefs depending on the context, rather than modifying or replacing beliefs when context changes. In this model, an instructor might simultaneously hold contradictory beliefs about teaching or learning, based on which course or group of students was being considered. This is in contrast to the model put

forward by Kember and Kwan (2000), in which instructors have a preferred approach to teaching based on deep-seated beliefs about teaching that can be tweaked by changing context.

This study also gives support to and extend the findings of Kang and Wallace (2005) beyond the realm of secondary teaching. We noted that while an instructor's sophisticated conception of teaching and learning, congruent with the science teaching reform ideals, is necessary to allow effective reformed teaching, this is not a sufficient condition. External factors such as student preparation, institutional culture, and lack of curricular reform at the disciplinary level also were identified by instructors as constraining their ability to enact reforms.

The results presented here have implications for the types of faculty development and systems reform needed in order to fully realize the goals of the science teaching reform movement. For instructors who have been unable or unwilling to successfully implement suggested reforms thus far, their individual beliefs about teaching and learning in their discipline must be addressed through discussion and collaborative practice, including work with experienced teacher-participants. In such situations, improved teaching practices will not result by simply informing instructors of reformed strategies, because the instructors' beliefs about teaching and learning are incongruent with these reforms. Through co-teaching or other collaborative, reflective practice, however, instructors would be asked to make explicit their teaching and learning models, reflect on their usefulness, defend their thinking, and resolve any areas of dissonance. "Making the unconscious conscious" would act as a crucial step in purposeful reform of teaching practices.

For other instructors, whose personal beliefs and models of teaching and learning already provide a foundation for reform of teaching practice, the institution, science disciplinary structure, or the larger educational system may still constrain the success of such reform. When

such contextual factors impact what is possible in a university classroom, institutional and instructor change must happen in concert to improve educational outcomes. This requires that greater communication between stakeholders – university administration, K-12 teachers and curriculum reformers, teacher educators, industry leaders, politicians, etc. – must be facilitated to reach a common understanding of the purpose of science teaching reform and the strategies proposed to enact such reform. Indeed, the arrival at such common understanding between secondary and higher science education is crucial in order to move current science education reform efforts beyond spotty local success. Only a coherent system that shares a common vision of successful science teaching and learning will allow us to break the perpetual cycle of didactic, content-centered science teaching, by enabling university science instructors to train current and future secondary teachers in ways congruent to how they are expected to train their own students.

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