UNIVERSITY OF CALIFORNIA,
IRVINE

Documenting Instructional Practices in Large Introductory STEM Lecture Courses

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Education

by

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Dissertation Committee:
Professor Mark Warschauer, Chair
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2017

DEDICATION

To

My mother and father, Thao and Thanh Vu

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

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The road to a doctorate degree is not done alone. It can only be achieved with help, patience, and sacrifice by loved ones; guidance and knowledge from mentors; and support from the school and granting organizations. I would like to acknowledge a few individuals who have made this journey possible. I will forever be grateful for what everyone has done.

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ABSTRACT OF THE DISSERTATION

Documenting Instructional Practices in Large Introductory STEM Lecture Courses

By

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Doctor of Philosophy in Education

University of California, Irvine, 2017

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STEM education reform in higher education is framed around the need to improve student learning outcomes, increase student retention, and increase the number of underrepresented minorities and female students in STEM fields, all of which would ultimately contribute to America's competitiveness and prosperity. To achieve these goals, education reformers call for an increase in the adoption of research-based "promising practices" in classrooms. Despite efforts to increase the adoption of more promising practices in classrooms, postsecondary instructors are still likely to lecture and use traditional teaching approaches. To shed light on this adoption dilemma, a mix-methods study was conducted. First, instructional practices in large introductory STEM courses were identified, followed by an analysis of factors that inhibit or contribute to the use of promising practices. Data were obtained from classroom observations (N = 259) of large gateway courses across STEM departments and from instructor interviews (N = 67). Results show that instructors are already aware of promising practices and that change strategies could move from focusing on the development and dissemination of promising practices to focusing on improving adoption rates. Teaching-track instructors such as lecturers

with potential for security of employment (LPSOE) and lecturers with security of employment (LSOE) have adopted promising practices more than other instructors. Interview data show that LPSOEs are also effective at disseminating promising practices to their peers, but opinion leaders (influential faculty in a department) are necessary to promote adoption of promising practices by higher ranking instructors. However, hiring more LPSOEs or opinion leaders will not be enough to shift instructional practices. Variations in the adoption of promising practices by instructors and across departments show that any reform strategy needs to be systematic and take into consideration how information is shared through communication channels, the adoption decision-making process by potential adopters, and the contextual barriers and drivers of adoption. Additionally, the strategy should be designed with multiple stages, with each stage given time for changes to have an effect. Taking a one-size fits all approach to STEM education reform will not work and may only perpetuate the cycle of non-adoption and continued use of teacher-centered instructional practices.

CHAPTER 1: INTRODUCTION AND BACKGROUND

Stephen Hawkings recently portended the end of mankind, but added that we could still save ourselves through increased science literacy (Matyszczyk, 2016). Although not in such dramatic terms, former President Obama also called for additional science, technology, engineering, and math (STEM) education to solve other world issues such as climate change, hunger, diseases, and the need for clean energy (The White House, 2009). These calls for science education are not responses to recent phenomena. Rather, they highlight the ongoing importance of STEM education in our lives. In fact, STEM education has been an important issue in American education for many years, especially after Russia launched Sputnik in 1957 and challenged America's dominance in science and technology (Arons, 1983; Dwyer, 1972). The National Science Foundation (NSF) has supported STEM education by directing over $20 billion dollars toward education improvements since the 1950s (NSF, n.d.). Additional evidence of America's attention to STEM education can be seen in the many reports that appear regularly and repeat the call for education reform. Some of these major reports include the President's Council of Advisors on Science and Technology (PCAST) "Engage to Excel" report (PCAST, 2012), the National Science Foundation/American Association for the Advancement of Science Vision and Change report (AAAS, 2011), and the National Research Council Discipline-Based Education Research report (Singer, Nielsen, & Schweingruber, 2012). They call for improving student learning outcomes, student retention, and the representation of underrepresented minorities and female students in STEM fields. In fact, the PCAST (2012) report suggests that America needs an additional one million STEM professionals on top of the current number over the next decade. Currently, American universities graduate 300,000 bachelor and associate degrees in STEM disciplines. To reach the goal outlined in the PCAST report, universities must graduate an additional 100,000 STEM students each year, an increase of 33% over the current rates (Lacey & Wright, 2009). Realistically, this challenge may be difficult to overcome. Some scholars like David E. Goldberg, an emeritus engineering professor at the University of Illinois at Urbana-Champaign, described the chances of reaching this goal as “essentially nil” (Drew, 2011). Historically, only 17% of college graduates receive their degrees in STEM. Among all nations, America is ranked 20th in the proportion of 24-year-olds with STEM degrees (Kuenzi, 2008). Unfortunately, the conditions that have contributed to low numbers of STEM graduates persist with no sign of abatement. For example, students still lack interest in obtaining STEM degrees (Chen, 2013; PCAST, 2010; Lacey & Wright, 2009). When students enter college with an initial interest in pursuing a STEM degree, they promptly switch out (Chang, Cerna, Han, & Saenz, 2008; Denson & Hill, 2010). Students switch out of STEM majors for many reasons. Although some common assumptions paint “switchers” as those students who lack the skills to overcome adversities in the STEM disciplines, studies have found that those who switch and those who persist are very similar on many measures of skill, motivation, and study-related behavior (Lowel, Salzman, Bernstein, & Henderson, 2009; Seymour & Hewitt, 1997). Interestingly, prior research finds that the major catalyst for switching majors is not the personal or the intrinsic attributes of the students, but their negative experiences with poor instructor quality and student weed-out practices such as grade curving which limits student success (Chen, 2013; PCAST, 2010; Seymour & Hewitt, 1997).

In a comprehensive study, Seymour and Hewitt (1997) found that among those who switched out of a STEM major, the top two factors cited by the students for their switching decisions were related to teaching quality, with poor teaching quality as the third most cited factor (36%). However, more alarming is the percentage of the switchers (90%) and the percentage of non-switchers (74%) who cited poor teaching quality as a concern. Students describe the teaching quality as formulaic and too focused on content knowledge rather than critical thinking or the hands-on skills that are representative of a career in science (NRC, 2001; Wood, 2003).

With such high attrition rates in STEM gateway courses, it is abundantly clear that reversing the trend requires political action and funding. One approach outlined in the PCAST report is to encourage postsecondary instructors to use instructional approaches grounded in research on human cognition (Bransford, Brown, & Cocking, 1999) and research-based instructional practices (Chickering & Gamson, 1987; Ewell, 1996; NRC, 2011; 2012). As a whole, these promising practices (PPs) are more student-centered and involve inquiry-based learning (Handelsman, Ebert-May, Beichner, Bruns, Chang, & DeHaan, 2004).

In two reports issued by the NRC (2011; 2012), eleven researched-based instructional practices were identified as "promising," with the potential to improve student learning outcomes (e.g., grades, engagement, motivation) and to achieve the national goal of increased student retention. Of these eleven practices, four pertain to instruction in the classroom and can be observed for research. Together with other change initiatives, it is believed that the increased use of PPs in post-secondary classrooms will contribute to the goal of STEM education reform.

Statement of the Problem

Despite the multitude of educational measurement instruments and techniques available to researchers (AAAS, 2013), the billions of dollars that have been spent to develop and disseminate PPs (Dancy & Henderson, 2010), or the tremendous amount of human effort exerted to change classrooms (e.g., SCALE-UP; NRC, 2011), actual adoption of PPs by instructors has fallen short of the expected transformational goals (Dancy & Henderson, 2010; Fairweather, 2008; NRC, 2011; 2012).

This lack of adoption of PPs has led education reformers to argue that the strategy of transforming education through development and dissemination has been ineffective. Fairweather (2008) concluded that “the problem in STEM education lies less in not knowing what works and more in getting people to use proven techniques” (p.28). Along with other education reformers, he proposed that national change efforts should shift from the traditional approach of development and dissemination to an approach that first investigates ways to improve educational transformation (Fairweather, 2008; Henderson, Beach, & Finkelstein, 2011).

Purpose of this Study

The first step to increase adoption rates of PPs is to understand instructional practices in “the wild” (Fairweather, 2008), as the decision to use them or not intersects with instructor beliefs, situational factors (e.g., class size, the physical space of lecture halls), and institutional policies or incentives for adoption. However, after many decades of STEM education reform, little is known about *how* or *why* research-based instructional strategies get implemented in the classroom (Henderson et al., 2011; NRC, 2011; 2012). This is highlighted in a study of teaching practices by Ebert-May (2000). She found that only 25% of the variance in teaching strategies could be explained by barriers such as class size or instructor experience. Without a clear understanding of the levers that influence pedagogic decisions, Ebert-May called for more research to “better understand why teaching varies” (NRC, 2011, p. 58). In fact, the findings of DBER report (NRC, 2012) also stress the need for more thorough and robust documentation of teaching practices. The report also highlighted several initiatives that could move STEM adoption goals forward. One of the steps was to create a baseline of instructional practices with more resolving power and accuracy than teacher self-reports. As with any change strategy, establishing a baseline is essential in understanding the diffusion of innovative strategies and in substantiating any claims about change (Rogers, 2003; Smith, Vinson, Smith, Lewin, & Stetzer, 2014). Heeding the call in the DBER report (NRC, 2011), this current study seeks (1) to document PPs from a broad array of instructors across STEM disciplines, and (2) to examine the factors that inhibit or promote the adoption of PPs.

Research Questions

Three research questions guided this study:

1. How prominent and widespread are so called "promising" instructional practices?
2. How do instructional practices differ across instructors (type of appointment, gender) and departments?
3. Within individual instructors and across the departments and the university, what inhibits or contributes to the adoption of particular instructional practices and diffusion of new approaches to instruction?

Significance of the Study

This current study addressed two weaknesses of prior studies that have attempted to document instructional practices. First, this current study examined instructional practices across all STEM disciplines. Although STEM instructional practices have been documented in previous studies, much of this work has been done at the classroom or departmental level (Dancy & Henderson, 2010). The assumption behind these studies is that teaching variation is discipline specific. However, Fairweather (2008) presented evidence to suggest this assumption is inaccurate, and that discipline specific reforms are "reinventing the wheel."

Without a systematic and thorough observation of a broad array of STEM courses, it is not possible to know the extent to which instructors are using PPs. Therefore, in this current study, I conducted a descriptive analysis of instructional practices of introductory courses across STEM disciplines. A second limitation of current research addressed in this study is that of self-report data. Because the study includes objective measurement of multiple STEM disciplines, it should provide insights into variations by discipline and instructor characteristics.

Limitations

Although a meticulous approach was employed in documenting instructional practices and the factors that promote and inhibit these practices in large STEM courses, there are some limitations to this research. We only observed two classes for each course. Although the syllabus was incorporated, it does not provide a complete picture of all the instructional practices used by STEM instructors. In this current study, we observed gateway courses with high enrollments. The study design assumed that they were very similar in regards to the number of students and the physical layout of the classroom (e.g., desks were bolted down). However, courses varied in the number of students enrolled within a range of 100-400 students. This variation in the number of enrolled students could impact the instructional practices observed and reported.

Study Background

Data from this current study is derived from a larger NSF funded study titled *Documenting Instructional Practices in STEM Lecture Courses*.

Since much attrition in STEM courses occurs early in undergraduate education (Chen, 2013; Seymour & Hewitt, 1997), it makes sense that efforts at improving student retention and increasing the number of STEM graduates focus on gateway courses (NRC, 2001; 2011). Gateway courses are large, introductory-level courses that provide students with foundational skills and knowledge for upper-level coursework. Due to the high enrollment of these courses, the main form of instruction is usually teacher-centered with limited opportunities for student-to-student or student-to-instructor interaction (Tobias, 2000). Although gateway courses are efficient at delivering content to a large audience (Biggs, 1999), the curriculum and pedagogy potentially act as "gatekeepers," discouraging many from continuing with a career in STEM (Labov, 2004; Seymour & Hewitt, 1997).

The pilot year started in Fall 2012. The research team developed pre/post surveys, a teaching assistant survey, and an instructor interview protocol. After human subject approval was obtained through the university Institutional Review Board, instructors were recruited and data were collected. Initial observations were conducted of nine gateway courses using the *UTeach Observation Protocol* (UTOP; Walkington, Arora, Ihorn, Gordon, Walker, & Abraham, 2012). However, since the research team could not use this observation protocol to adequately measure instruction in large-enrollment course and to obtain high inter-rater reliability, a new protocol (described in Chapter 3) was created. Data from the nine pilot courses were later recoded using video recordings of the original observations and the new observation protocol. Additional adjustments were made to the surveys and interview protocol during Summer 2013.

Following the pilot study, in Year 1, data from course observations, surveys, and instructor interviews were collected in Fall 2013 and Winter 2014. Spring 2014 was used to conduct data analysis. Improvements made to the study design and the observation protocol were continuous and ongoing with feedback from course instructors.

In Year 2 of the study, course observations were conducted throughout the 2014-2015 academic year. However, course instructors were not interviewed due to resource limitations. In addition, surveys of TAs and students were discontinued because their use limited instructor recruitment and they were not considered an essential measure of instructional practices in gateway courses.

In Year 3 of the study, instructor interviews were resumed with additional staff support. Instructors for Year 2 of the study were contacted. Those instructors who consented were subsequently interviewed. This current study examines only observation and interview data from Years 1 and 2.

CHAPTER 2: LITERATURE REVIEW

Evidence shows that the percentage of instructors who lecture in their classrooms has remained stable, despite ample data demonstrating the relative efficacy of alternative teaching methods for improving student learning and retention (Hurtado, Eagan, Pryor, Wang, & Tran, 2012). To help understand why more effective instructional practices are not widely adopted by instructors, the present study aims to document instructional practices in large-enrollment STEM university courses and examines factors that contribute to or prevent the adoption of PPs (Fairweather, 2008; Henderson & Dancy, 2007; Hora, Oleson, & Ferrare, 2013). This literature review is organized according to the sections listed below:

- Definition of PPs
- Documenting Undergraduate Teaching Practices
- Barriers to Reform
- Change Strategies
- Diffusion of Innovation

This approach to organization clarifies the meaning of pedagogy that is considered "promising" and reviews the literature on the documentation of instructional practices, barriers, and dissemination strategies related to PPs. The last two sections argue for a theoretical perspective to study the adoption of PPs as part of a decision-making process that is situated in a social system.

Definition of "Promising Practices"

The adoption of PPs by university instructors is one of the cornerstones of STEM education reform. The NRC (2011) report identified 11 PPs; four of these are within the purview of the instructor in the *classroom*. I define these four PPs in the next section.

Teaching epistemology and metacognition. The NRC (2011) report considers teaching epistemology explicitly and coherently to be a promising instructional practice that has positive ramifications for students. Reimer, Schenke, Nguyen, O'Dowd, Domina, and Warschauer (2016) define epistemology "as understanding the concepts, separating fact from opinion, and critical analysis of concepts" (p. 5). Under the umbrella of this approach, instructors could model problem-solving techniques by "thinking aloud" or making explicit the thinking process of an expert as he or she solves a problem. Sadler (NRC, 2011) found that students who had prior experiences in solving quantitative problems and analyzing data were more likely to be successful in college science courses.

In addition to teaching epistemology explicitly, teaching epistemology coherently has been shown to benefit students (e.g., Ewell, 1996). Instructional strategies that fall into this category include making connections across course topics to provide a broad understanding of the course and making connections between course topics and everyday experiences such as STEM in the news (Ewell & Jones, 1996; Froyd, 2008).

Concomitant with epistemology is metacognitive instruction. The DBER Report (NRC, 2011) defined metacognition as the "mind's ability to monitor and control its own activities," (p. 153). Instructional practices that encourage metacognition help students think about what they know (NRC, 2011). Instructor actions that illustrate metacognitive instruction include explicitly explaining their rationale for learner-centered pedagogy, defining learning objectives, or using class time to demonstrate problem-solving strategies to students.

Formative assessments. The NRC (2011) report suggested that instructors use formative assessments to shape their instructional practices. Formative assessments provide data that are used for pedagogic improvement rather than evaluation (Froyd, 2008) and contrast with summative assessments (i.e., midterms, finals) that are graded and impact students' grades. Common formative assessments include student responses during question-driven instruction (Beatty, Gerace, Leonard, & Dufresne, 2006) which can be done orally or through student response systems such as iClickers (Reimer et al., 2015), or from quickly written in-class reflection essays (i.e., minute paper; Beatty et al., 2005). Instructors can use student responses in these activities as a measure of student understanding and can correct any misconceptions through feedback or modification of course instruction. The allure of this instructional practice is its ease of implementation and its efficacy at improving student learning (Black & William, 1998; NRC, 2001). When combined with peer-instruction (Crouch & Mazur, 2001), a type of activity where students work with each other to clarify concepts, formative assessments have been shown to have many positive influences on student performance.

Active learning. A growing body of empirical research on how people learn has consistently demonstrated that student learning is enhanced when instructors use practices that promote student engagement through active learning (e.g., Prince, 2004). Active learning instruction is usually contrasted with lecturing (Handelsman et al., 2004) and defined as instruction that "engages students in the process of learning through activities and/or discussions in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work" (Freeman, Eddy, McDonough, Smith, Okoroafor, & Jordt, 2014, p. 8410). The simplest form of active learning instruction can take place when instructors pause during lecture to allow students opportunities to participate or contribute to the learning process (Michael, 2007; Prince, 2004). The activity can be as simple as asking students to clarify their notes with a partner through "think-pair-share" (Mazur, 2009), and it can be as basic as asking students to reflect on their learning by writing "minute papers" (Chizmar & Ostrosky, 1998). The activity can be more elaborate, with several students working collaboratively through project-based learning (Michael & Modell, 2003).

Active learning instruction can also involve the use of technology, such as student response systems (i.e., iClickers; Reimer et al., 2015). With iClickers, students can immediately demonstrate their level of understanding (Caldwell, 2007). These systems have been demonstrated to increase student attentiveness, alertness, attendance, and engagement, as well as decrease course attrition (Caldwell, 2007). Reimer et al. (2015) confirmed that iClickers were beneficial for all students in large introductory courses, but were most beneficial for female students.

In a comprehensive meta-analysis (N = 225) of STEM courses in higher education, evidence overwhelmingly supported the use of active learning instruction over traditional lecture-based instruction (Freeman et al., 2014). It was found that active learning had an average effect size of .47 for test scores and was effective across disciplines, for large and small class sizes, for majors and non-majors, and for introductory and upper-division courses. Amazingly, it exceeded an effect size of .4 for all classroom-based educational interventions (Springer, Stane, & Donovan, 1999) and .39 for K-12 educational interventions (Lipsey & Wilson, 2001). In addition to the impact on student performance, Freeman et al. (2014) found that the raw average failure rate of 34% under traditional lecturing decreased to 22% under active learning.

Collaboration. Theories of learning (Bransford, 1999) and research on group learning (e.g., Terenzini, Cabrera, Colbeck, Parente, & Bjorklund, 2001) as well as meta-analyses (Springer et al., 1999), support the use of group learning activities during class and outside the classroom in learning communities (Chickering & Gamson, 1987; Froyd & Ohland, 2005). For example, Springer et al. (1999) found that collaborative learning improved academic achievement and improved the quality of students' interpersonal interactions, self-esteem, perceptions of social support, attitudes about school, and retention in academic programs. Additionally, when integrated with problem-based learning, the effect size of group learning (d = .54) was greater than that of individual learning (d = .23) for academic achievement measures (Springer et al., 1999). Ewell and Jones (1996) also suggested that group learning enhances communication and problem-solving skills necessary for participation in the modern workforce.

Groups can be formed spontaneously in the classroom or the grouping can be more structured and assigned by the instructor (Froyd, 2008). The many instantiations of group learning include peer instruction (Mazur, 2009) or peer-led team learning such as group projects.

Although students might lack the skills to work in groups (Algert & Froyd, 2003) and the physical arrangements of classrooms in large introductory STEM courses might pose challenges to creating group learning opportunities, studies suggest that these barriers can be overcome (Henderson & Dancy, 2007).

Documenting Undergraduate Teaching Practices

As with any plan for education reform, having good information is essential in understanding the impact of change efforts (AAAS, 2013). The AAAS supports the use of surveys, observations, and interviews as important measurement techniques to better understand teaching practices. These measurement techniques serve a valuable function in research and provide much detail into undergraduate STEM teaching practices (AAAS, 2013; Berk, 2005). In the section below, I describe three instruments (i.e., surveys, observations, interviews) used to measure and describe undergraduate teaching practices, and I will discuss prior studies that have used these instruments to document teaching practices.

Surveys. Surveys can provide an easy method to learn about teaching practices from large numbers of faculty who might be spread across large distances or departments. Although surveys are an efficient way of obtaining information from many participants, evidence suggests that self-evaluations might be biased because of low response rates (Brawner, Felder, & Allen, 2001) and the tendency of participants to provide responses that they believe are favorable rather than responses that accurately reflect their beliefs (Berk, 2005; Ebert-May, Derting, Hodder, Momsen, Long, & Jardeleza, 2011).

Despite some weaknesses with surveys, they are commonly used to obtain information about teaching practices. For example, Brawner et al. (2001) administered a survey to 1,621 faculty members at eight universities comprising the Southeastern University and College Coalition for Engineering Education. The survey gathered information on a variety of promising instructional practices and showed the percentages of instructors using these practices and the frequency with which they were using them in their classrooms. Results showed that 65% of instructors wrote course learning objectives, 60% reported assigning small group work exercises for brief intervals in their classes, with 22% doing so once a week or more, and 37% reported using active learning for most of a class period, with 8% doing so once a week or more. In regards to group learning, the researchers found that 73% of the respondents reported giving assignments for which students had the option of working in teams, with 54% of the respondents giving assignments for which teams were required.

Another survey that has been distributed consistently over many years is the Higher Education Research Institute (HERI) faculty survey. In 2013-2014, the survey was distributed to 269 four-year colleges and universities (Eagan, Stolzenberg, Lozano, Aragon, Suchard, & Hurtado, 2014). Based on responses from 16,112 full-time undergraduate teaching faculty members, the researchers were able to determine that there was an increase in the use of several promising instructional practices including small group learning, peer-feedback, student-selected topics for course content, and class discussions over a period of 15 years from 1989 to 2014. Additionally, results showed that the use of lecturing in classes was in decline, albeit slightly.

In addition to the HERI survey, the Postsecondary Instructional Practices Survey can be used to study instructional practices in STEM disciplines (Walter et al., 2016). Based on the results of a survey of 827 postsecondary instructors from four institutions of higher education, the researchers found that promising practices were more likely to occur in smaller classes and in non-STEM courses. However, when controlling for class size, STEM instructors were just as likely to employ PPs. Other findings indicate differences in instructional practices employed by male and female instructors as well as between instructors with various years of experience.

Observations. This measurement technique can capture the visible teaching practices that occur in the classroom (AAAS, 2013). With adequate resources and trained personnel, observations can be a great source of information (Wieman, 2015). There are many validated observation protocols that have been developed to document undergraduate teaching practices (AAAS, 2013). Smith et al. (2014) categorized these protocols into two groups: open-ended and structured. The AAAS (2013) calls them *holistic* and *segmented*, respectively.

The open-ended or holistic observation protocols allow users to describe classroom activities and make judgments about particular teaching practices (Smith et al., 2014). An example of an open-ended observation protocol is the Reformed Teaching Observation Protocol (RTOP; Sawada et al., 2002), which has been used widely at various levels and across disciplines and by those interested in “reformed” teaching practices (AAAS, 2013). This means the protocol focuses on practices consistent with the literature on student-centered learning. For example, observers are asked to assess instructors' questions and determine whether the questions "triggered divergent modes of thinking." Other items in the protocol include the value instructors place on student participation and student ideas. For some researchers such as Smith et al. (2014), the use of observer comments in RTOP makes it difficult to standardize or compare data across observers and learning environments. To overcome these limitations, researchers can use more structured protocols. An example of this type of protocol is the Teaching Dimensions Observation Protocol (TDOP), which asks observers to take an inventory of 46 instructor and student behaviors every two minutes (Hora, Oleson, & Ferrare, 2013). The behaviors are organized into six categories that include teaching methods, pedagogical strategies, cognitive demand, student-teacher interactions, student engagement, and instructional technology. Although thorough, this set of codes does not capture all the dimensions of classroom instruction (Smith et al., 2014). Also, structured or segmented observation protocols limit observer comments. In addition, the complexity and training commitment TDOP limits its use in some cases (Smith et al., 2014). To alleviate the constraints and limitation of TDOP, Smith et al. (2014) created the Classroom Observation Protocol (COPUS), which allows researchers to understand how instructors and students spend their time in class. It requires less time to learn and to implement by limiting the number of codes to 25 instructor behaviors.

Overall, there are four holistic and four segmented observation protocols outlined in AAAS (2013). They offer researchers a great tool to measure a variety of teaching practices. Yet, they do not uncover the rationale instructors might have for choosing to implement certain activities. Interviews with instructors can reveal the decision-making process instructors go through when planning their courses and the concomitant activities.

Interviews. A measurement technique that has the potential to uncover unobservable teaching practices is the instructor interview (Creswell, 2012). Interviews require rigorous planning and analytical methods to ensure that reliability and validity standards are satisfied. Although interviews can be used as the sole source of data for research, they usually complement other measurement techniques such as observation protocols. Interviews can "provide an opportunity for researchers to explore complex and ill-defined problems; develop more in-depth understanding; explore faculty and student perceptions; pursue questions of causality" (AAAS, 2013, p. 24). Most interviews use open-ended or semi-structured questions. Open-ended questions (e.g., In what ways do students interact with each in your course?) allow more flexibility to the interview process and can provide rich and unexpected responses. Although interviews are labor intensive, they have been used to clarify an instructor's use of a specific innovation, teaching practices, and broader beliefs about teaching and learning. As cited in AAAS (2013), Henderson and Dancy (2007) conducted interviews with physics instructors to understand the connection between decision-making and teaching practices. The interviews were semi-structured, with questions asking instructors to describe course structure and requirements.

The analysis of interviews begins with the complete transcription of all audio-recorded interviews. These transcriptions can be uploaded to a software program that acts as a storage and code management system (Creswell, 2012). The analysis of interviews relies on the researcher's interpretation, but skilled researchers do not "overstep their interpretation" (AAAS, 2013, p. 20). The reliability of interpretations is usually checked across multiple researchers and done iteratively until a high degree of agreement is achieved.

Barriers to Reform

The rate of adoption of PPs among STEM instructors has been slow, and it has perplexed and frustrated many reformers (NRC, 2012; PCAST, 2012). Michael (2007) suggested that the main method to increase adoption through dissemination, professional development, has been ineffective. In professional development workshops, the exposure to new methods is brief and interactions with colleagues are limited. As a result, there is no reinforcement or motivation to change the learning environment (Windschitl, 2002). However, the problem may be far more complex and extensive than the method of dissemination. For example, Michael (2007) identified 22 barriers to using PPs and organized them into three categories: student characteristics (e.g., students do not know how to do active learning); teacher characteristics (e.g., teachers lack preparation time); pedagogic issues (e.g., class size and physical structure of the classroom make it difficult to do promising practices). Additionally, Henderson et al. (2011) examined situational factors that limited the use of PPs and identified six major themes that overlapped with the barriers identified by Michael (2007). These include: expectations of content coverage; lack of instructor time; department norms; student resistance; class size and room layout; and time structure. In light of these barriers, schools still lack an incentive structure that would motivate instructors to persevere and overcome the challenges (Frayer, 1999; Kember & McKay, 1996; Romano, Hoesing, O'Donovan, & Weinsheimer, 2004). In fact, schools have systems that might be punitive to those who attempt new instructional methods. For example, prior studies show that using new teaching approaches that deviate from student expectations sometimes results in negative student evaluations, which could potentially affect an instructor's career (Anderson, 2002; 2007). Also, the emphasis on research rather than teaching by many universities constrains the appeal of new instructional methods (Fairweather, 2008; Hannan, 2005).

Despite these aforementioned barriers, an extraordinary effort has been exerted to increase the use of PPs in the classrooms by institutions and teachers alike.

Change Strategies

The amount of the effort being exerted to shift teaching to more student-centered practices can be seen in the Government Accountability Office (2005) report, which listed over 207 federal education programs that support STEM education. Of the 207 programs, 73 were specific to improving teacher education in STEM. An example is the NSF's Transforming Undergraduate Education in Science Program which promotes "widespread implementation of educational innovations" (Feser, Borrego, Pimmel, & Della-Piana, 2012). According to Henderson et al. (2011), change strategies to achieve the goal of widespread implementation can be placed in four categories: disseminating curriculum and pedagogy, developing reflective teachers, developing policy, and developing shared vision. However, disseminating curriculum and pedagogy has garnered the most attention and is the most widely used strategy (Henderson et al., 2011). This strategy seeks to increase instructor awareness of promising practices, with the hope that instructors will implement them in classrooms (Henderson & Dancy, 2007). Increasing awareness is usually accomplished through workshops, presentations, and publications, with training designed for faculty of varying position types. For example, the New Faculty Workshop in Physics and Astronomy targets new faculty while the Delta Program in Research, Teaching, and Learning at the University of Wisconsin, Madison supports graduate or post-doctoral students (NRC, 2011). Other, more established professional development programs such as the Faculty Institutes for Reforming Science and the National Academies' Summer Institutes provide training to tenured and non-tenured faculty alike (NRC, 2011). Although initial evaluations of these professional development programs suggested that faculty "learn new ideas there" (NRC, 2011, p. 58), not much is known about the sustainability of the new ideas or instructional practices that faculty learn in these workshops.

Diffusion of Innovation

Unfortunately, current change strategies have largely been ineffective at shifting instructional practices. As a result, education reformers are calling for more research to understand how to improve adoption of PPs (e.g., Fairweather, 2008). A perspective that is garnering much attention in STEM education reform and sheds light on the adoption dilemma is the diffusion of innovation theory (DoIT; Froyd, 2010; Rogers, 2003; Wejnert, 2002). This framework describes the instructor decision-making process as occurring in five stages and beginning with an individual's (1) *knowledge* of the innovation, which can be gained through communication channels such as mass media or interpersonal communications. Upon exposure, an individual forms an opinion about the innovation; this is called the (2) *persuasion* stage. The opinion formed can be favorable or unfavorable based on characteristics of the innovation. The characteristics of the innovation help the individual answer relevant questions, such as: *What are the consequences of the innovation?* and *What are the advantages and disadvantages?* The answer to these questions will likely determine an individual's (3) *decision* to adopt or reject the innovation. At this stage, the decision to reject or accept an innovation is not final. The individual who rejects the innovation might be persuaded to implement it at a later time when a "critical-mass" of adopters makes it difficult to continue to reject the innovation. If an innovation is adopted, the individual will (4) *implement* the innovation and put it into use. However, in many cases, the innovation will be reinvented to accommodate the individual's schema and match the individual's skills and the individual's local conditions. If the innovation is successfully implemented, the individual might choose to continue using it in the (5) *confirmation* stage. In this stage, the individual seeks continued confirmation of the adoption decision and will try to control the level of dissonance, or "an uncomfortable state of mind" (Rogers, 2003, p. 185). Although, the decision to adopt an innovation at this stage is much firmer than at the beginning of the process, the discontinuance of the innovation can occur if a critical-mass of adopters is not achieved by the individual's employing organization, or if the individual experiences disenchantment with the innovation. Overall, this depiction of the decision-making pathway that an instructor traverses when deciding to adopt or reject instructional practices provides a useful framework for STEM education scholars, reformers, and policymakers to understand the factors that contribute to or inhibit the adoption of promising practices. In the following section, I provide additional information about the three main elements of the DoIT that affect the adoption of innovation: characteristics of the innovation, communication channels, and characteristics of the instructors.

Innovation. Based on the definition provided in Rogers (2003), an "innovation" can be an "idea, place, or object" (p. 12). This definition does not require an innovation to be completely novel and unknown to everyone. It only matters if the innovation is perceived as new by instructors. Therefore, a PP that might have been used for decades can still be considered an innovation if an instructor perceives it as new. Upon perception of a PP as an innovation, instructors make adoption decisions by evaluating five characteristics of the innovation: relative advantage, compatibility, complexity, trialability, and observability.

The *relative advantage* of an innovation is the economic or social benefit that an innovation is perceived to provide (Rogers, 2003). Members of a social system are more likely to adopt an innovation that is perceived to offer advantages. However, adopters do not treat all advantages equally. Some individuals will adopt for financial advantages while others are more responsive to social approval (Fliegel, Kivlin, & Sekhon, 1968).

Compatibility refers to how an innovation might align with potential adopters' existing sociocultural values and beliefs, past experiences, and needs. The degree of alignment is positively related to the rate of adoption. Rogers (2003) provided several examples to illustrate the importance of compatibility in the adoption of innovation. In one example, despite the health benefits of boiling water, Peruvian villagers rejected the innovation because it conflicted with their belief that hot water was only given to sick people.

An innovation's *complexity* is "the degree to which an innovation is perceived as relatively difficult to understand and to use" (Rogers, 2003, p. 257). Innovations that are perceived as less complex will be adopted at a faster rate.

Trialability is "the degree to which an innovation may be experimented with on a limited basis" (Rogers, 2003, p. 258). This characteristic of an innovation is positively associated with adoption rate.

Observability is "the degree to which the results of an innovation are visible to others" (Rogers, 2003, p. 258). It is also positively related to the adoption rate.

Individuals learn about an innovation through two types of communication channels: mass media and interpersonal communications. Mass media such as journals and conferences are more likely to create awareness of an innovation. However, interpersonal communication is more effective at convincing non-adopters to adopt (Coleman et al., 1966). Usually interpersonal communication is between individuals who are homophilous, or similar to each other in beliefs and socioeconomic status. Yet, a certain level of heterophily is necessary for the exchange of ideas (Roling et al., 1976).

Members. An innovation that is introduced into a social system is adopted by its members differently and at different rates. Rogers (2003) created five categories of adopters to describe their rate of adoption. Members in each category share similar qualities but could differ dramatically from members of different categories. These categories include: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards.

Innovators. Innovators are the first to adopt an innovation. Rogers (2003) described them as “venturesome” and “cosmopolite.” In other words, they are able and willing to go beyond their social system to gain information about an innovation. Additionally, they have the financial resources to mitigate the effects of an innovation that might be unprofitable or unproductive, and they have the type of disposition to cope with the uncertainty or distress that usually accompanies the adoption of an innovation.

Early Adopters. Early adopters are the next members in a social system to adopt an innovation after Innovators. Unlike Innovators, they are more “localites” or integrated into the social system (Rogers, 2003). Their extensive connections in the social network allow them to be opinion leaders who are respected by other members of the social system. As a result of their position in their organization, Early Adopters are more judicious in their decision-making. As Rogers (2003) puts it, “In one sense, early adopters put their stamp of approval on a new idea by adopting it” (p. 283).

Early Majority. This large group of adopters are the next group to adopt an innovation after Early Adopters and represent 1/3 of the members of a social system. They interact frequently with other members of the social system but do not hold positions of power. Rogers (2003) writes, “They follow with deliberate willingness in adopting innovations but seldom lead” (p. 284).

Late Majority. These members of a social system are the next group to adopt an innovation after the Early Majority and also represent a third of the members of a social system. These adopters require much peer pressure and a shift in social norms that favors an innovation before they will commit to adoption.

Laggards. Members in a social system who adopt an innovation last are labeled Laggards. Unlike Innovators, Laggards are at the other end of the adoption continuum and have scarce financial resources. Therefore, they are limited in their ability to take risks that accompany the adoption of an innovation. Not only do Laggards lack financial resources, but they also lack social connections to other members. According to Rogers (2003), "The point of reference for the Laggards is the past. Decisions are often made in terms of what has been done previously" (p. 284).

In examining the differences between adopters in the categories described above, it is apparent that individual characteristics affect adoption rate. Rogers (2003) identified three major individual characteristics: (1) socioeconomic status, (2) personality values, and (3) communication behavior. Through a summary of the current literature on the diffusion research, Rogers provides generalizations about these characteristics and their connections to adoption rates.

Socioeconomic characteristics. Through six generalizations, Rogers (2003) shows that an individual's level of education, financial resources, and social mobility are positively related to the adoption rate. Interestingly, age does not play a role in the adoption rate.

If organizations, departments, or institutions are the unit of analysis, then size does matter, with larger units being more likely to adopt an innovation before smaller units.

Personality variables. Rogers (2003) provides ten generalizations that demonstrate certain individual characteristics such as aspirations, intelligence, empathy, a positive attitude toward change, and the ability to deal with abstraction or uncertainty are positively related to adoption rate. However, those members of a social system who are more fatalistic and dogmatic are less likely to adopt an innovation. Rogers (2003) defined fatalism as, "the degree to which an individual perceives a lack of ability to control his or her future," and defines dogmatism as, "the degree to which an individual has a relatively closed belief system" (p. 290). In other words, a dogmatic person is unlikely to be open to new ideas.

Communication behavior. A theme that emerges from Rogers's (2003) nine generalizations about communication behavior is that those members who are active participants in their social system, and those with greater social network connections, are more likely to adopt an innovation. The two types of connections that contribute to greater adoption rate are the connections to members outside of the social system and the connections to change agents. These connections are important because they diversify a member's knowledge base and provide access to knowledge of innovations.

Situative Perspective

In addition to the DoIT, a situative perspective is necessary to accommodate for the complexity of instruction inherent within classrooms across college campuses. Although the *knowledge-persuasion-decision* process is linear, Rogers (2003) argues that the process occurs in complex social systems. Within a social system, interpersonal interactions and cultural factors can influence the innovation-decision at multiple points in the process. For example, the informal conversations between colleagues or the training that instructors receive early in their career could influence decisions about a particular innovative teaching strategy. The importance of these factors in the adoption of innovation can be seen in a training program aimed at preparing faculty to use a learning management system (Bennet & Bennett, 2003). Leveraging the influence of human interactions and cultural factors into a training program based on the innovation-decision framework, Bennet and Bennett (2003) increased the adoption rate of a new technology (Blackboard). The authors concluded (along with Boyce, 2003), that change strategies need to incorporate local conditions to achieve desired outcomes. In light of these findings, a situative perspective (Greeno, 1998) in analyzing the factors that might influence the adoption of promising practices is warranted. In this view, learning is not an isolated act of cognition, but rather a process of gaining entry to a discourse of practitioners and a process embedded within a particular context. A situative approach places a premium on learners' experiences, social participation, use of mediating devices (e.g., tools and technologies), and positions within various activity systems and communities of practice.

Together, the DoIT and the situative perspective frame the research approach that takes into account the instructional practices and the role situational or institutional conditions play in the pedagogic decisions instructors make. This approach will provide a more multidimensional and nuanced study of educational reform in higher education. In Figure 1, I combined the DoIT and the situative perspective and presented the theoretical framework for this study. First, the diagram shows the innovation-decision process by an individual. In this process, the communication channels constantly feed information to individuals as they make their adoption decisions. Yet, communication channels are only one of many factors that influence individual decision-making. These other factors include prior conditions, perceptions of the innovation, and individual characteristics. Second, the diagram shows that the instructor innovation-decision process is embedded in a specific social context. In the case of this study, the contexts are classrooms, departments, and the university.

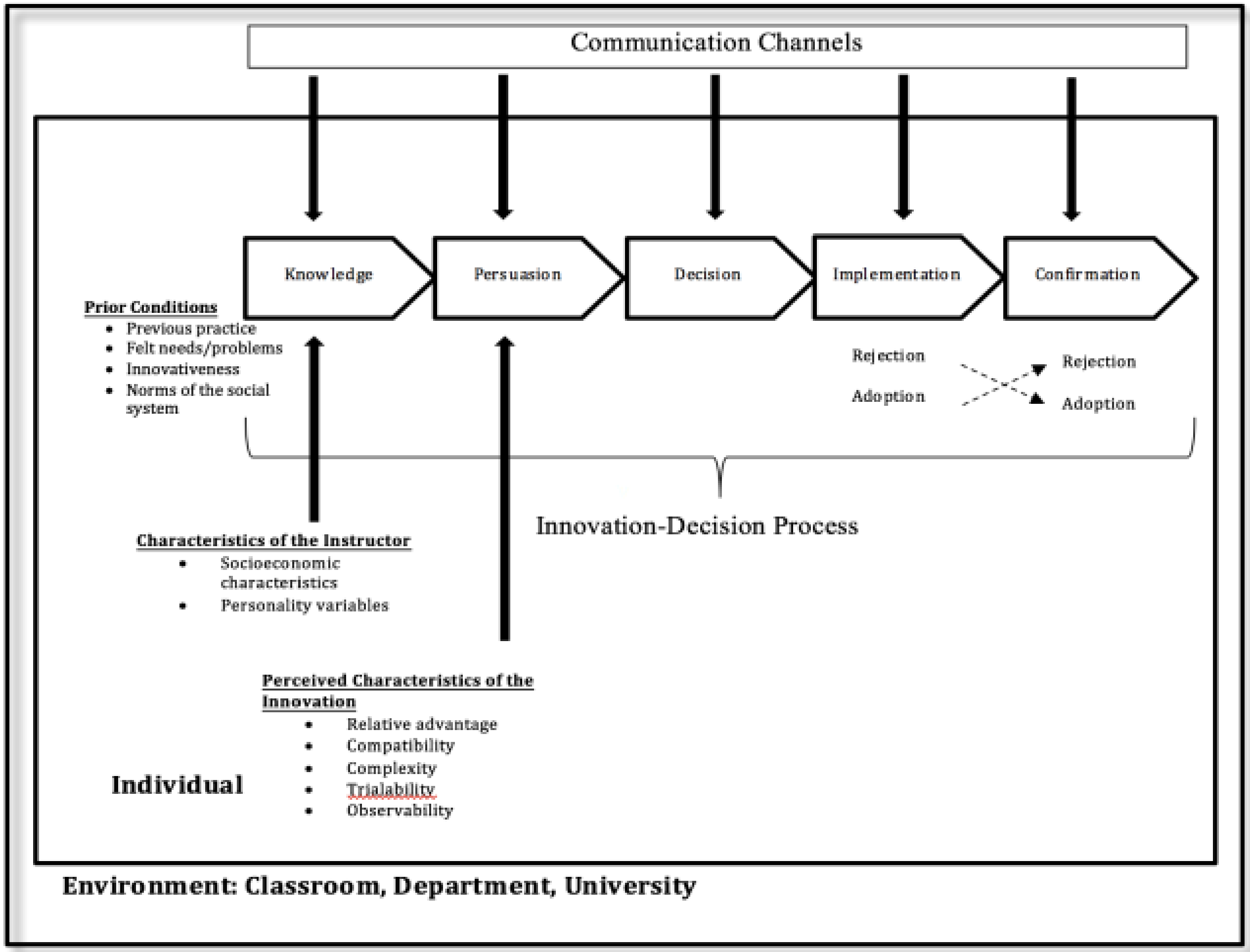

Figure 2.1. Theoretical framework: diffusion of innovation theory combined with the situative perspective. *Note*: Adapted from Rogers (2003).

CHAPTER 3: METHODOLOGY

Using a mixed-methods approach, I conducted a descriptive analysis of instructional practices in large introductory STEM courses, followed by an analysis of factors that inhibit or contribute to pedagogic decisions that instructors make. Based on the AAAS (2013) recommendation of using multiple measurement techniques to describe teaching practices, I collected data from course observations, instructor interviews, and course syllabi of high-enrollment gateway courses across STEM departments at a major research university (UCH; pseudonym) in California.

Study Context and Participants

UCH. UCH is a public university. As of 2016, the institution enrolled 26,889 undergraduate students, with a larger proportion enrolled in STEM degree programs than in non-STEM degree programs (University of California, 2016). The university has a high graduation rate (88%), and the majority of students graduate within six years. In a survey of student satisfaction given by the university, 89% of students reported that they felt UCH was committed to undergraduate education and 82% felt satisfied with their overall academic experience. However, only 63% were satisfied with the value of education for the price they paid.

In 2014, 416 instructors (38% of tenured faculty) were employed in the STEM disciplines as tenured faculty (University of California, 2016). Across the university, the student to faculty ration is 19 to 1.

Courses. From Spring 2013 to Spring 2015, we conducted 259 observations of 35 different undergraduate introductory STEM courses that had an average enrollment of 278 students. Table 3.1 shows the number of different courses in each department that were observed, the total number of observations for each department, and the average number of students in each course by department.

Overall, 87% of all gateway courses in the STEM disciplines were observed during the study period. Although attempts were made to observe each course twice a quarter (10 weeks), various factors such as scheduling conflicts between observers and course instructors occasionally limited observations to only once a quarter. Table 3.2, the first table in Appendix C, provides a more detailed list of courses, their titles, and the number of observations for each course title.

Table 3.1

Courses Observed and Average Number of Students in each Course by Department

Department	Courses	Observations	Average # of Students
Biology	5	37	337
Chemistry	6	91	313
Engineering/ICS	12	36	229
Math	6	53	216
Physics	6	43	270
Average			278
Total	35	259	

Instructors. Table 3.3 describes the instructor sample for the observations and the interviews by instructor position type, gender, and department. Instructors held various position types: graduate student (*n* = 5*)*, researcher (*n* = 2), lecturer (*n* = 11), lecturer with potential for security of employment (LPSOE; *n* = 6), lecturer with security of employment (LSOE; *n* = 3), assistant professor (*n* = 10), associate professor (*n* = 14), and professor (*n* = 34). They taught courses across STEM departments: Biology (*n* = 23), Chemistry (*n* = 21), Engineering and ICS (*n* = 14), Math (n = 14), and Physics (*n* = 14).

Course sections were taught by 86 instructors; 57 were male and 29 were female. As a result of the disparity in the number of courses taught by male and female instructors, the study team interviewed more male instructors (n = 42) than female instructors (n = 25), for a total of 67 instructors who were interviewed. Nineteen instructors either did not respond to requests or declined requests to be interviewed.

Table 3.3

Instructor Sample for Observation and Interview Data by Instructor Position Type and Gender, and by Department

Instructor Sample	Observation		Interview	
	n	%	*n*	%
Position type				
Graduate Student	5	6	5	7
Post-doc	1	1	1	1
Research Scientist	2	2	2	3
Lecturer	11	13	7	10
Lecturer PSOE	6	7	6	9
Lecturer SOE	3	3	3	4
Assistant professor	10	12	7	10
Associate professor	14	16	10	15
Professor	34	40	26	39
Gender				
Female	29	34	25	37
Male	57	66	42	63
Department				
Biology	23	27	15	22.4
Chemistry	21	24	19	28.3
Engineering/ICS	14	16.3	11	16.4
Math	14	16.3	11	16.4
Physics	14	16.3	11	16.4
Total (*N*)	86		67	

Measures

Simple Protocol for Observing Undergraduate Teaching (SPROUT). We conducted systematic observations of courses with the goal of visiting each section twice during a quarter, once during the first four weeks and a second time during the last four weeks of the quarter, from Spring 2013 to Spring 2015. The course observations were completed using the Simple Protocol for Observing Undergraduate Teaching (SPROUT), which was researcher-developed and based on existing validated observation instruments (RTOP; Sawada, Piburn, Judson, Turley, Falconer, Benford, & Bloom, 2002; TDOP; Hora et al., 2014; UTOP; Walkington et al., 2012). The SPROUT was developed with four goals in mind: (a) to capture instructor and student behaviors in gateway lecture courses, (b) provide opportunities for instructors to reflect on their own instruction, (c) stimulate departmental conversations related to evidence-based instruction, and (d) link instructional practices to student outcomes (Reimer et al., 2016). It differs from other observation protocols in that it is non-evaluative, does not require observers to take measurements at timed intervals, and does not measure behaviors using a Likert scale. With minimal training (1-2 hours), observers can quickly and reliably use the observation protocol. The protocol can be used to describe classroom activities and instructor behaviors by taking detailed field notes during the lecture and by checking dichotomous indicators (yes/no) to indicate the presence or absence of specific instructional practices identified as promising by the NRC (2012). Testing of the SPROUT resulted in an inter-rater reliability of Cohen's kappa = 0.80. A sample of the SPROUT is found in Appendix A.

Interviews. The interview sample was drawn from the population of instructors who were observed each year. These instructors were contacted via email, phone calls, and visits to office hours to schedule interviews. Luckily, the majority of observed instructors granted requests for interviews. The interviews were semi-structured and based on an interview protocol that is fully described in Appendix B. The interview protocol consisted of questions related to several major topics. Table 3.4, the second table in Appendix C, lists the topics of the interviews and provides an example of questions for each topic.

Interviews typically lasted between 30 minutes to one hour, depending on the availability of the instructors and the length of their responses. Each interview was audio-recorded and transcribed verbatim, except for one interview. For this one case, the instructor did not permit audio recording of the interview.

Throughout this study, references to instructors in the study sample will be done by their pseudonyms.

Course syllabi. Syllabi were collected from all observed courses. However, for analysis, only one syllabus for each course taught by an instructor was used, since instructors typically used the same syllabus for each course. Table 3.5 provides details of the syllabi sample by instructor position type and gender, and by department. In total, 91 syllabi were collected for this study.

Table 3.5

Syllabi Sample by Instructor Position Type and Gender, and by Department

Syllabi Sample	*n*	%
Position Type		
Graduate Student	6	7
Researcher	2	2
Lecturer	22	24
Lecturer PSOE	7	8
Lecturer SOE	5	6
Assistant	6	7
Associate	12	13
Professor	31	34
Sex		
Female	36	40
Male	55	60
Department		
Biology	12	13
Chemistry	29	32
Engineering/ICS	13	14
Math	17	19
Physics	20	22
Total (*N*)	91	

Analyses

RQ1. How prominent and widespread are so called "promising" instructional practices? The SPROUT data were used to uncover instructional practices employed by course instructors. Data were coded using a protocol designed by the research team, and constructs were generated from the raw data using analytical methods in Reimer et al. (2016). In this method, coded items from the SPROUT were used to create composite variables for four PPs. For example, to measure instructional practices related to Epistemology, five items from the SPROUT were used: (a) whether or not the instructor solves problems in class, (b) whether or not the instructor makes connections between course content and current events or real world applications, (c) whether or not the instructor references prior content, (d) whether or not the instructor summarizes content, and (e) whether or not the instructor shows students how to apply or extend knowledge. Based on the list of PPs outlined in the NRC (2012) report, four composite variables of PPs related to classroom instruction were created: 1) Epistemology, 2) Assessment, 3) Active Learning, and 4) Collaboration. Table 3.6, the third table in Appendix C, provides a list of SPROUT items that comprise each PP and a list of instructor actions representative of the SPROUT items. In total, five SPROUT items comprised Epistemology, two items for Assessment, four items for Active Learning, and one item for Collaboration. The prevalence of each SPROUT item was determined by calculating the percentage of the number of times the item was observed over the total number of class observations. Because each PP is a composite of several SPROUT items, an average of the percentages was used to represent the prevalence of each PP.

RQ2. How do instructional practices differ across instructors and STEM disciplines? To answer this question, I compared the prevalence of PPs across instructor variables and departments. Differences across instructor variables and across departments were analyzed using either t-tests or one-way analysis of variance (ANOVA), with the Bonferroni multiple comparisons procedure as a post-hoc test to compare mean responses between various instructor groups and between departments.

RQ3. Within individual instructors and across the departments and the university, what contributes to, or inhibits, adoption of particular instructional practices and diffusion of new approaches to instruction? To answer this question, I analyzed the instructor interview data. Interviews were first transcribed verbatim and uploaded to Dedoose, a qualitative web application for data storage, coding, and theme development. Thematic, iterative coding methods (Saldaña, 2008) were used to see the kinds of recurring topics that emerge and to identify the themes in the data and how they relate to each other. King and Horrocks (2010) provided the following definition for themes: "Themes are recurrent and distinctive features of participants' accounts, characterizing particular perceptions and/or experiences, which the researcher sees as relevant to the research question" (p. 150). The themes were organized according to pre-structured framework defined by the DoIT (Miles & Huberman, 1994).

I used Dedoose to organize and to generate codes to represent given characteristics of studied contexts such as available technologies, symbolic and material resources, drivers and barriers to implementation of promising instructional strategies, and incentive systems within UCI departments.

CHAPTER 4: RESULTS

RQ1: How prominent and widespread are so called "promising" instructional practices?

Table 4.1 shows that instructional practices related to Epistemology were observed more often (57.8%) than other PPs. Of particular interest within the construct of Epistemology, the specific instructional strategy of giving students opportunities to observe or engage in problem-solving was overwhelmingly seen in 226 (87.3%) of the 259 observed classes. The activities related to Assessment were seen in 24.9% of the classes, followed by activities for Active Learning (25.1%), and finally activities for Collaboration (16.6%).

Table 4.1

Percentage of Observed Classes Using Promising Practices

Promising Practice	*n*	%
Epistemology		
Problem-solving	226	87.3
Real world	178	68.7
Prior content	176	68.0
Exam content	83	32.0
Big ideas	85	32.8
Average		57.8
Assessment		
Formative	118	45.6
In-class assessment	11	4.2
Average		24.9
Active Learning		
iClickers	84	32.4
Interactive	149	57.5
Deskwork	23	8.9
Student presentation	4	1.5
Average		25.1
Collaboration		
Groupwork	43	16.6
N (observations)	259	

Additional observational data revealed that problem solving activities were done individually as well as in groups. These group activities were all unstructured and organized in an impromptu manner (e.g., instructors asked their students to form groups with other students who were nearby). In addition to solving problems, students also formed groups to discuss questions or concepts.

Observed instances of group work often included the use of technology, especially iClickers. Instructors used iClickers in 32.4% of observed classes to engage students, check for understanding, and to take attendance. Points were given to students for their active participation in iClicker activities, but the point value was usually low compared to the total course point value. In many cases, instructors gave only participation points or no points at all. In addition to iClickers, instructors used technology in the classroom for the display of information. This includes Elmo document cameras, iPads, and older devices such as overhead projectors.

Technology was not limited to the classroom. Instructors also used online tools such as Facebook and Piazza as forums for student discussion, and homework systems such as Mastering Genetics, Mastering Physics, and Sapling.

RQ2: How do instructional practices differ across instructors (position types and gender) and departments?

I present results from the SPROUT data, analyzing differences in the use of PPs across instructor position types and between instructor gender, and across departments.

Position types. Because some position types (i.e., graduate student, researcher, LSOE, and assistant professor) was not observed often, I combined them into larger categories in order to identify differences across various categories of instructors. Table 4.2 was used to create different instructor categories that were based on tenure status, seniority, and job track (research versus teaching). Table 4.3 presents the number of courses that were observed by instructor position type and gender, and by department in which instructors worked.

Table 4.2

Instructor Categories by Tenure Status, Seniority, and Job Track

Tenure Status	**Seniority Ranking**	**Instructor Position Research Track**	**Instructor Position Teaching Track**
Non-tenured	Non-tenure track	Grad student Post-doctoral Researcher	Lecturer
	Junior tenure track	Assistant professor	LPSOE
Tenured	Early tenured	Associate professor	LSOE
	Senior tenured	Professor	Senior LSOE

Table 4.3

Number of Class Observations by Instructor Tenure Status, Seniority, Job Track, and Gender, and by Department

Instructor Categories	*n*	%
Tenure status		
Non-tenured	109	42.1
Tenured	150	61.4
Seniority Ranking		
Non-tenure track	68	26.3
Junior tenure track	40	15.4
Early tenured	30	11.6
Senior tenured	121	46.7
Job track (all instructors)		
Research	142	54.8
Teaching	117	45.2
Job track (tenure-track instructors only)		
Research	129	67.5
Teaching	62	32.5
Gender		
Female	107	41.3
Male	152	58.7
Department		
Biology	36	13.9
Chemistry	91	35.1
Engineering/ICS	36	13.9
Math	54	20.8
Physics	42	16.2

Non-tenured v. Tenured. Analysis of the interview data from this current study and data from prior studies suggested that the incentive structure of the tenure system can impact the use of PPs in the classroom (e.g., Fairweather, 2008). To test these claims, instructors were divided into two categories based on their tenure status: non-tenured v. tenured. Non-tenured instructors included graduate students, researchers, and post-docs, lecturers, assistant professors, and LPSOEs. Tenured instructors included associate professors, LSOEs, full professors, and senior LSOEs. Courses taught by tenured instructors were observed more often than courses taught by non-tenured instructors (159 observations, 61.4%; 109 observations, 42.1%, respectively; see Table 4.3). Regardless of tenure status, Epistemology was observed far more often than other PPs, especially Collaboration (Figure 4.1). For all PPs, a higher percentage of classes taught by non-tenured instructors were observed to incorporate PPs than classes taught by tenured instructors. These differences were significant for three PPs: Epistemology [$t(185) < .01$], Assessment [$t(211) = .005$], and Collaboration [$t(199) = .04$] (Table 4.4).

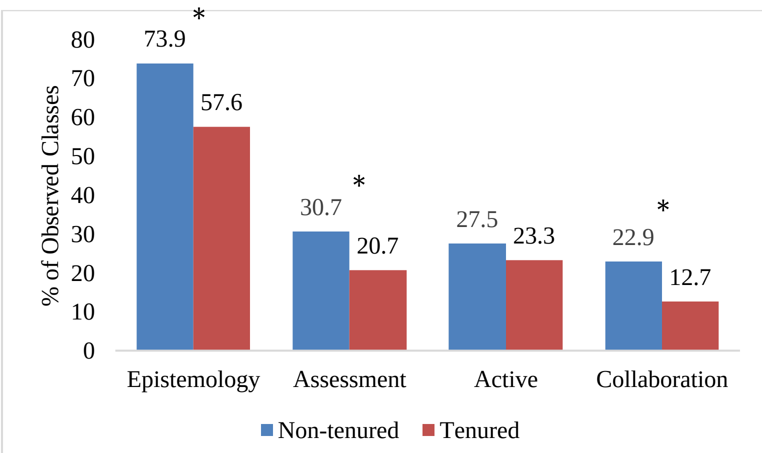

Figure 4.1. Average percentage of observed classes using PPs between non-tenured and tenured instructors. *Note*: * Significant at $p < .05$.

Table 4.4

T-test of PP Use Between Non-tenured and Tenured Instructors by PP

	Mean		Variance		*p*
	Non-tenured	Tenured	Non-tenured	Tenured	
Epistemology	3.70	2.88	2.42	1.25	< .01*
Assessment	.61	.41	.37	.27	.005*
Active Learning	1.10	.93	.61	.57	.08
Collaboration	.23	.13	.18	.11	.04*

Note: *Significant at $p < .05$.

Seniority ranking. Instructor seniority was examined for differences in instructors' use of PPs. Four instructor categories were created: non-tenure track (graduate students, post-docs, researchers, lecturers), junior-tenure track (assistant professors, LPSOEs), early-tenured (associate professors, LSOEs), and senior-tenured (full professors). Senior-tenured track instructors were observed most often (121 times, 46.7%), followed by non-tenure track instructors (68 times, 26.3%), then junior-tenure track instructors (40 times, 15.4%), and finally early-tenured track (30 times, 11.6%; see Table 4.3). Regardless of seniority, Epistemology was observed in a higher percentage of classes for all tested PPs. Overall, junior-track instructors were observed to implement PPs in a higher percentage of classes than other instructor categories for all PPs (Figure 4.2). However, one-way ANOVA results were only significant for Collaboration [$F(3, 255) = 3.55$, $p = .015$], but not for other PPs (Table 4.5). A post-hoc t-test confirmed suspicions that junior tenure-track instructors (assistant professors and LPSOEs) implemented collaborative activities significantly in a higher percentage of classes than senior-tenured instructors who are considered to be generally older.

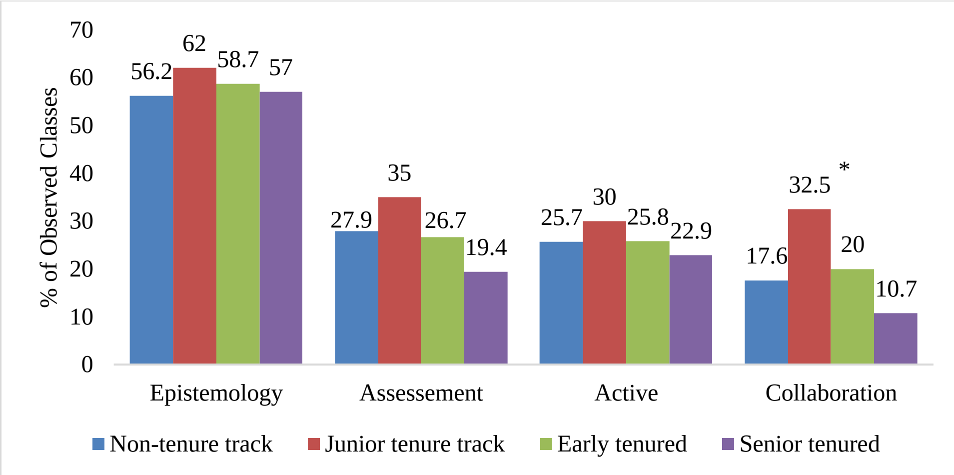

Figure 4.2. Average percentage of observed classes using PPs across instructor ranks. *Note*: *Significant at $p < .05$.

Table 4.5

One-way Across Instructor Seniority Ranking ANOVA of PP Use by PP

	Source	*df*	*SS*	*MS*	*F*	*p*
Epistemology	Between Groups	3	2.44	.82	.67	.57
	Within Groups	255	311	1.22		
Assessment	Between Groups	3	.61	.20	.24	.87
	Within Groups	255	218.5	.86		
Active Learning	Between Groups	3	2.51	.84	1.42	.24
	Within Groups	255	150.5	.59		
Collaboration	Between Groups	3	1.46	.49	3.55	.015*
	Within Groups	255	35.1	.14		

Note: *Significant at $p < .05$.

Research v. Teaching track (all instructors). Two instructor job tracks (research and teaching job tracks) were investigated to test assumptions about job responsibilities and their impact on instructors' use of PPs. The instructors in the research track included graduate students, post-docs, researchers, assistant professors, associate professors, and full professors. Instructors in the teaching track included lecturers, LPSOEs, and LSOEs. Courses taught by instructors in the research and teaching tracks were observed 142 (54.8%) and 117 times (45.2%), respectively. Regardless of job track, Epistemology was observed more frequently than other PPs. In Figure 4.3, there was no clear pattern that differentiated research and teaching track instructors. However, t-test results revealed that teaching-track instructors implemented collaborative activities significantly in a higher percentage of classes than research-track instructors [$t(220) = 1.97$, $p = .046$] (Table 4.6).

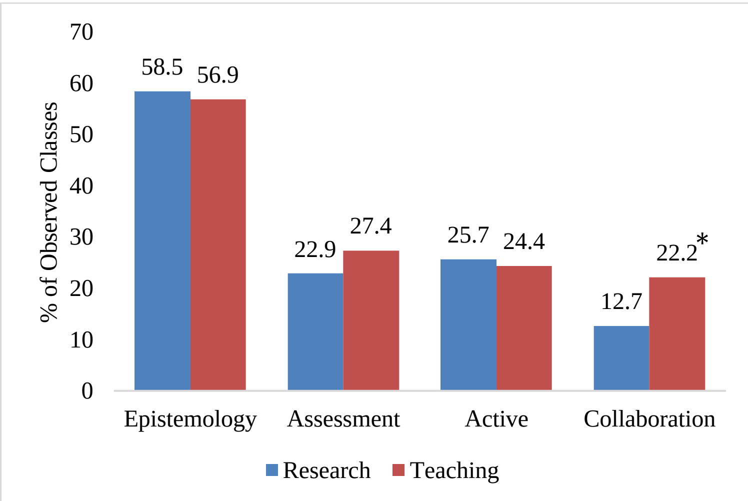

Figure 4.3. Average percentage of observed classes using PPs between all research and teaching-track instructors. *Note:* *Significant at $p < .05$.

Table 4.6

T-test of PP Use Between Research and Teaching Track Instructors (All Instructors) by PP

	Mean		Variance		*p*
	Research	Teaching	Research	Teaching	
Epistemology	2.92	2.84	1.14	1.32	.58
Assessment	.46	.55	.29	.35	.21
Active Learning	1.02	.97	.58	.61	.38
Collaboration	.13	.22	.11	.17	.04*

Note: *Significant at $p < .05$.

Research v. Teaching (tenure track only). Information conveyed through instructor interviews in the current study suggested that LPSOEs and LSOEs were tasked by their departments to implement and disseminate PPs. To test whether LPSOEs and LSOEs use more PPs than other groups of instructors, I combined them into one category and compared their instructional practices with those of the research-track instructors. Lecturers, graduate students, researchers, and post-docs were excluded from the analysis because they are not on the tenure track, in either the research or teaching job tracks. We observed 62 (32.5%) and 129 (67.5%) classes taught by teaching and research-track instructors, respectively (Table 4.3). Again, regardless of the job track, Epistemology was observed more frequently than other PPs. In general, for all PPs, teaching-track instructors were observed to implement PPs in a higher percentage of classes than research-track instructors (Figure 4.4). Interestingly, in the prior model where *all* research track and teaching track instructors were included in the analysis, the general pattern of difference was not as clear. Although observation results showed differences between job tracks, t-test results showed no significant differences between research or teaching instructors (tenure-track only) for all PPs: Epistemology [$t(189) = 1.97$, $p = .87$], Assessment [$t(189) = 1.97$, $p = .69$], Active Learning [$t(189) = 1.97$, $p = .19$], and Collaboration [$t(188) = 1.97$, $p = .26$] (Table 4.7).

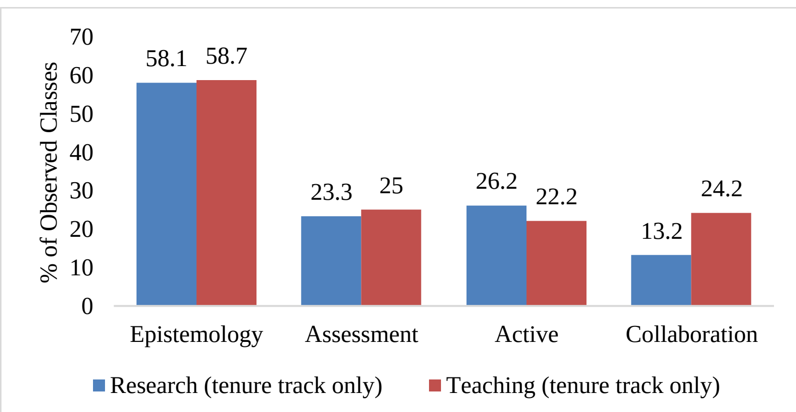

Figure 4.4. Average percentage of observed classes using PPs between research and teaching-track instructors (tenure-track only).

Table 4.7

T-test of PP Use Between Research and Teaching-Track Instructors (Tenure-track Only) by PP

	Mean		Variance		*p*
	Research	Teaching	Research	Teaching	
Epistemology	2.90	2.93	1.16	1.47	.87
Assessment	.465	.5	.30	.35	.69
Active Learning	1.04	.89	.56	.72	.19
Collaboration	.17	.24	.14	.19	.25

Gender. Differences in the use of PPs between female and male instructors were investigated. A smaller number of classes taught by female instructors (107; 41.3%) were observed than those taught by male instructors (152; 58.7%) (Table 4.3). Regardless of instructor gender, Epistemology was observed in a higher percentage of classes than other PPs (Figure 4.5). Overall, female instructors were observed to implement all four PPs in a higher percentage of classes than male instructors, with the most striking difference in the percentage of classes incorporating collaborative activities. However, t-test results comparing PP use by female and male instructors showed that only Collaboration was significant [$t(257) = 1.97$, $p = .012$] (Table 4.8).

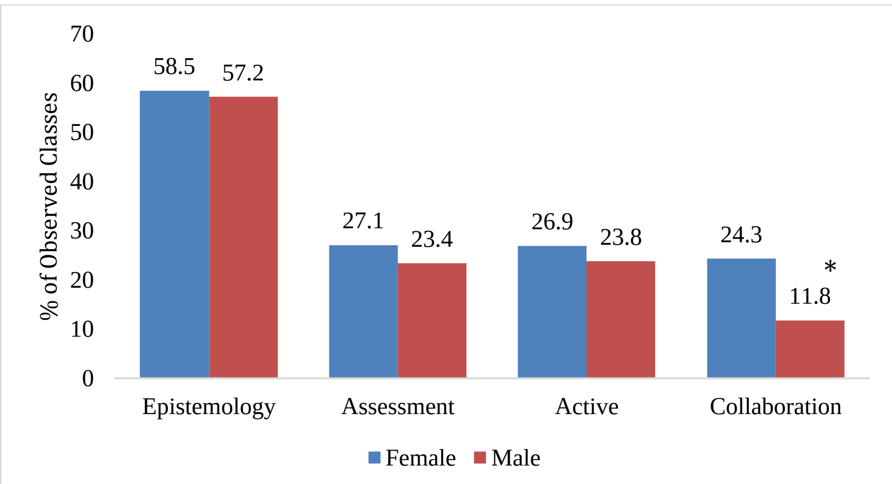

Figure 4.5. Average percentage of observed classes using PP between female and male instructors. *Note:* *Significant at $p < .05$.

Table 4.8.
T-test of PP Use Between Female and Male Instructors by PP

	Mean		Variance		*p*
	Male	Female	Male	Female	
Epistemology	2.86	2.92	1.21	1.24	.650
Assessment	.467	.542	.290	.364	.295
Active Learning	.954	1.07	.587	.598	.214
Collaboration	.118	.243	.105	.186	.012*

Note: * $p < .05$

Departments. University departments were compared to investigate differences in their use of PPs. Classes in the chemistry department were observed most often (91 times, 35.1%) followed by math (54 times, 20.8%), physics (42 times, 16.2%), and finally biology and engineering/ICS (both 36 times, 13.9%) (Table 4.9). In comparing PP use across departments, it was observed that a higher percentage of chemistry classes implemented Epistemology. However, excluding Epistemology, the biology department was observed to implement the other PPs (i.e., Assessment, Active Learning, and Collaboration) in a higher percentage of classes than other departments.

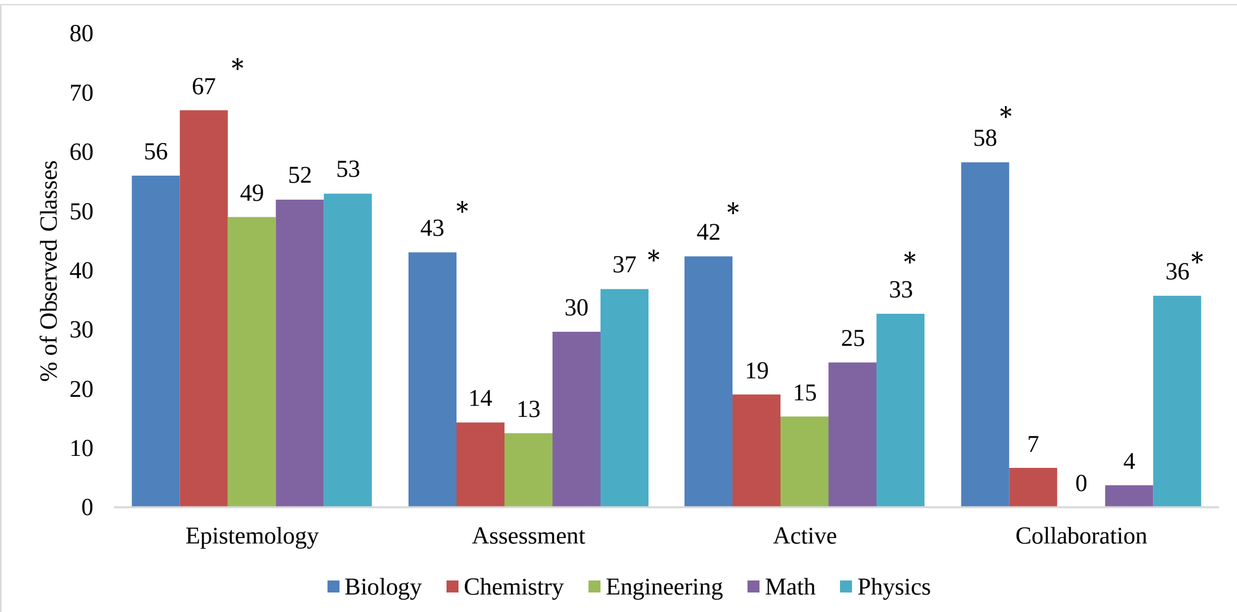

Figure 4.6. Average percentage of observed classes using PPs across departments. *Note*: *Significant at $p < .05$.

Notably, one-way ANOVA results showed significant differences across departments for all PPs (Table 4.9). Post hoc t-test results confirmed that a higher percentage of classes in the chemistry department implemented Epistemology than classes in engineering, math, and physics, but not higher than the classes in the biology department.

In contrast, a much lower percentage of classes in the chemistry department incorporated PPs for Assessment, Active Learning, and Collaboration. In fact, post-hoc t-test results showed that the biology department implemented Assessment, Active Learning, and Collaboration in a higher percentage of classes than other departments, including chemistry, engineering, and math (but not physics). Additionally, physics implemented PPs significantly in a higher percentage of classes than chemistry, engineering, and math for all PPs except Epistemology.

Table 4.9

One-way Across Department ANOVA of PP Use by PP

	Source	*SS*	*df*	*MS*	*F*	*p*
Epistemology	Between Groups	34.1	4	8.52	7.73	<.0001*
	Within Groups	279.7	254	1.10		
Assessment	Between Groups	14.2	4	3.54	14.1	<.0001*
	Within Groups	63.7	254	.251		
Active Learning	Between Groups	32.1	4	8.04	16.9	<.0001*
	Within Groups	120.8	254	.48		
Collaboration	Between Groups	10.6	4	2.66	26.1	<.0001*
	Within Groups	25.9	255	.101		

Note: *Significant at $p < .05$.

RQ3: Within individual instructors' classrooms and across the departments and the university, what contributes to, or inhibits, adoption of particular instructional practices and diffusion of "promising" approaches to instruction?

To understand why differences existed among instructors and across departments, instructors were interviewed about their instructional practices. In this section, I transition from presenting results of the SPROUT to the results of the instructor interview data. First, I describe the factors that inhibit or contribute to the diffusion of PPs, as narrated by the participants. The factors that inhibit the diffusion of PPs will be referred to as Barriers while the factors that contribute to the diffusion of PPs will be referred to Drivers (Shadle, Marker, & Earl, 2017).

Analysis of instructor interviews (*N* = 67) began with thematic coding of these interviews (Boyatzis, 1998). Iterative coding of instructor interviews resulted in themes that were later organized under the categories of Barriers and Drivers and subsequently divided into the four main factors (communication channels, environment, innovation, and instructors) discussed in my theoretical framework that is based on the DoIT (Rogers, 2003). I labeled these four main factors “parent codes” and the themes organized under them “child codes”; those factors under the child codes were labeled “grandchild codes.” Figure 4.7 shows the categories and the parent codes associated with them. Table 4.10 shows the code counts for each category by parent codes. Overall, there were more than three times as many codes for Barriers (391 codes) as for Drivers (115 codes). For Barriers, instructors discussed with much more frequency issues related to their environment (246 codes) than issues related to the innovation, or PP (15 codes). In regards to Drivers, instructors discussed with equal frequency issues related to communication channels (39 codes), the teaching environment (32 codes), and instructor characteristics (34 codes). Again, issues related to innovation (10 codes) were seldom discussed.

Figure 4.7. Organization of coding for Barriers and Drivers.

Table 4.10

Code Counts for Barriers and Drivers

Parent Code	Barriers	Drivers
Communication Channels	31	39
Environment	246	32
Innovation	15	10
Instructor	101	34
Total (*N*)	391	115

Barriers to the Diffusion of Promising Practices

After thematic analysis was conducted on the interview data, the themes that emerged were organized under the parent codes. Twelve themes were labeled “child codes,” twelve themes were labeled “grandchild codes,” and four themes were labeled “great-grandchild codes.” Figure 4.8 shows the coding structure for the category Barriers. Table 4.11, the fourth table in Appendix C, provides a summary of the frequency counts for Barriers by instructor descriptors.

Overall, there was almost double the number of excerpts coded in the interview data for male instructors (256) as compared with female instructors (135). In the five departments represented in our data, Physical Sciences (233) had the most excerpts, followed by Biology (93), Engineering (32), ICS (29), Social Ecology (4), respectively. For position types, professors (132) had the most coded excerpts, which corresponds with the number of professors interviewed. Other position types have similar number of coded excerpts: assistant professor (33), LSOE (35), LPSOE (30), lecturer (43), and graduate student (35). Researcher (4) had the least number of coded excerpts as a result of only two researchers participating in these interviews.

In the following section, I describe the various code levels and provide descriptions and examples of excerpts that represent each code. I organize the following section based on the four parent codes: (1) communication channel, (2) environment, (3) innovation, and (4) instructor.

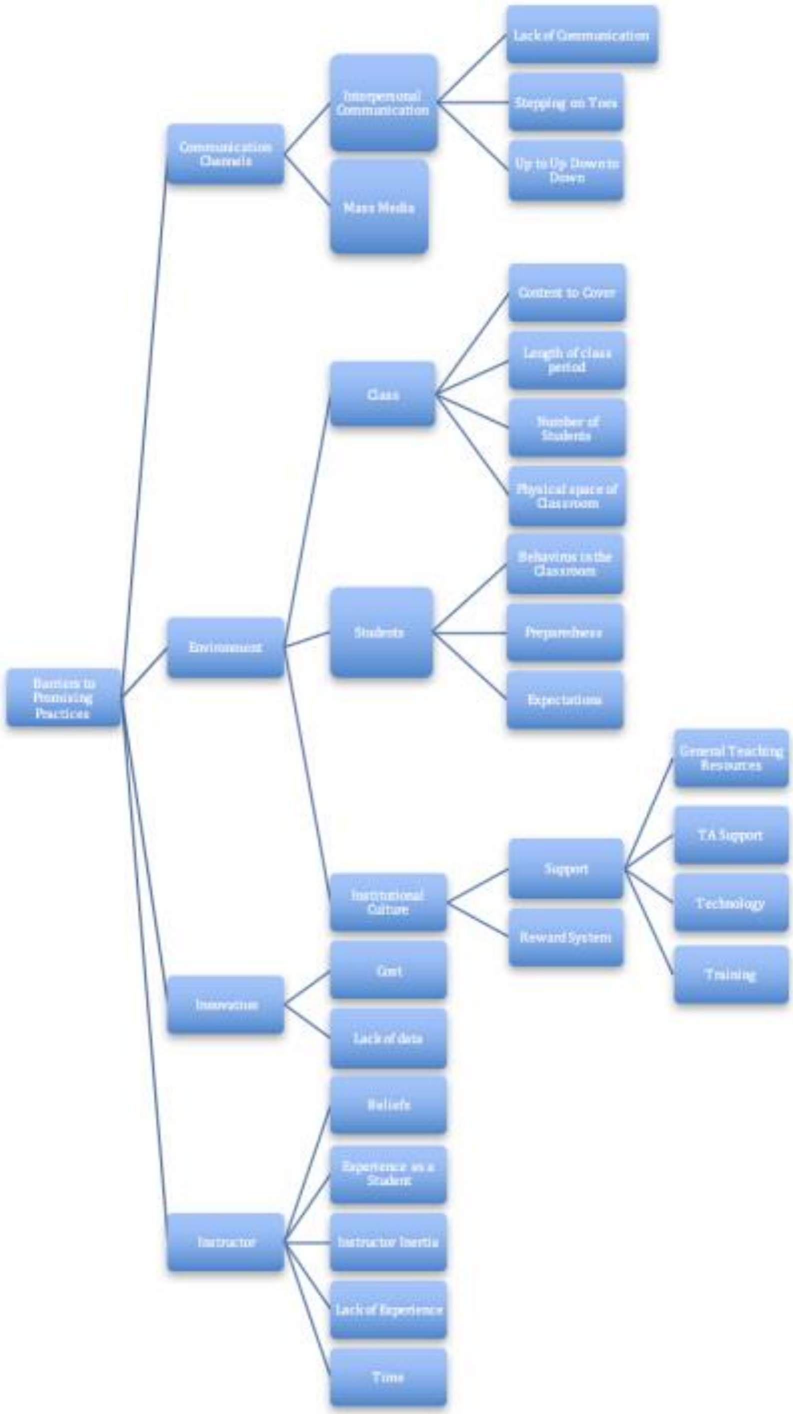

Figure 4.8. Coding structure for Barriers.

Communication channels. Instructors learn about innovations such as PPs through interpersonal communication or through mass media (Rogers, 2003). However, under certain conditions, the dissemination of information about PPs could be constrained or limited. From our interview data, barriers in interpersonal communication were more evident than barriers through mass media. Instructors reported three types of barriers in interpersonal communication: lack of communication, stepping on toes, and "up to up, down to down" (Bryk et al., 2016).

Table 4.12 describes the communication channel barriers and provides examples that illustrate each barrier. In general, instructors felt that there was a lack of communication regarding issues of teaching in their departments. As one instructor stated, "I mean, there's no formal mechanism for reporting and disseminating teaching practices in the department. It's something I kind of wish we did have" (D. Cash, personal communication, January 6, 2016). The comments attributed the lack of communication between instructors to busy schedules and a reluctance by instructors to intrude on each other's classroom turf (i.e., stepping on toes). As one instructor stated, "I feel teaching is a lot like parenting. I have two kids and if you tell me how to raise my kids, I'll maybe hit you – you know, so I shouldn't be telling you how to teach your class either" (J. Shuman, personal communication, September 28, 2015). Besides the fear of stepping on another instructor's toes, instructors described a social system that discourages communication across instructor seniority ranks, a barrier that has been called "up to up, down to down" by Bryk et al. (2016). This barrier is exemplified in statements by two instructors on the opposite ends of the seniority ranking system, a professor and a lecturer.

Professor	Lecturer
"I think if you had a formal sort of discussion of undergraduate teaching, what you often get is someone who maybe doesn't do the research anymore. That's not the role model I can follow" (T. Rizzo, personal communication, January 25, 2016).	"I'm kind of out of the loop. I don't go to faculty meetings—I feel a little bit out of the loop" (A. Kim, personal communication, October 2, 2015).

Table 4.12

Barriers to PPs: Interpersonal Communication

Barriers	**Description**	**Interview Excerpts**
Lack of communication	General lack of communication between instructors to exchange or discuss teaching strategies.	"There's no formal mechanism for reporting and disseminating teaching practices in the department. It's something I kind of wish we did have" (D. Cash, January 6, 2016).
Stepping on toes	Belief that instructors are independent in the classroom. This prevents the sharing of pedagogic information and knowledge.	I feel teaching is a lot like parenting. I have two kids and it's like, if you tell me how to raise my kids, I'll maybe hit you – you know, so I shouldn't be telling you how to teach your class either" (J. Shuman, September 28, 2015).
Up to up, down to down (Bryk et al., 2016)	Barrier that results from a lack of communication between instructors of different ranks.	"You sort of gravitate towards the ones that you find are close to you" (T. Rizzo, January 25, 2016).

Note: Excerpts from interview data.

In addition to receiving information about teaching practices through interpersonal communication, instructors also have the potential to learn about them through mass media (Rogers, 2003). Yet, instructors in this current study did not report engagement with mass media, which was unexpected considering the importance of mass media in the DoIT and the theoretical framework for this study.

Environment. The environment is the context in which instructors work. It encompasses the classroom, students in the classroom, and the university. In the classroom, the barriers mentioned were the course content, length of a class period, the physical space of the classroom, and the number of students enrolled in each course.

Although, the course content is usually decided by the instructors in a department, instructors feel a need to cover the chapters in a book. For example, an instructor stated, “I get told that I’m going to teach these ten chapters out of the book and I have to cover it – there’s other elements of the curriculum especially for chemistry majors later that rely on that material” (D. Van, personal communication, October 21, 2015). As a result of this need to cover particular content, instructors chose instructional practices that did not take time away from the overarching goal of delivering content. This drive is emphasized by an instructor who said, “It’s this drive to get content covered. You have to complete the syllabus. There is no time, you know. And that’s my challenge actually” (R. Arase, personal communication, June 21, 2013). An additional constraint on the time to deliver the course content, beyond the duration of the term, is the length of a class period. Instructors believed that a typical class period (e.g., 50 minutes) was not enough class time to incorporate the PPs that comprise Active Learning or Collaboration. The presumption was that PPs take more time to implement than lecturing. An instructor suggested a more flexible class period: “To do an effective job, what we need is flexibility to have three hours to spend one week or two hours another time” (D. Van, personal communication, October 21, 2015).

Instructors also felt that the physical layout of the classroom constrained the implementation of PPs, especially the arrangement of desks and chairs that are immobile and limit student movement. A common refrain from instructors is, “The seats are not designed to be moved around so that students can work collaboratively” (D. Van, personal communication, October 21, 2015). Another instructor added, “You can talk to the person next to you. That's about it" (M. Kat, personal communication, October 28, 2015). For instructors, this type of seating arrangement also limits instructor and TA interactions with students. As noted by an instructor, "A couple of TAs would have to be at the lectures. Somebody has to walk around and talk to these groups. How many groups are you going to have? Are you going to have that many people interacting with them?" (H. So, personal communication, November 6, 2015).

However, the most challenging classroom barrier described by instructors was the sheer number of students in the classroom. Instructors reported that they taught up to 450 students. As a result, instructors anticipated several challenges to implementing PPs, including forming groups for collaborative work, helping all the students, and being able to hear individual responses if all 450 students were speaking at once (e.g., O. Clint, personal communication, February 11, 2016).

In addition to student numbers, student behaviors can also impact instructor pedagogic decisions. For example, student behaviors such as cheating, not attending class, coming to class unprepared (e.g., not completing assigned reading), and participating in activities with reluctance tended to discourage instructors' use of PPs. It is not only student behaviors, but also their level of preparedness prior to enrolling in the course and their expectations of the course that influence pedagogic choices instructors make.

Although it easy to see instructors' work as mainly in the classroom, instructors also work in a university department, which is nested in a larger school and the institution as a whole. Outside the classroom, the institutional culture can inhibit the use of PPs if the culture favors more traditional approaches to teaching (B. Sayer, personal communication, December 10, 2015). Also, if the tenure system favors research over teaching, instructors will be less inclined to implement PPs in their classrooms (e.g., Fairweather, 2008). Instructors may also be less inclined to use PPs if they lack support from their institution. Interview data show that a lack of general teaching resources, TA support, reliable technology, technology used for PPs, and professional development could diminish instructors' use of PPs in the classroom (e.g., S. Tate, personal communication, January 6, 2016). Table 4.13, the fifth table in Appendix C, describes the barriers that exist in instructors' environment and provides excerpt examples that exemplify the barriers. Barriers are listed under the type of environment: class, institution, students.

The importance of professional development can be seen in a case study from our interview data. This case study is an assistant professor who was new to teaching at the time of our research (O. Nova, personal communication, December 10, 2015). When she first started, she used some of the PPs developed by a LSOE in the department, but was unsuccessful in implementing some active learning strategies. As a result, she switched back to doing more lectures and cutting out the use of iClickers in the classroom. Instead, she asked students to raise their hands in response to her questions. This shows how important instructor training is in the use of PPs. Without the proper training, the instructors might be unsuccessful in their implementation of certain PPs. Students could push back, leading to instructors concluding that PPs do not work.

Innovation. Although the perceived characteristics of an innovation can have an impact on the diffusion of PPs, there were few instructor comments to support the idea that they play a role. Of the several perceived characteristics identified by the DoIT, three characteristics were mentioned by instructors in our sample (Table 4.14). The comments that were coded suggest that the cost associated with PP implementation and the lack of data to show advantage inhibited instructors' use of PPs. The cost of PPs could include the purchase of the technology that instructors might need for successful implementation (e.g., iClickers for active learning activities). When instructors mentioned the cost of the PP as a barrier, they were expressing their concern for students who might be burdened with additional school costs, especially if the cost cannot be amortized across quarters and courses. For example, an instructor commented, "If we have a system that we can do it without having [students] pay more money or that we would universally implement in engineering, I would be in favor" (L. Wan, personal communication, October 16, 2015).

Another characteristic of PPs that inhibits adoption is the perceived lack of advantage. Instructors either did not see enough data to support the need to adopt PPs or felt the research supporting PPs did not provide meaningful evidence. This is highlighted by a reluctant instructor who commented: "I think it would work well, but I still need to see whether I have evidence for that" (M. Smith, personal communication, January 7, 2015).

Table 4.14

Barriers: Characteristics of the Innovation

Barriers	Description	Interview Excerpts
Cost	The cost associated with PPs, e.g., iClickers for students.	"I thought about using iClickers, then my TAs all objected to it. They said it's an extra expense to add on to the students" (L. Wan, October 16, 2015).
Data	Lack of data or inconclusive data.	"I think it would work well, but I still need to see whether I have evidence for that" (M. Smith, January 7, 2016).

Note: Excerpts from interview data.

Instructor. Analysis of the interview data shows that there are three prominent barriers associated with instructors as a category: instructor beliefs about their abilities and about teaching, instructor inertia, and instructor's lack of time. Other less prominent barriers are instructor lack of experience and instructor experiences as students. Table 4.15, the sixth table in Appendix C, provides the codes, the descriptions of the codes, and interview excerpts that exemplify the codes. Instructors hold certain beliefs about learning and teaching which may not be conducive to their use of PPs. From the point of view of the instructor, these beliefs include the following: students learn more if they can “sit quietly and think about things” on their own (H. Sole, personal communication, November 6, 2015); instructors should be “able to talk in class” (R. Patterson, November 24, 2015); the best way to convey information is through lectures (H. Sole, personal communication, November 6, 2015); and PPs should occur in discussion sections (D. Van, October 21, 2015).

Another instructor barrier is the tendency to teach the way they were taught or teach using familiar methods with which they are comfortable. Using the description by an instructor in our data sample, I refer to this tendency as “instructor inertia” (T. Rizzo, personal communication, January 25, 2016). The instructor expanded on the instructor inertia by saying, “Part of it is just simply my inertia of going away from what I grew up [with] and how [I expect] teaching should work, and to just able to let go of that” (T. Rizzo, personal communication, January 25, 2016).

Some instructors made connections between instructor inertia and time. They admitted that they did not want to teach differently because they lacked the time, or that teaching differently would require too much time. These time related comments showcased a conflict between instructor teaching responsibilities and their need to conduct research. This is evident in a comment by an instructor who said, “I spend 60 hours a week outside of teaching doing research. And so, to put in, you know, into one lecture 10 or 12 hours, it just can’t happen” (D. Baker, personal communication, December 4, 2013). This lack of time has overwhelmed some instructors, especially one instructor who was apologetic and said, “I feel bad that I’m not being as innovative as you know, the some…optimal innovators. And again, I tell you, I’m kind of feeling that I'm barely keeping my head above water" (R. Patterson, personal communication, November 24, 2015). Even when instructors might have time to implement PPs, their lack of experience could be a barrier. An instructor admitted, "I mean, I did not know how you could make math exciting" (D. Baker, personal communication, December 4, 2013). Other instructors indicated that they did not know how to engage students in high-enrollment courses.

Drivers of Promising Practices

For the category "Drivers of PPs," the analysis resulted in two child codes under the parent code Communication Channels (interpersonal communication, mass media), three child codes (classroom, institution, outside university support) under the parent code Environment, two child codes (advantage: data to support PPs, observability: normalization of PPs) under the parent code Innovation, and six child codes (early career training, experiences as a student, frustration that led to change, instructor beliefs, mentors, opportunities for reflection) under the parent code Instructors. Table 4.16, the seventh table in Appendix C, provides a list of Drivers, their descriptions, and excerpts from interviews that exemplify each driver.

Table 4.17

Frequency Count of Drivers of PPs

Drivers	**Count**
Communication Channel	39
Environment	32
Innovation	10
Instructor	35
Total (*N*)	114

Overall, there were 114 interview excerpts coded for Drivers, which was only a third of the number of excerpts coded for Barriers. Three main parent codes had very similar frequency counts: communication channel (39), environment (32), and instructor (35). Innovation (10) had the fewest attributed number of excerpts (Table 4.17).

Frequency counts of Drivers by instructor variables and by department are shown in Table 4.18, the eighth table in Appendix C. As expected, there were more excerpts coded for male instructors (77) than female instructors (34). Four position types had the most number of excerpts coded for this category: professor (29), assistant professor (23), LPSOE (15), and associate professor (14).

Below, I describe the various drivers organized under the parent, child, and grandchild codes.

Communication channels. The analysis of the interview data shows that instructors learned about PPs primarily through interpersonal communication with colleagues. Three different groups of colleagues emerged from the data: co-workers, LPSOEs and LSOEs, and opinion leaders. Co-workers are other instructors in the department or colleagues at the university. LPSOEs and LSOEs are classified differently than co-workers because they are described as instructors whose job responsibilities emphasize teaching over research. Opinion leaders are also classified differently because they exert more influence than other instructors in a department. Notably, interview data suggest equal influence by co-workers (12 coded excerpts), LPSOEs and LSOEs (16 coded excerpts), and opinion leaders (10 coded excerpts), despite the disparity in the number of these position types throughout the focal university's departments (Table 4.18).

Instructors describe learning about PPs mainly through informal rather than formal interactions. These informal interactions are not sponsored by the institution and could occur during lunch meetings or conversations with colleagues. As described by an instructor, "We have faculty lunch meeting in the organic chemistry [department]. Usually Friday we come together for lunch. It's just every time, randomly some discussion, and then sometimes the people you know mention [practices they are trying] and then we talk about [them]" (Z. Gown, personal communication, February 6, 2014). Through these informal interactions, instructors are "inspired by friends and colleagues" (A. Kang, personal communication, January 19, 2016), look at other instructors' materials (e.g., handouts or syllabi), and observe other instructors' classes.

Instructors also learn about PPs through mass media such as STEM education journals, newspapers, and the internet. However, there are fewer coded excerpts related to mass media than interpersonal communication in this analysis. Of the three excerpts that discussed mass media, one mentioned research journals, while two mentioned the *New York Times* newspaper.

Environment. The factors that contribute to adoption of PPs can be found in the classroom, in the university, and from external organizations. In the classroom, positive student reaction to PPs was the main driver to instructors' use of PPs. Outside the classroom, the university plays a large role in instructors' adoption of PPs. Universities can positively drive the adoption of PPs by providing professional development, teaching resources such as iClickers, and by hiring instructors who have experience with PPs.

Instructors mentioned the professional development that they received from the university throughout their career trajectory as a reason they adopted PPs. The training instructors received early in their career included training when they were graduate students, pedagogic training as post-doctoral scholars, and training in formal programs such as the Howard Hughes National Academy Summer Institute. Instructors also mentioned informal training from colleagues as important factors in their uptake of PPs. Sometimes these training sessions originated from a LPSOE or LSOE. One instructor credited a mentor for her use of PPs (O. Nova, personal communication, December 10, 2015). In addition to influences from others, one instructor mentioned an opportunity to watch a video of his own class as a turning point in his teaching (M. Smith, personal communication, January 7, 2016).

For instructors who adopted PPs, the availability of technology associated with those practices was essential. Through the normalization of technology such as iClickers, instructors were able to obtain information and ideas for activities from their colleagues. Additionally, normalization of technology use throughout their department served to alleviate instructor concerns that their students might incur additional costs affiliated with the purchase of a new device that was not used in other courses.

The role the university plays in influencing the use of PPs also includes the hiring of LPSOEs or LSOEs who are tasked with implementing, researching, and disseminating information about PPs. Instructors who are LPSOEs or LSOEs in our interview data reported that they adopted PPs because it was an explicit job responsibility.

Beyond the university, support from external organizations was mentioned as driver of PPs. An example of this support is book publishers making available prepared teaching materials (e.g., Powerpoint slides) and videos for instructors to use.

Innovation. Two characteristics of PPs were mentioned as reasons for their adoption by instructors. First, data that show the relative advantages of PPs over traditional instructional practices served to promote the use of PPs in classrooms. Data usually came from published research studies but also from research conducted internally in departments.

The second characteristic of PPs that promoted adoption was observability. Observability of PPs contributed to adoption in two ways. Instructors reported that opportunities to observe classes taught by their colleagues demonstrated the potential for student learning afforded by PPs. Also, by observing PPs in other classes, instructors felt PPs were normalized in the department and that using them was accepted by the department and by students. This is evidenced by an instructor who said, "I had a group of people who came to my office hours and they had said, oh yeah, you teach the same way as [another teacher in the department]. Well if one person's doing it, it may be crazy. If two people are doing it, there must be some validity to it" (A. Brink, personal communication, December 12, 2013).

Instructor. Instructors have certain beliefs, dispositions, and experiences that influence their pedagogic decisions. In regards to PPs, several instructor beliefs were mentioned as drivers to the adoption of PPs. These include instructor beliefs about themselves and their ability to implement PPs, and the belief that PPs are more effective at promoting student learning than traditional teaching methods. This belief is represented by the quotes "I became increasingly convinced that students learn virtually nothing from lecture" (B. Hide, personal communication, October 19, 2015) and "if you're just lecturing, yes you can deliver content, but content doesn't really matter anymore" (J. Shuman, personal communication, September 28, 2015).

Instructors' experiences as students could also impact their decision to adopt PPs. These experiences can occur at all levels of their education. In the interview data, an instructor described his experience as an undergraduate student in a physics class. In that class, learning was through opportunities for problem solving. This experience was formative in his belief about the importance of problem-solving. This belief held firm even after becoming a university professor and witnessing other instructors' lecturing.

CHAPTER 5: DISCUSSION

In this study, I documented instructional practices in large STEM courses and the factors that contribute or inhibit the use of PPs in the classroom. I present this discussion section by the order of the research questions.

How prominent and widespread are so called "promising" instructional practices?

In comparing instructors' use of PPs by their position types, gender, and departmental affiliation, Epistemology was observed in the highest percentage of classes. A possible explanation is that these activities are natural extensions of lecturing and do not require any additional equipment, reconfiguration of the classroom, or student movement. If viewed through the lens that activities related to Epistemology and lecturing are very similar, then the findings of this study are consistent with the results of prior studies (e.g., Hora et al., 2014), which show that lecturing is nuanced and is usually accompanied by other instructional strategies. However, the intent of this view was not to lend defense to those who might conclude that lecturing could be used as a PP. Rather, the argument is that if instructors are engaging in activities that do not deviate from their natural inclination to lecture, then PPs might be best promoted by first mapping instructor classroom routines prior to the introduction of any new instructional practice. This will ensure that new instructional practices fit within those routines and increase the likelihood of adoption (Hall, 2010). Later in this discussion, when discussing barriers to adoption, I will revisit this idea of classroom routines and what is natural for instructors, and imagine how education reformers can leverage this knowledge to increase adoption of PPs.

In contrast to Epistemology, Collaboration was seen least often of the four PPs that were studied. Notably, Collaboration was the PP where significant differences were found between various instructor position types and between instructor gender, and among departments.

However, these differences might provide a path to improving student learning. In Reimer (2017), several instructional practices were studied in connection with changes in student learning outcomes. Collaboration was identified as one of the levers that contributed to academic gains. Consequently, improving the amount of collaborative activities in classrooms could be one way to reach some goals of STEM education reform.

How do instructional practices differ across instructors (type of appointment, gender) and departments?

Position types. Differences in instructional practices by instructor position type were investigated by comparing several instructor categories: 1) Non-tenured v. Tenured; 2) Instructor seniority ranking; 3) Research track v. Teaching track (all instructors), 4) Research track v. Teaching track (tenure-track only).

This study found that non-tenured instructors were more likely to implement PPs than tenured instructors. Further investigation of PPs by seniority showed that junior tenure track (assistant professor and LPSOE) implemented PPs more frequently than instructors of different ranks, with Collaboration being significantly more prevalent. Additional analysis by job track showed that teaching instructors were more likely to implement PPs, especially within the construct of Collaboration. Through these multiple comparisons of instructor categories, the findings narrow and point to *LPSOEs* as instructors who have widely adopted PPs. The identification of LPSOEs as high users of PPs is important because it reaffirms the ostensible strategy by the university to hire teaching-track instructors such LPSOEs and LSOEs to increase the use of PPs in STEM classrooms.

Departments. Significant differences in the use of PPs across departments were very striking. The two departments that implemented PPs significantly more than other departments were biology and physics, which is consistent with previous studies that measured differences in instructional practices across university departments (e.g., Hora et al., 2013). An explanation for these differences is the amount of time departments have had in implementing new teaching strategies (e.g., Froyd, 2008). This favors the physics department which has had a longer history of implementing PPs than other departments (e.g., Shadle et al., 2017). However, history alone might not explain the differences in the use of PPs. From the interview data, it was discovered that the two opinion leaders mentioned in this study were instructors in the biology and physics department. Not only were they high users of PPs, they were instrumental in hiring LPSOEs. One instructor in the study revealed a fact about one of the opinion leaders, “[She] was able to hire people who were extremely important in developing techniques and approaches and just coming up with ideas” (R. Ware, personal communication, February 11, 2016). Several other instructors confirmed the importance of the opinion leader and her role in their hiring and use of PPs. Rogers (2003) further supports the important role opinion leaders play when he wrote: “Opinion leaders serve as a model for the innovation behavior of their followers” (p. 27).

Although the high use of PPs by the physics and biology department might be explained by the history of implementation and opinion leadership, what are the implications of these differences? First, the differences suggest that there is a lack of communication across departments. Our interview data lend support to this argument, with one instructor stating, “There’s no formal mechanism for reporting and disseminating teaching practices in the department. It’s something I kind of wish we did have” (D. Cash, personal communication, January 6, 2016). Second, there are department-specific conditions that challenge the implementation of PPs. As a result, having a one-size fits all change strategy might not work.

Within individual instructors and across the departments and the university, what inhibits

or contributes to the adoption of particular instructional practices and diffusion of new approaches to instruction?

The results of the interview data show a broad array of both Barriers and Drivers to the diffusion of PPs. Our findings echo those found in many studies that span decades and multiple educational settings, including K-12 (Fullan, 2016; Henderson & Dancy, 2007; Michael, 2007). Yet, when framed within the DoIT, the findings construct a clearer picture that explains the adoption dilemma that has plagued STEM education reformers (Henderson et al., 2011). In this section, I describe this picture through a discussion of the prominent categories that influence instructional decisions.

Communication channels. Communication channels in university serve as conduits to convey information about PPs among instructors. Rogers (2003) found that both interpersonal and mass media were important in determining the rate of adoption, with mass media being more important in bringing about *awareness* of an innovation, and interpersonal communication playing a more prominent role in bringing about *adoption*. The findings from this current study reaffirm the conclusions in Rogers (2003), but also provide additional information about how instructors in this current study receive information about PPs. Although studies of Barriers and Drivers of PPs normally do not focus on communication channels (e.g., Froyd, 2008; Henderson & Dancy, 2007), the results show that information and where it comes from plays a major role in instructors' decision-making processes and have implications for the success or failure of PPs during the implementation process.

As predicted from the DoIT, instructors receive their information from both mass media and through interpersonal communication. Within this study population, the online version of the *New York Times* was cited as a form of mass media that generated instructor awareness of PPs.

However, interpersonal communication was responsible for both bringing about awareness and contributing to the adoption of PPs. These interpersonal communications were the result of interactions that took place in both formal and informal conditions. As previously discussed, formal conditions are defined in this study as those events sanctioned or organized by the department while informal conditions include lunch with colleagues or “meetings” in the hallway. In regards to interactions that lead to discussions on pedagogy, informal interpersonal communication was more prevalent than formal. Through informal interpersonal communication, instructors learn about PPs, co-create course materials, choose course textbooks, and share teaching strategies. There were two categories of instructors who were instrumental in disseminating information: teaching track instructors such as LPSOEs and LSOEs, and opinion leaders. Two opinion leaders in our study were specifically mentioned. One was a professor who had become a top university administrator; another was a professor who had received the Howard Hughes Medical Institute award. However, teaching-track instructors such as LPSOEs and LSOEs were cited more often as persons responsible for diffusing information about PPs to other instructors.

For decades, education reformers have assumed that communication channels are effective at disseminating information. Fairweather (2008) described a typical strategy in which innovative teaching practices are designed and disseminated. Armed with evidence that these practices were effective, the assumption was that PPs would automatically diffuse through schools and pass along to teachers who would adopt them. Most efforts to reform undergraduate STEM education start from a presumptive reform model, one based primarily on in-classroom innovation and the teaching-learning process. The premise here is that the collection of hundreds if not thousands of individual faculty member improvements, initiated at least in part by empirical evidence of effectiveness, will lead to an aggregate change of a high order of magnitude.

However, the results from this current study show that the strategy to increase adoption through dissemination efforts alone has been ineffective. Instructors in this study often lamented a lack of discussions about teaching between instructors in their departments. Two main reasons were cited for the lack of collegiality: Instructors' unwillingness to intrude upon each other's autonomy in the classroom and a seniority system that keeps instructors isolated by rank.

There is a professional culture that places high value on instructor autonomy. Tagg (2012) labeled instructor independence as an "endowment," or something valuable that instructors do not easily relinquish. As a result, instructors abstained from foisting their views of teaching on other instructors—this was particularly evident in one instructor's comparison of teaching to parenting, with intrusion on both parental and professional autonomy considered to be highly offensive (J. Shuman, personal communication, September 28, 2015). Interestingly, this comment was made by a LPSOE. Despite his self-acknowledged professional responsibility to disseminate information about PPs, he was unwilling to violate the tacit rule of not intruding on another instructor's turf, especially that of a higher-ranking instructor.

Differences in rank were another reason that instructors did not generally discuss teaching among themselves. As described by one lecturer, "I'm kind of out of the loop. I don't go to faculty meetings. The research and teaching sort of thing" (S. Queen, personal communication, December 10, 2013).

The second reason communication channels proved ineffective to increase adoption is that the information instructors receive might not be accurate or thorough. Although instructors did not explicitly state that the quality of information they received was a barrier to adoption, there is evidence of instructors abandoning their use of certain PPs for these reasons. Upon further examination of the reasons for rejection, it was found that instructors passed along to their colleagues their knowledge of PPs and possibly the accompanying syllabi or course material unsystematically and without providing much support or guidance. Although we could attribute instructors' abandoning of PPs to poor implementation, the reason for issues of implementation goes beyond instructor effort and includes the fact that instructors who are just adopting unfamiliar PPs are at a disadvantage given the lack of scaffolding and support. Evidence from Fullan (2016) supports this conclusion, as "purposeful interaction is essential for continuous improvement" (p. 108).

Environment. The environment in which university instructors work includes the classroom and the institution. Students are also included in this analysis of environment because they affect instructional practices.

Classroom. In the classroom, our results show that the physical space of the classroom, especially the arrangement and small size of desks, create barriers to instructors who attempt to implement PPs. In addition to the physical space, instructors also have to contend with non-physical factors such as the large numbers of students, the length of the class period, and the course content to cover. These findings are consistent with findings from previous related studies (e.g., Henderson & Dancy, 2007; Michael, 2007; Shadle et al., 2017), and build upon them in important ways.

Despite these barriers in the classroom, some instructors still implement PPs in creative ways. For example, one instructor allowed student seating only in every other row to create space for him to maneuver between students. This approach opened the possibility for more student collaboration by allowing him to interact with all students. Another instructor created a participation zone consisting of several rows of students in front of the classroom. Students sitting in these rows were expected to do all the reading, interact with the instructor, and volunteer to come to the board to solve problems. Confining interactions and problem solving to only a small segment of the students in the classroom reduced the instructor's need to reach all the students, but created a very active learning environment. Since students rotated in and out of the participation zone, all students had opportunities to interact with the instructor and solve problems in class. These examples of instructors overcoming challenges in the classroom demonstrate that classroom barriers might not be the only reason PPs are not being adopted by the majority of instructors. This hypothesis is shared by numerous studies (e.g., Henderson & Dancy, 2007; Michael, 2007) and especially Lund et al. (2015) who not only found that instructors were able to overcome classroom-related barriers, but that instructors in large classes and amphitheater-style seating enacted more collaborative learning activities than instructors who did not teach in this type of classroom.

Institution. There is an individual-blame bias inherent in STEM education reform with the call for education reform placing the burden of change squarely on the shoulders of instructors (AAAS, 2011). Indeed, it is not uncommon to find research studies framing barriers to educational reform in terms of instructor characteristics (Kuh & Ikenberry, 2009). Despite this bias in the literature, Brownell and Tanner (2012) argue that it might be necessary to shift the focus to the system. Rogers (2003) describes several examples in which there were beneficial results when the system was the focus of change rather than the instructor.

The results of this current study show that it might be necessary to place more emphasis on the role that environmental factors play, especially the role of the institution. The first indicator of this is in the comparison of instructor characteristics and environmental factors

(Figure 5.1). The number of barriers attributed to the environment outweigh those related to the instructor, both in the number of barriers in associated with each and the number of excerpts coded. Sunal et al. (2001) also concluded that the institution has more control over change than instructors. In fact, they found that instructors were in control of only a handful of inconsequential barriers.

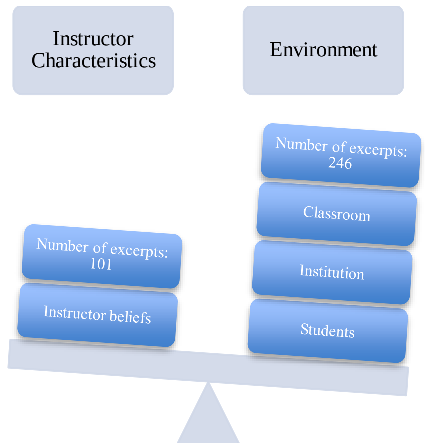

Figure 5.1. Comparison of instructor characteristics and environmental factors that impact instructional practices.

The results also show that the institution affects instructional practices in three ways: through the institutional culture, the level of learning resources support, and the reward system inherent in tenure. These findings are mentioned across the literature (e.g., Brownell, 2012; Henderson & Dancy, 2007; Michael, 2007). Overall, these findings are persistent and can be traced back decades to earlier studies (e.g., Cuban, 1990; Fullan, 2016).

To understand the role that the institution plays in an instructor's instructional practices, I analyzed the decision-making of one instructor who was a high user of PPs. Through the analysis, it was evident there were several key areas where his instructional decisions were based on the institution's prior conditions. First, his access to high users of PPs, people from whom he was able to obtain information about iClickers and other teaching strategies, was through proximal location of offices. Because office location is decided by school administrators, his first exposure to iClickers and innovative teaching strategies was the result of the institution's actions. Other studies (e.g., Frank et al., 2004) reinforce the argument that institutions have much influence over instructor social networks through control of office space and the organization of opportunities for instructors to meet and socialize.

Second, the institutional support for iClickers from my case study's department made the decision to use them much easier. As stated by another instructor in the same department, "This is something that most of the physics instructors do for the big classes and so I basically just inherited it from what other people have done" (M. Smith, personal communication, January 7, 2016). This shows that departments can influence and increase the adoption of PPs by making learning resources available and fostering a departmental culture that supports active learning pedagogy.

Finally, through the actions of the school's registrar, the instructor in this case study was able to teach in a room with only 70% enrollment capacity. As a result of administrative action and support, he created a more collaborative learning environment and adopted more PPs. This case study exemplifies the importance of institutional support in the type of learning that students receive.

Students. Certain student behaviors in the classroom, level of preparedness (e.g., completing required reading before class), and expectations can affect instructors' pedagogic decisions. Behaviors that make it challenging for instructors to implement PPs include cheating, lack of attendance or class preparation, and active resistance to the learning strategies associated with PPs. As a result of student behaviors such as cheating, some instructors in the study became frustrated and rejected the PPs associated with the behavior, while other instructors opted to modify their lessons. For example, an instructor did not want to completely "flip" his class because students did not complete their readings prior to coming to class (a requirement for flipping the class). His comments conveyed a sense of frustration, "I would say that my lectures are hopefully maybe a 50/50 balance between me talking and them doing stuff. I don't think I could get too much more than that. I don't think I could ever get to just problem-solving during lecture. Not all students are capable of following that" (B. Sayer, personal communication, December 10, 2015).

In addition to student behaviors, student expectations and their diverse levels of course readiness (e.g., reading or math skills) force instructors to limit the use of PPs in the classroom. These findings are certainly consistent with findings from previous related studies, e.g., work by Michael (2007) who found the following: students do not know how to do active learning; active learning is compromised because students do not come to class prepared; students are unwilling to engage in active learning; active learning is difficult to do because of student heterogeneity; students lack the maturity needed for active learning; and student expectations about learning are a barrier. Crucially, these findings frame student behaviors and expectations in two important ways that may have implications for universities wishing to embark on change initiatives. First, student behaviors and expectations are products of experiences in an education system highly dependent on the lecture to deliver course content (e.g., NRC, 2012). For example, an instructor described his students' reaction when they came to his class and had to engage in more active learning strategies: "You do get a lot of complaints about the workload and I think especially in contrast to some of the other similar classes where they don't have that workload; it's an adjustment for them" (B. Sayer, personal communication, December 10, 2015). This type of student reaction was also evident in other instructor comments. School learning culture and experiences have molded student expectations and provided limited exposure to PPs (NRC, 2001). When the type of learning in courses with high levels of PPs did not match their expectations, students resisted by complaining, not attending classes, behaving in ways that demonstrate their displeasure (e.g., not participating in class), enrolling in other courses that do not have active learning components, and ultimately rating the instructor poorly on end-of-quarter evaluations or websites such as ratemyprofessor.com.

The second important way that we can think about student behaviors and expectations is that classifying them as barriers might not be wholly accurate. Much of our evidence shows that these student "barriers" do not necessarily prevent or hinder the use of PPs. Rather, they serve to inform and shape instructional practices (Figure 5.2).

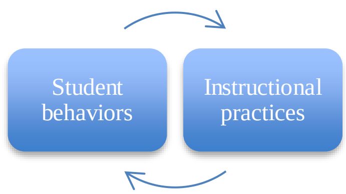

Figure 5.2. How student behaviors influence instructional practices.

Evidence shows that instructors generally adapt their instructional practices to address student behaviors. For example, instructors who were using iClickers in active learning activities stopped using the devices when students complained about participation points associated with the activities. However, the instructors did not stop doing the activity altogether. Instead of using the iClickers, the instructors asked students to raise their hands to register an answer. In another example, an instructor made a point at the beginning of every course he taught to explain the rationale for doing more active learning to his students.

Instructor characteristics. Instructors have beliefs about teaching and student learning that allow them to overcome a lack of institutional support, presence of student resistance, or problems with implementing some innovative teaching strategy. For example, an instructor said, "There was no institutional support for it, so I had to just do it by trial. I think going back [to a typical lecture] is not an option because I know it doesn't work" (P. Dale, personal communication, September 21, 2015).

Some epistemological beliefs are deeply rooted and seem to be shaped by various factors that include experiences as students, mentors and teachers, early career training, and frustrations as teachers. For example, an instructor said, "My mom always used to say never forget you don't teach curriculum, you teach the students" (A. Kim, personal communication, October 2, 2015). Other beliefs pertaining to teaching and learning were formed from experiences as students, e.g., "We tend to teach the way we were taught" (T. Rizzo, personal communication, January 25, 2016). However, there is evidence that these beliefs can shift as a result of early career training as well as mandates from their supervisors.

Unfortunately, instructor beliefs are very difficult to overcome once they are established. For example, an instructor was unwilling to give iClickers a try because he had seen a poorly implemented activity with iClickers. Even though he had read research articles afterward that contradicted his conceptualizations of iClickers, he was steadfast in his previous judgment.

Through the analysis of extant Barriers and Drivers, it is evident that instructors react to change through two overt patterns of behavior. First, instructors behave in the ways that seem most natural to them. By "natural," I mean actions that do not take much time or effort, and do not go against their existing beliefs, interests, or conceptualizations of learning and teaching. Our evidence shows that instructor pedagogic decisions and actions are consistent with their mental frameworks and daily routines. Tagg (2012) reminds readers that instructors are "just like you and me…they are making their way through the challenges of daily life with the same strengths and weaknesses that most exhibit" (np). Brownell (2012) described this tendency to act in ways that are natural as fulfillment of one's identity. Together with Sunal et al. (2001), Brownell argued that instructors are afraid to "come out" as teachers because their professional identity is closely associated with research rather than teaching. They added that instructors use more traditional lecturing approaches because of the familiarity of the lecture style. Results from this current study confirm the previous argument and also show that, when seeking information about teaching, instructors go online, not necessarily looking for peer-reviewed education research but rather for articles in the *New York Times* and other forms of mass media that they normally visit. Scientific journals such as *Science* have arrived at similar conclusions and started to include more education research articles, in an effort to reach this audience. This approach is also being adopted by scientific conference organizers, who have begun to host more education sections within their annual meetings (Brownell, 2012). Additional evidence of instructors doing what is natural is in how they communicate with one another: they mostly talk to colleagues who are similar in rank and to those whose offices are located nearby, not to instructors in another department or education consultants in organizations on campus who provide training on instructional practices. In many cases, discussions about teaching occur during lunch or chance encounters in the hallways. These brief meetings do not take much time to organize and occur through normal daily activities.

The second pattern of behavior is that instructors change their teaching only in the face of a real or apparent need, such as dissatisfaction with their conceptualization of teaching or low demonstration of learning by their students. Sunal et al. (2001) and other scholars studying change in these settings (e.g., Fullan, 2016) have made similar observations. It is evident in how some teaching-track instructors describe their turn to PPs. Despite years of learning through lecture-based instruction, several of them admitted during interviews that it was not their natural inclination to teach using PPs, but something that they embraced as part of their new work-related circumstances. For some, they are not absolute believers in active learning strategies, but are committed to implementing them for the sake of the job. Other instructors who changed their instructional practices saw a need when they received extremely low student evaluations. Instructors in our study made concerted efforts to change their instructional practices when they received low student evaluation scores and critical student comments. One of these instructors described the process in the following statement, "I got 2.8 overall (out of 5), which is, you know, below, below the lowest. And I was very upset because I put so much time into the class. It was unbelievable. So, I just sat and thought what can I modify to improve" (O. Nova, personal communication, December 10, 2015).

Perceived innovation characteristics. Rogers (2003) described five key characteristics of innovations that affect adoption. A key characteristic is the relative advantage of the innovation. Despite overwhelming data that demonstrate the advantages of using PPs, traditional teaching approaches persist (e.g., Handelsman et al., 2004). If the relative advantage of PPs is not convincing enough for instructors, then what characteristics of PPs are instructors using to make their decisions? Our results showed two major considerations: the *cost* and *benefit* associated with the adoption of PPs. Wejnert (2002) supports this argument but notes that costs and benefits should be further subdivided into the following categories: monetary and nonmonetary, direct and indirect, and public and private. Overall, Wejnert saw costs as the risks associated with adoption. This view that risk is a consideration in adopting practices is further supported by Panzano and Roth (2006), who found that decisions related to adoption of new practices were made with consideration of the perceived risks. Fullan (2016) also recognized that there are risk and reward considerations, but sees them as motivating factors that are based on instructors' "reality." In other words, the value of these factors is subjective.

Using Wejnert's subcategorization of costs and benefits, I organized the results of my study that are related to the perceived characteristics of innovations into Table 5.1. This table lists the perceived characteristics of PPs as cost and benefit, and further differentiates them as public or private.

Table 5.1

Perceived Public and Private Costs/Benefits of Adopting PPs

	Costs	Benefits
Public	None identified	• Increased student learning • Increased student retention • Reduced academic achievement gaps • Increase American innovation/competitiveness • Improve American economy
Private	• Cost to purchase instructional resources • Loss of time (that can be devoted to other activities, i.e., research) • Lower student evaluations • Risk to obtaining tenure	• Job security or advancement (for LPSOE and LSOE) • Personal satisfaction

Table 5.1 presents evidence suggesting that instructors might perceive adoption to be a private, rather than a public cost. Interview data demonstrate that instructors are acutely aware of the monetary costs associated with the purchase of devices used for PPs, especially the indirect costs to students (e.g., purchase of iClickers). Instructors identified two nonmonetary costs to the adoption of PPs. First, they described costs in terms of the amount of time that they have to spend in planning and implementing PPs in their curriculum. Instructors saw the time commitment to PPs as a factor that diminished their capacity to engage in other activities related

to their jobs, especially in conducting research that is highly valued by the university (Borrego, 2010; Shadle et al., 2017). Findings by Fairweather (2008) indicate that instructor perceptions of the university's priorities are not unfounded: institutions pay instructors more for research productivity than for teaching well. Ultimately, instructors who allocate more of their time and effort to teaching could incur monetary costs. The second nonmonetary cost is in the form of student resistance and lower student evaluations (Fairweather, 2008). In this current study, there is evidence that students reacted angrily to some instructors' attempts at using PPs. One instructor described this hostility in the following comment: "I've had students who will say the first couple of weeks [that] they hated this class, [and] they didn't understand what I was trying to do. They thought I was full of sh*t" (P. Dale, personal communication, September 21, 2015).

Regardless of these private costs, some instructors still invested the time to incorporate PPs into their lesson. Who are these instructors? Evidence shows that the instructors who are doing this are the teaching-track instructors such as LPSOEs and LSOEs. A possible reason is that these instructors are more willing to adopt PPs because their job description requires them to focus more on teaching. As explained by an LSOE: "I was tasked with modifying the courses for all the instructors. Because the department wanted to switch things up, we had the reason to do it" (B. Sayer, personal communication, December 10, 2015). However, for other position types, incorporating PPs exposes them to risks without the potential for reward. For example, when an assistant professor was asked about the possibility of flipping her class to allow for more active learning, she replied, "For an assistant professor, it's a terrible idea. So, you'll never [get] tenure" (O. Nova, personal communication, December 10, 2015). This supports the findings from Panzano and Roth (2006), who explain that instructors weigh costs vs. rewards when making adoption decisions about new practices. These authors also suggest that early adopters are not only weighing risk and reward, but their ability to manage the risks involved.

Based on this view, one possible reason that instructors might not adopt PPs is that they might not see the benefits. Upon further inspection of the literature on STEM education reform, the beneficiaries of change are students and society (e.g., improved learning, engagement, greater retention, etc.), with relatively parsimonious discussion of instructor benefits. Amazingly, House (1974; as cited in Rogers, 2003) came to a similar conclusion over 40 years ago. He wrote: “The personal costs of trying new innovations are often high…and seldom is there any indication that innovations are worth the investment” (p. 27).

However, there are too many examples both inside and outside of education that demonstrate that incentivizing action does not always work. Fullan (2016) made this point clear when he described a study in which 90% of hospital patients who had major surgeries to save their life returned to the unhealthy lifestyle and the eating habits that endangered their lives in the first place. This is perhaps indicative of a general human failure to accurately weigh cost and benefit. In the university lecture hall where the stakes are arguably much lower than hospitals, it is necessary to pursue another avenue of effecting change. For this reason, we examine the other characteristics of an innovation that influence decisions to adopt or reject. Work by Fullan (2016) and other change scholars such as Bryk et al. (2016) and Rogers (2003) lend credence to the argument that it is necessary to also consider the compatibility of innovations with instructor daily routines and beliefs.

In fact, there is evidence that indicates instructors are willing to exert time and effort to ensure student success in ways that are not related to the use of PPs. For example, instructors in this current study have invited students to work in their research labs, even in research labs in remote locations outside the United States. Other instructors socialized with their students outside of the classroom environment by inviting them to lunch. An instructor held office hours from 9 to 5 once a week to accommodate students' busy schedules. In addition, instructors collaborated with different organizations on campus such as the Learning and Resource Center or Student Housing to find convenient ways to support student learning. In all of these examples, instructors committed their time and energy without the lure of incentives or evidence that these strategies are effective.

Although, the findings described above may seem to complicate our understanding of instructors' decision-making process, this discussion clarifies the need for the approach described in the Recommendation section below.

Recommendations

A major goal in STEM education reform is to increase instructors' adoption of promising practices. Although the goals of this study were to document instructional practices and drivers and barriers to the adoption of PPs, the findings of this current study have unmasked several problematic areas in the diffusion of these innovative teaching practices. Based on these findings, I recommend some actions that a university can take as part of its change strategy:

(1) *Change needs to be framed as a systems problem* (Bryk et al., 2016; Fullan, 2016; Rogers, 2003). In Figure 5.3, we see that instructors design their classrooms and lessons in response to student behaviors and their larger institutional context. Overall, we see that the institution exerts much influence on both students and instructors.

(2*) Change needs to take into consideration the decision-making processes and lived experiences of instructors*. Bryk et al. (2016) argued that, "the predominant causes of failure lie in how we organize the work that we ask people to carry out" (p. 61).

(3) *Change must be planned and collaboratively defined, with incremental change goals* (Sunal et al., 2001).

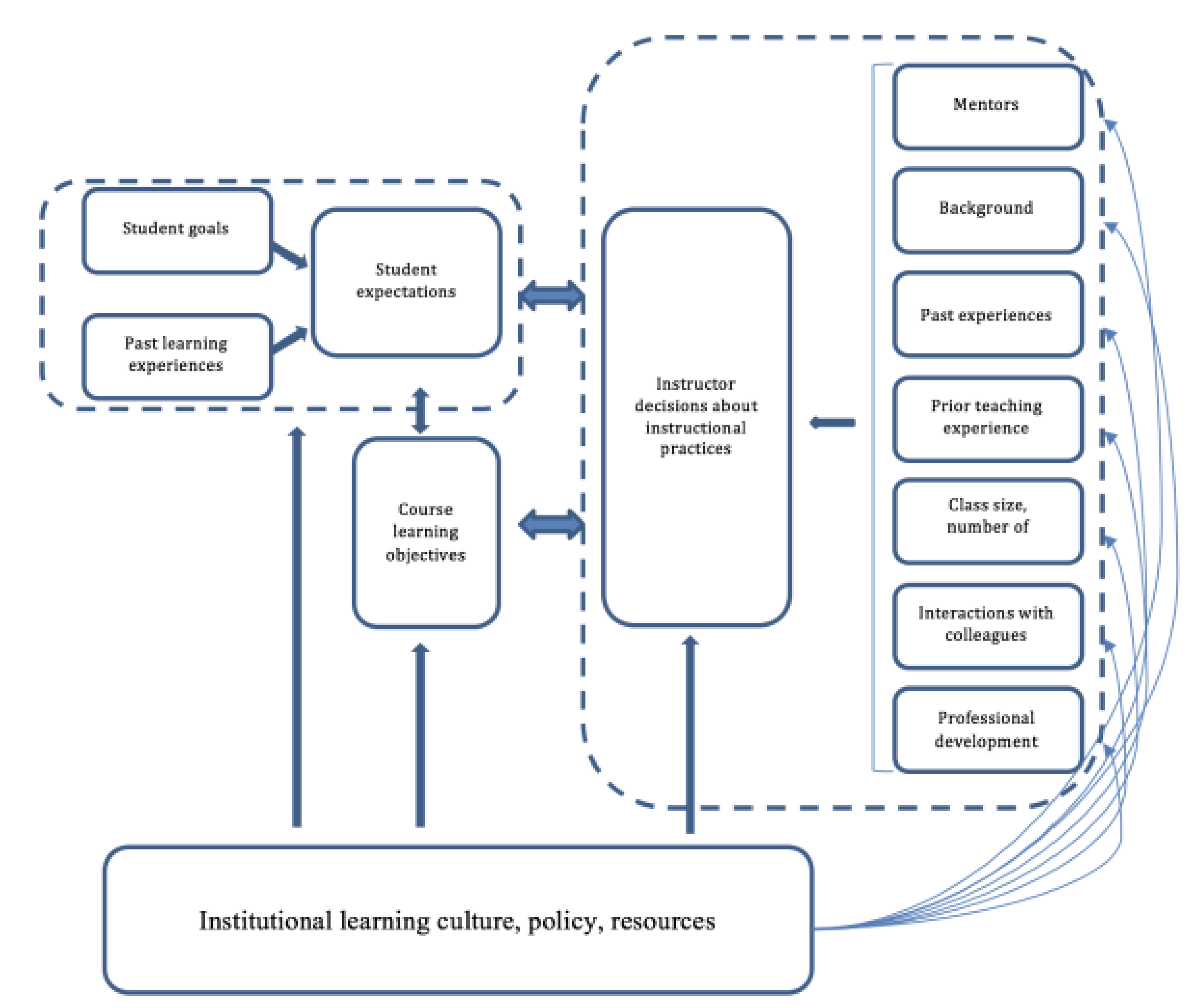

Figure 5.3. The factors that influence instructor decisions about teaching practices.

Using the main ideas discussed above, I recommend action steps that constitute a larger strategy to improve the adoption of innovative teaching strategies. The steps listed below can be acted upon in the order they are described, and the steps can overlap.

1. Create a change strategy that is
    a. "Sticky": brief, focused, actionable, memorable (Fullan, 2016, p. 86)
    b. Collaborative

    c. Adaptable

2. Build capacity to achieve change goals by

    a. Improving communication

    b. Developing teaching skills

    c. Providing support and resources

    d. Developing assessment strategies to measure change outcomes

    e. Shifting student and instructor expectations

3. Take action

    a. Implement change strategy

    b. Measure outcomes of change strategy

    c. Iteratively refine change strategy

Create a Change Strategy

From the results of the interview data, the ostensible diffusion strategy at the university being studied was to hire teaching-track instructors such as LPSOEs or LSOEs who are expected to diffuse their knowledge and understanding of PPs to other instructors in their departments. Most instructors in the interview data sample seemed to be aware of this strategy, as it was mentioned repeatedly. Notably, most instructors were aware that the university would like to see more PPs in the classrooms. Despite awareness of both the strategy and its institutional desirability, the reform plan seemed to rely on haphazard and informal interactions to change instructional practices. Therefore, I recommend that universities should begin the change effort with a more structured plan of change that includes specific strategies for dissemination and adoption. Bryk et al. (2016) recommended that any change effort involve the instructors. The strategy should be based on a “collaborative, systematic, long-term view of professional development" (Sunal et al., 2001, p. 254). Additionally, there should be defined incremental adoption goals that can be measured (Bryk et al., 2016), but only to a certain extent (authors caution against over-planning, e.g., Fullan, 2016). Instead, the plan should be "sticky"—brief, focused, actionable, and memorable (Fullan, 2016). In addition, over-commitment to the plan by leadership could be detrimental. Rather, better outcomes may be had by leaders who are committed to the goals and who can also see that there are multiple "realities," as perceived by the instructors who are tasked with carrying out the change strategy.

Build Capacity for Change

Improve communication. A university should strive to achieve improved communication for all instructors within and across departments. To achieve this goal, universities could:

1. Shuffle instructor office assignments so that LPSOE and LSOE offices are interspersed throughout a department. This will increase the proximity of instructors who are sources of information to other instructors in the department. This potentially could increase the informal interactions between instructors and expose tenured faculty to more PPs.
2. Make greater use of opinion leaders to reach a larger number of high-ranking faculty. In our sample, only two individuals (3% of the study) were mentioned as persons who could be opinion leaders.
3. Increase collaboration and interactions between instructors across *different* departments (Sunal et al., 2001). There are multiple ways that this could be accomplished, but instructors seemed to favor informal interpersonal communication. Since this is a more "natural" way of exchanging information, I recommend that these opportunities to exchange teaching ideas be encouraged informally as "brownbag" lunch presentations

where STEM instructors from across the campus could gather and share teaching ideas. These informal exchanges of teaching ideas should be followed up by more structured support and professional development.

Professional development. Our findings indicate the importance of professional development for early career professionals. For graduate students, all lecturers, LPSOEs, and assistant professors, professional development beyond the current levels is recommended.

Universities have largely ignored pedagogic training at the graduate and post-doctoral level (Boyer Commission on Educating Undergraduates in the Research University, 2002; Fairweather et al., 1996). As a result, new instructors have a model of teaching that is based only on their experiences as students. This can perpetuate the practice of lecturing since the majority of teaching at universities is through lectures (Mazur, 2009). Compounding the problem is that new instructors might also apply assumptions about teaching and learning that are not evidence-based (Connolly, 2008). If left uncorrected, these inaccurate assumptions can be difficult to dislodge, even when instructors are later faced with new and convincing information (Prince, 2004).

The consequences of neglecting teaching and overemphasizing research at the graduate and post-doctoral level suggest that universities need to provide pedagogic training at early career levels as a way to (a) cultivate a teaching identity, (b) develop teaching skills that are more evidence-based and theoretically driven, and thus closely aligned with PPs, and (c) increase the number of instructors who use PPs (Brownell & Tanner, 2012). To achieve these goals, universities could do the following:

1. Provide structured training to graduate students in implementing active learning strategies specifically designed for large STEM courses. Currently, graduate students at the focal

university are given training to be TAs, but this training is only relevant in small discussion sections (B. Jenner, personal communication, May 20, June 2017).

2. Provide mentorship by assigning graduate students to an instructor who serves as a teaching mentor.
3. Require graduate students to submit a teaching portfolio upon graduation, which could include materials relevant to large STEM courses, e.g., lesson plans, a teaching demo video, self-assessments, a reflection essay on their strengths and weaknesses as instructors.
4. Require graduate students to take coursework in pedagogy. If no courses are available in the STEM departments, students could be asked to take courses in other departments, e.g., Education. At another level, STEM departments could develop specific courses alongside discipline experts in Education, which could be used to instruct students across schools and disciplines.

Overall, a university should provide *structured* training in pedagogy to its graduate students and strive to cultivate a teaching identity that is as robust as the research identity (Sunal et al., 2001).

In addition to training graduate students, universities could also provide training to the LPSOEs and LSOEs who are tasked with developing and disseminating information about PPs. Some of these instructors in our data have had pedagogical training at the post-doctoral level. Others were simply given the responsibility of teaching without any prior pedagogical training. A deeper concern is that all of these lecturers have no training in disseminating information, training others, or providing support. Their task is further complicated when they have to fulfill their job responsibilities by assisting more senior ranking instructors. As a result of these concerns, universities should provide training to the “trainers.”

Other early-career instructors such as assistant professors would also benefit from professional development. A common refrain heard from assistant professors was that they had hoped for some training. This is evidenced by one instructor’s recollection: “I thought now the first day I showed up for that class. It will be a colleague sitting there. Another colleague to evaluate how I do, or the week before we start, someone will tell me how I have to teach, give me some [feedback]. No one was there to check. My work was never verified, evaluated, anything. That’s something I would really like” (M. Smith, personal communication, January 7, 2016). Based on comments like the one above and from other instructors who share those sentiments, I recommend that a structured mentorship program be initiated for instructors who may be new to teaching or teaching a course for the first time.

Shift Student Learning Expectations

One of the reasons instructors are reluctant to stray from the traditional approach to teaching is that students have certain expectations of the kinds of instruction they will receive in large lecture courses. To shift these expectations, instructors could explicitly state the course’s learning objectives in their syllabi. Additionally, universities could shift student expectations much more dramatically through several scenarios:

- During student orientation, there should be presentations or discussions of the types of instructional practices students could encounter in STEM courses, focusing on active learning activities, and with discourse that legitimates these types of activities.

- Videos that showcase student learning through active learning activities in large STEM courses could be created and uploaded to the university's website or social media channels for prospective and current students to view.
- Course descriptions can be rewritten to include the pedagogic approach, including the use of PPs.
- Creation of student development workshops that promote collaborative learning through activities and discussions that teach students strategies for working together effectively, e.g., creating shared mental models, holding each other responsible (Fransen, Kirschner, & Erkens, 2011).

Provide Support and Resources

The support and resources that instructors need come in the form of reliable technology, online resources, and more TAs trained in assisting in large courses, and administrative action that alleviates "classroom presses" such as time and opportunities for reflection.

The first step would be to convene the instructors in a department to determine the teaching materials they may need to engage students in active learning strategies. These items can be placed in a central location where all instructors can retrieve them. By making technology related resources used in active learning readily available (e.g., iClickers), instructors will not have to deal with concerns that their students will incur additional expenses in taking a course.

Besides teaching materials, instructors also need opportunities to observe successful implementation of activities consistent with promising practices. Our research indicates that instructors rarely have time and occasion to observe their colleagues in action. This is reaffirmed by the following comment from an instructor in our data: "We actually do not know how [each colleague] teaches because we don't go and sit in each other's lecture. We don't have time for that. So, having a way of maybe exchanging a bit more of the information would be useful" (M. Smith, personal communication, January 7, 2015). As a result of comments like the one above, I recommend creating an online destination where exemplar videos of instructors (from the same university) implementing or demonstrating PPs can be uploaded. However, I do not recommend uploading entire lectures to this online location. Best practices in online education recommend that videos be "chunked" into short segments that demonstrate a specific topic (Grant & Thorton, 2007). There should be multiple examples of the topic, demonstrated by instructors of varying position types to accommodate for different teaching styles. In addition to these exemplar teaching videos, the online resource destination should provide access to research and links to teaching communities and other resources on campus. Most importantly, access to this online resource destination should be in a prominent place that instructors normally visit, e.g., the front page of the school's learning management system.

Another way that schools can support instructors is by providing and training a sufficient number of TAs who can assist instructors in the use of PPs in large courses. Currently, new graduate students are mainly trained to lead small classroom activities, not activities in large lecture halls (B. Jenner, personal communication, May 2, 2017).

Overall, departments can alleviate the classroom presses such as time and lack of opportunities for reflection by providing support—with a heavy dose of patience—as instructors attempt new instructional practices for the first time.

Measure Outcomes

From the current research, instructors frequently use data to help implement changes in their teaching. They use anecdotal data gleaned from conversations with their TAs or students, student evaluations, action-research data, and data from published studies. Unfortunately, change is not always followed by *improvement,* especially without a specific plan. As Bryk et al. (2016) write, "we cannot improve at scale what we cannot measure" (p. 87). Therefore, they recommend that institutional change plans measure for accountability, improvement, and academic research. Additionally, these measures can be determined collaboratively by instructors, administrators, and other stakeholders at the beginning of the change effort.

Iteratively Refine

No matter how well change is planned, the expected results rarely materialize (Fullan, 2016). This is evident in the countless number of change initiatives that have failed to increase the number of instructors using PPs (e.g., Henderson & Dancy, 2007). This is also evident in attempts at change inside and outside of education (Fullan, 2016; Rogers, 2003). Therefore, a different approach to enacting change is necessary. Senge et al. (2000) argued that a "learning orientation" is the best approach to solving complex problems. They write:

> In a school that's learning, people who traditionally may have been suspicious of one another—parents and teachers, educators and local business people, administrators and union members, people inside and outside the school walls, students and adults—recognize their common stake in the future of the school system and the things they can learn from one another. (p. 5)

Based on the learning orientation approach, universities seeking to improve the adoption rate of PPs should see change as an incremental and iterative process. Fullan provided a guideline that suggests significant change in the implementation of specific innovations will occur between 2 or 3 years. However, schools should expect institutional reforms to take much longer, between 5 or 10 years.

Conclusion

STEM education reform in higher education is predicated on the adoption of more student-centered instructional practices by instructors. Despite great human efforts and billions of dollars spent in attempts to sway university instructors to use more PPs, change has been limited. Data from this current study demonstrate that instructors are indeed aware of PPs and that further dissemination efforts would not be fruitful. As a result, I agree with education reformers like Fairweather (2008), who argued that it is time to shift change efforts from developing and disseminating innovative teaching strategies to instead improving adoption strategies. One strategy that has been effective at increasing the use of PPs is the hiring of LPSOEs and LSOEs. These instructors are high users of PPs and are effective at disseminating PPs to their peers. However, opinion leaders are necessary to disseminate PPs to more senior instructors and to those who do not have contact with LPSOEs and LSOEs. However, hiring additional teaching instructors and opinion leaders might not be enough to increase adoption of PPs. Change strategies need to address systemic factors, rather than just instructor-related factors. These systemic factors include how information is communicated through communication channels, the decision-making process by potential adopters, and the contextual barriers and drivers of adoption. Also, change strategies should allow for adequate time for meaningful changes. Therefore, the strategy should involve multiple stages, with each stage being adaptable to the current school conditions. Additionally, Fullan (2016) warn against dogmatic approaches to change. Rather, the adoption dilemma should be approached with a plan and the reformers should be armed with the knowledge that most plans never work out exactly as expected. Not only should change strategies be adaptable to unexpected challenges, but they should also take into consideration contextual factors that vary across departments or instructor characteristics. Again, Fullan (2016) writes:

> Understanding why most attempts at educational reform fail goes far beyond the identification of specific technical problems such as lack of good materials, ineffective professional development, or minimal administrative support. In more fundamental terms, education fails partly because…solving substantial problems is an inherently complex business. (p. 87)

Overall, taking a one-size fits all approach to STEM education reform will not work and could perpetuate the cycle of non-adoption and continued use of teacher-centered instructional practices.

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Appendix A

Simple Protocol for Observing Undergraduate Teaching (SPROUT)	
SPROUT is designed to give an objective measure of instructional practices in undergraduate STEM courses. It contains a series of dichotomous questions (yes or no) that note the presence or absence of certain occurrences. SPROUT also includes opportunities for the researcher to include qualitative evidence supporting the observation of instructional practices. This material is based upon work supported by the National Science Foundation under Grant Number 1256500.	
I. BACKGROUND INFORMATION	
Lecturer:	
Date of Observation:	
Start & End Time of Observation:	
Wave:	
Course Name:	
Course Code:	
Observer:	
Location:	
Current Total Enrollment:	
Approx. Attendance at Lecture:	
Seat Location of Observation:	
II. LESSON OVERVIEW	
(a) Lesson Description:	

Evidence:
(b) Describe Faculty-Student Interaction:
Evidence:
(c) Describe Peer Interactions (If Any):
Evidence:
(d) Describe Problem-Solving (If Any):
Evidence:
(e) Describe the resources used by the instructor and by the students (including technology):
Evidence:
III. TEACHING DIMENSIONS
(a) Teaching Methods
1. Lecture without Visuals: ☐ Yes ☐ No
Evidence:
2. Lecture with Pre-Made Visuals: ☐ Yes ☐ No
Evidence:
3. Lecture with Handwritten Visuals: ☐ Yes ☐ No
Evidence:
4. Lecturing with Demonstration of Topic or Phenomena: ☐ Yes ☐ No
Evidence:

5. Interactive Lecture:

	Yes		No

Evidence:

a. If yes, how many instances?	

6. Deskwork:

	Yes		No

Evidence:

7. Student Presentation:

	Yes		No

Evidence:

8. Does the instructor solve problems in front of the class?

	Yes		No

If yes, indicate percentages Advanced vs. Algorithmic:

Problem Type	Percentage (%) (0, 25, 50, 75, 100)
a. Algorithmic	
b. Advanced	

Evidence:

9. Does the instructor warn the class about common mistakes/misconceptions?

	Yes		No

Evidence:

a. If yes, how many times?	

(b) Pedagogical Moves Observed:

1. Illustration with the real world:

	Yes		No

Evidence:

2. References prior course content:

	Yes		No

Evidence:

3. Assessment:

	Yes		No

Evidence:

4. Gauges student understanding:

	Yes		No

Evidence:

a. If yes, did the instructor modify the lesson accordingly as a result of gauging student understanding?

	Yes		No		N/A

Evidence:

5. Does the instructor mention specifically what students need to know for the test or exam?

	Yes		No

Evidence:

6. Does the instructor summarize the ideas presented in lecture?

	Yes		No

Evidence:

(c) Instructor/Student Interactions Observed (Types of Q & A)

1. Instructor display question:

Percentage (%) (0, 25, 50, 75, 100)	**Fixed Values**			**Result Value**
	3	Yes	One Student Responds	
	2	Yes	Collectively Students Respond	
	1	Yes	No One Responds	
	0	No	Did Not Happen	
			Total Value	

Evidence:

2. Instructor open-ended question:

Percentage (%) (0, 25, 50, 75, 100)	Fixed Values			Result Value
	3	Yes	One Student Responds	
	2	Yes	Collectively Students Respond	
	1	Yes	No One Responds	
	0	No	Did Not Happen	
			Total Value	

Evidence:

3. Instructor checks for student understanding:

Percentage (%) (0, 25, 50, 75, 100)	Fixed Values			Result Value
	3	Yes	One Student Responds	
	2	Yes	Collectively Students Respond	
	1	Yes	No One Responds	
	0	No	Did Not Happen	
			Total Value	

Evidence:
4. Student corrects instructor: ☐ Yes ☐ No
Evidence:
5. Student administrative question: ☐ Yes ☐ No
Evidence:
6. Student classroom environmental question: ☐ Yes ☐ No
Evidence:
7. Student conceptual question: ☐ Yes ☐ No
Evidence:
(d) Observed Student Behavior at Two Time Points (observers randomly)
After 20 Minutes
1.
2.
3.
4.
5.
6.

7.
8.
9.
10.
After 40 Minutes
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
(e) Instructional Technology
1. Book(s):
Yes No
2. Pointer:
Yes No
3. Chalk-board/White-board:
Yes No

4. Overhead:				
		Yes		No
5. PowerPoint or Other Digital Slides:				
		Yes		No
6. Clickers:				
		Yes		No

If yes:	
a. How many questions?	
b. What was the format of the questions? (Multiple Choice, True/False, or Both)	
c. What were the types of questions? (Content-Recall, Calculation Based, or Both)	

d. Were students given a second chance to answer the question?

	Yes		No		N/A

e. Were students encouraged to discuss the clicker question with their peers?

	Yes		No		N/A

7. Demonstration Equipment:				
		Yes		No
8. Movie, Documentary, Video Clips, or YouTube Video:				
		Yes		No

9. Calculator: ☐ Yes ☐ No
10. Simulations: ☐ Yes ☐ No
11. Website: ☐ Yes ☐ No
IV. SUMMARY COMMENTS

Appendix B

INSTRUCTOR INTERVIEW TOPICS AND QUESTIONS

BACKGROUND & INTRODUCTION:

How many times have you taught this course before?

To what extent does the material in this class relate to your research interests/field? Do you try to incorporate your research into your class?

ACTIVE LEARNING:

In what ways do you hope to engage and/or involve students during your lectures?

FORMATIVE ASSESSMENTS:

In what ways do you gauge student understanding during your lectures? (Such as clickers.)

FACULTY-STUDENT INTERACTION:

Interaction with students during lecture and outside of class

PEER INTERACTION:

In what ways do students interact with each in your course?

TECHNOLOGY:

Can you describe any technology used in course (in and outside of lecture)?

PROBLEM SOLVING:

How is problem solving (e.g., math problems, case studies, coding and debugging) incorporated into the course?

DATA DRIVEN INSTRUCTION:

Do you adjust your training across quarters or data or feedback or evaluation or monitoring student progress?

Systematic or informal?

CHANGE COURSE IN THE FUTURE

How has your instruction changed in the last few years?

What kinds of changes are you contemplating in the next few years?

FLIPPED/ONLINE CLASSES

What do you think of flipping the classroom (define)?

Have you ever thought of offering this class online?

CONVERSATIONS WITH COLLEAGUES

Do you talk to colleagues about teaching?

COURSE VALUE

Instructor value of the course for students

Importance of course to student trajectory in STEM fields

STUDENT READINESS

Are students adequately prepared to take this course? What do you think they are missing?

What are the best indicators of student readiness?

FUTURE OF THE LECTURE SYSTEM

Are you satisfied with the lecture system?

Where do you see your lecturing going in the next five years?

Do you think online learning will change the lecture system?

Are online courses obliterating the courses?

PREPARING STUDENTS FOR STEM CAREERS

How would you change the higher education system to better prepare students for STEM careers?

BALANCE B/W TEACHING & RESEARCH

How does teaching relate to your research?

Do you find teaching competes or complements research? Why and how?

TAS

How do you use and train TAs?

Is there anything else you think we should know about your course?

Appendix C

Table 3.2

Courses Titles

Course	Course Title	Observations (n)
Biological Sciences		
Bio Sci 93	DNA to Organisms	14
Bio Sci 94	Organisms to Ecosystems	12
Bio Sci 97	Genetics	3
Bio Sci 98	Biochemistry	3
Bio Sci 99	Molecular Biology	4
Engineering		
EECS 10	Computational Methods in Electrical and Computer Engineering	2
EECS 12	Introduction to Programming	2
Engr 7A	Introduction to Engineering 1	2
Engr 7B	Introduction to Engineering 2	2
EngrCEE 20	Introduction to Computational Problem Solving	2
EngrCEE 30	Introduction to Computational Problem Solving	2
EngrMAE 10	Introduction to Engineering Computations	6
EngrMAE 30/ EngrCEE 30	Statics	2
EngrMAE 91	Introduction to Thermodynamics	2
ICS 6B	Boolean Algebra and Logic	2
ICS 31/CSE 41	Intro to Programming	8
ICS 33/CSE 42	Intermediate Programming	4
Math		
Math 1B	Pre-Calculus	1
Math 2A	Single-Variable Calculus	12
Math 2B	Single-Variable Calculus	12
Math 2D	Multivariable Calculus	8
Stats 7	Basic Statistics	15
Stats 8	Introduction to Biological Statistics	6
Physical Sciences		
Chem 1A	General Chemistry 1	24
Chem 1B	General Chemistry 2	18
Chem 1C	General Chemistry 3	12
Chem 51A	Organic Chemistry 1	14
Chem 51B	Organic Chemistry 2	7
Chem 51C	Organic Chemistry 3	16

	Physics 3A	Basic Physics 1	7
	Physics 3B	Basic Physics 2	4
	Physics 3C	Basic Physics 3	6
	Physics 7C	Classical Physics	15
	Physics 7D	Classical Physics	8
	Physics 7E	Classical Physics	2
Total			259

Table 3.4

Interview Topics and Sample Questions

Topics	Sample Questions
Instructor's background and experience with the observed course	To what extent does the material in this class relate to your research interests/field?
In-class instructional strategies	In what ways do you hope to engage and/or involve students during your lectures?
Formative assessments	In what ways do you gauge student understanding during your lectures?
Faculty-student interaction	In what ways do you interact with students during lecture and outside of class?
Peer interaction	In what ways do students interact in your course?
Technology in the classroom	Can you describe any technology used in the course (in and outside of lecture)?
Problem solving	How is problem solving (e.g., math problems, case studies, coding and debugging) incorporated into the course?
Data driven instruction	How do you adjust your classroom practices across quarters? What kind of data do you use to inform your decisions?
Plans for future iterations of the course	How has your instruction changed in the last few years?
Conversations with colleagues	Do you talk to colleagues about teaching?
Student readiness	Are students adequately prepared to take this course? What do you think they are missing?
Future of the lecture system	Are you satisfied with the lecture system?
Preparing students for STEM careers	How would you change the higher education system to better prepare students for STEM careers?
Balance between teaching and research	How does teaching relate to your research?

Table 3.6

SPROUT and Syllabus Coding Definitions and Examples

Promising Practice	Definition	Example of Instructor Action	Source
Epistemology			
Data	Analysis or manipulation of data.	Instructor solves problems in class.	SPROUT Item 3.a.8 (Problem solving)
Connect course content to scientific research or science in the real world	Instructor relates concepts directly to scientific work OR the instructor relates content to real-world examples.	Instructor make connections between course content and current events or real world applications.	SPROUT Item 3.b.1 (Real world)
Conceptual framework	Course concepts are related to one another and to outside bodies of knowledge.	Instructor uses concept maps or illustrates how concepts are applied to solve problems.	SPROUT Item 3.b.2 (Prior content) Item 3.b.6 (Summary of content)
Apply or extend	Students extend and apply knowledge to new or challenging situations or to relevant contexts.	Instructor work on problems or projects that required them to seek out new information not previously covered in class?	SPROUT Item 3.b.5 (Exam content)
Assessment			
Formative assessment	Instructor uses formative assessment techniques and feedback loops to change practice.	Teachers ask students to demonstrate their skills in short exercises. Examples include: • Show of hands • iClicker questions • Pre-class assignments	SPROUT Item 3.b.3 (Assessment) Item 3.b.4 (Formative)
Active Learning			
Active learning	Getting students to do anything course-related in class other than watch and listen to the instructor and take notes.	Students discuss course material in class, complete written work, use iClickers to respond to instructor questions.	SPROUT Item 3.a.5 (Interactive lecture) Item 3.a.6 (Deskwork) Item 3.a.7 (Groupwork) Item 3.a.8 (Presentation)
Collaboration			
Collaborative learning	Providing structured group learning experiences.	Students interact with one another. This can be accomplished in pairs/groups, and as structured or unstructured collaborative learning.	SPROUT Item 3.a.7 (Groupwork)

Table 4.11

Frequency Count of Barriers by Instructor Position Type and Gender, and by Department

	Barriers (total)	**Communication Channel**	Interpersonal communication	**Environment**	Class	Institution	Students	**Innovation**	Cost	Lack of data to support change	**Instructor**	Beliefs	Instructor experience as a student	Instructor inertia	Lack of experience	Time
Total	391	31	30	246	115	52	77	15	8	7	101	36	1	20	8	36
Position Type																
Administrator	5	0	0	2	1	0	1	2	1	1	1	0	0	0	0	1
Professor	132	12	11	84	48	15	21	3	2	1	32	13	0	6	2	11
Associate Professor	67	5	5	42	19	8	15	3	3	0	17	6	0	5	1	5
Assistant Professor	33	1	1	23	3	7	13	4	1	3	5	1	0	1	0	3
LSOE	35	1	1	12	6	3	3	1	0	1	22	10	1	4	3	4
LPSOE	30	4	4	23	11	6	6	0	0	0	3	0	0	0	1	2
Lecturer	43	6	6	22	8	7	7	1	1	0	14	3	0	4	0	7
Graduate Student	35	1	1	27	18	2	7	0	0	0	7	3	0	0	1	3
Researcher	4	0	0	3	0	2	1	1	0	1	0	0	0	0	0	0
Gender																
F	135	9	9	90	41	18	31	3	2	1	33	10	0	3	2	18
M	256	22	21	155	74	34	46	12	6	6	68	26	1	17	6	18
Department																
Biology	93	6	6	71	27	21	22	1	0	1	16	2	0	4	2	8
Engineering	32	4	4	19	12	1	6	3	2	1	6	2	0	1	0	3
ICS	29	2	2	8	2	3	3	0	0	0	19	7	1	2	2	7
Physical Sciences	233	19	18	143	70	27	46	11	6	5	60	25	0	13	4	18
Social Ecology	4	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0

Table 4.13

Barriers: Environment

Barriers	**Description**	**Interview Excerpts**
Classroom		
Course content to cover	Instructors usually have to teach a certain textbook chosen by their department and they have to teach certain topics or chapters in a given period of time.	"I have so much content to cover, I can't have anything that's slowing me down" (D. Van, October 21, 2015).
Length of class period	Class periods (e.g., 50 minutes) are usually determined by the university.	"When we do the lecture thing it's not because it's the right thing to do but because [when] you get assigned to one hour it's actually fifty minutes" (D. Van, October 21, 2015).
Number of students	The number of students enrolled in the course. Introductory STEM courses have high enrollment.	"I don't break them up to small groups, which I know is a great learning strategy because . . . it's so loud in a 400-person class that I've done it a few times and it just was too distracting" (S. Les, June 11, 2013).
Classroom space and desk arrangement	Introductory STEM courses are usually taught in lecture halls that have small tables arranged in rows and limit movement by students.	"We just don't have any classrooms that have floating desks—this is an issue. I think it does restrict this active learning component" (M. Kat, October 28, 2015).
Institution		
Institutional culture	The values and norms of the institution that are connected to learning and teaching.	"I think there's going to be like a cultural shift that has to happen before it makes sense" (A. Kang, January 19, 2016).

Lack of support	Instructors need support in a variety of ways. My analysis shows that instructors need support in the areas listed below. A lack of support in these areas acts as a barrier to implementation of PPs in the classroom: • General teaching resources • TA support • Reliable technology • Training	"Well, I think there's several things that we should do and that we don't do because resources are so limited" (R. Ware, February 11, 2016). "I need a much bigger TA allocation if I were to break [my class] down into smaller groups" (S. Avni, September 28, 2015). "I resented the possibility of having another gadget that might fail, and thereby upset the class" (M. Smith, January 7, 2016). "I have no training to achieve this" (B. Sayer, December 10, 2015).
Reward system	The tenure system weighs an instructor's body of research work, teaching performance, and community service equally to determine promotion. However, instructors feel the system gives more weight to research.	"Your career is judged by three criteria, right? Teaching, research, and service, okay. And when anybody actually looks at it and makes a judgment, it's just research. Teaching is sort of a low-level criteria in your advancement" (H. Sole, October 21, 2015).
Students		
Behaviors in classroom	Students' behavior can negatively affect an instructor's decision to implement PPs. My analysis found several types of behaviors that can act as barriers. These include the following: • Cheating • Students do not show up to class. Some instructors have claimed that attendance is only 50%. Instructors feel low attendance rates limit	"The one thing I found with the physical clickers, it was a bit frustrating is that I realized students were giving them to their friends and so I'd see somebody reach into their backpack, and click like eight buttons. That was a little frustrating" (S. Queen, December 10, 2013).

	effectiveness of collaborative activities. • Students do not read prior to coming to class. When this happens, instructors feel collaborative activities or problem solving activities would not be effective. • Student resistance	"It's got a crummy atmosphere to a group meeting. You know, if there's only a handful of students there, then I think they're looking at each other going, you know, why am I here" (C. Lou, March 8, 2014)? "I insist a lot for them to read the book but I frankly I doubt that they are doing it so" (G. Ritz, September 23, 2015). "I've had students who will say the first week, first couple of weeks, they hated this class, they didn't understand what I was trying to do" (K. Dale, September 21, 2015).
Student preparedness	Students enroll in the course without the foundational skills, e.g., math or English skills.	"It's like, they couldn't walk and now you teach them how to run. And then they have to stumble all the time" (A. Tad, December 4, 2013).
Student expectations	In introductory STEM courses that are taught in lecture halls, students typically expect instructors to lecture. When instructors implement active learning strategies or collaborative activities, it defies their expectations. Although, it could lead to student resistance, it is not always the case.	"It's well charted territory, they know what's expected… why would they take this crazy professor who's doing weird stuff that they don't understand and it's so hard and they have to think about stuff. What is this nonsense, you know?" (P. Dale, September 21, 2015).

Note: Excerpts from instructor interview data.

Table 4.15

Barriers: Instructor Characteristics

Barriers	**Description**	**Interview Excerpts**
Beliefs	Instructor beliefs about themselves, their abilities to teach, and how students learn.	"I think that's a mistake. How do you test it, eventually? You give them an exam where they all talk to each other" (H. Sole, November 6, 2015)?
Experience as a Student	Experiences instructors had as students.	"I did fairly well on the AP exam, and in reflection, I felt kind of empowered that I was learning myself. There's still more information in a passive form than the active form of somebody trying to teach them how to do something" (R. Patterson, November 24, 2015).
Inertia	Instructors' tendency to teach the way they were taught.	"We can't quite emotionally force ourselves from lecturing" (A. Kang, January 19, 2016).
Teaching Experience	Instructors' lack of experience in using PPs.	"I would not jump into a flipped class where I have no experience with the class" (S. Ryan, December 11, 2013).
Time	Instructors' lack of time to spend on PPs.	"I spend 60 hours a week outside of teaching doing research. And so, to put in, you know, into one lecture, to put in 10 or 12 hours, it just can't happen" (D. Baker, December 4, 2013).

Note: Excerpts from interview data.

Table 4.16

Drivers of Promising Practices

Drivers	Description	Excerpt from interviews
Communication Channels		
Colleagues	Other instructors in the department who provide information about PPs.	"It was a part of all the professors who told me okay, this is really simple" (M. Smith, January 7, 2016).
LPSOE/LSOE	These full-time lecturers with security of employment are usually hired to develop, research, and disseminate information about PPs.	"There was this one year, under the guidance of the MBNB lecturer, we actually did a lot of changes, which include clicker in the classroom, pre-lecture quiz, and then there is also homework that's done electronically" (S. Tate, January 6, 2016).
Opinion leader	These high-ranked instructors who have more influence than LPSOE or LSOE.	"I know our new dean of undergraduate education, he's really interested in this and he's willing to spend resources towards this problem. So, I think it's sort of, the right time" (T. Rizzo, January 25, 2016).
Mass media	All forms of mass media.	"You may have seen this New York Times article about low income students. First generation student and what was going on in the University of Texas. And it really started bothering me, you know, that I'm not addressing that issue" (R. Arase, June 21, 2013).
Environment		
Professional development	Training the university provides to instructors throughout their career trajectory.	"I heard about it quite a while before I started teaching. Yeah, I heard about it as a post doc when talking about how one deals with teaching in a faculty position and in particular with large classes" (B. Hide, October 9, 2015).
Requirement by department	This is usually only true for LPSOE or LSOE who were hired to focus on	"[A colleague] and I were tasked with modifying the Biosci courses for all the instructors. So, one year, it was taught traditionally, and in that one-year period,

		teaching with an emphasis on PPs.	we started developing materials to make it more active the following year" (B. Sayer, December 10, 2015).
	Technology	Technology that is needed to implement PPs, e.g., iClickers. In addition to making technology available, the university also needs to provide technology that is reliable.	"It's hard to interact with the students of course. The clicker gives them an option to sort of test how much they're following about what I'm saying without being put on the spot" (R. Patterson, November 24, 2015).
	Positive student reaction	Student reaction to instructors' use of PPs.	"Well, just based on student reviews, I definitely appreciate it and like it and I get a lot of comments: We can tell that you really care because you try to talk to us" (R. Range, April 23, 2013).
	Outside support	Support from outside organizations that can include pre-made materials such as videos or questions.	"HHMI award was extremely important in actually providing external validation and made it easier [to adopt new practices] as one of the resources" (R. Ware, February 11, 2016).
Innovation			
	Data to support PPs	Research that demonstrates the positive effects of PPs on student learning.	"I used the data, the published data. When you want institutionalized change especially in a big department, the only thing that scientists really respect is real numbers. And, so, this helped me convince people within the department to make changes" (R. Arase, June 21, 2013).
	Normalization	When PPs are seen as standard teaching practice, then instructors are more inclined to adopt them.	"I think having a college where it's not just one course, you know, taught by a professor or one or two courses, but having more and more people in the university realize that active learning is the way to teach" (M. Kat, October 28, 2015).
Instructor			
	Experience as a student	Experiences instructors encountered as students	"I was a biochem double major. I didn't end up finishing my bio major, but what appealed to me about chemistry was that it

	that motivated them to adopt PPs.	actually made you think. So, my goal is to get these students who just want to come in and memorize everything, I want to get them thinking. I want to train their critical thinking skills" (A. Queen, December 10, 2013).
Frustration that lead to change	Frustrations felt by instructors which led to changes in instructional practices.	"In the past I did that with emails, but then, I feel like all the students are not really benefitting from this. With the message board, the nice thing about that is that the students can be anonymous while they post the questions" (K. Fami, February 26, 2014).
Instructor beliefs	Instructor beliefs about themselves, their abilities, and the types of instructional practices that would improve student learning.	"Part of it is comfort, and I'm comfortable with these types of things" (R. Ware, February 11, 2016).

Note: Excerpts from instructor interviews.

Table 4.18

Frequency Count of Drivers of PPs by Instructor Position Type and Gender, and by Department

	Drivers of promising practices	Communication Channels	Interpersonal communication	Mass media	Environment	Institution	Classroom	Outside university support	Innovation	Advantage: Data to support PPs	Observability: Normalization of PPs	Instructor	Early career training	Experiences as a student	Frustrations that lead to change	Instructor beliefs	Mentors	Opportunities for reflection
Total frequency count	111	38	35	3	30	20	6	4	9	4	5	35	10	4	3	16	1	1
Position Type																		
Administrator	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Assistant Professor	23	11	10	1	4	4	0	0	1	0	1	7	3	1	0	2	1	0
Associate Professor	14	8	8	0	3	1	1	1	1	0	1	2	0	0	0	1	0	1
Graduate Student	5	0	0	0	0	0	0	0	0	0	0	5	2	0	2	1	0	0
LPSOE	15	5	5	0	3	1	2	0	1	0	1	6	3	0	0	3	0	0
Lecturer	8	2	2	0	3	3	0	0	1	1	0	2	0	1	0	1	0	0
Professor	29	6	5	1	10	8	1	1	3	1	2	10	1	0	1	8	0	0
Researcher	7	3	3	0	5	2	1	2	0	0	0	0	0	0	0	0	0	0
LSOE	6	3	2	1	1	1	0	0	1	1	0	1	0	1	0	0	0	0
Gender																		
F	34	11	11	0	9	8	1	0	4	2	2	10	3	1	2	3	1	0
M	77	27	24	3	21	12	5	4	5	2	3	25	7	3	1	13	0	1
Department																		
Biological Sciences	41	20	19	1	8	3	4	1	1	0	1	12	6	1	0	4	1	0
Engineering	5	0	0	0	2	1	1	0	1	1	0	2	0	0	0	2	0	0
ICS	5	1	1	0	2	2	0	0	0	0	0	2	0	1	1	0	0	0
Physical Sciences	60	17	15	2	18	14	1	3	7	3	4	19	4	2	2	10	0	1