INTERACTION AND INNOVATION: THE IMPACTS OF SOCIAL FACTORS AND CLASSROOM TYPE ON UNIVERSITY BIOLOGY INSTRUCTOR CLASSROOM ASSESSMENT DECISIONS

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ABSTRACT

Efforts to improve university science education continue to emphasize the importance of active learning, including frequent formative assessment and timely feedback that helps students reach desired learning outcomes. Yet, nationwide, many instructors continue to use primarily lecture-based teaching methods, with limited use of formative assessment and feedback. Factors that affect instructor adoption and implementation of new teaching techniques include departmental norms, peer interaction, and classroom environment. In this work, a model of the impacts of departmental teaching and social norms and peer interactions on instructor innovation decision is presented. This model is then used to explore 1) instructor teaching-related interactions within a single biology department, assessing the conditions for innovation diffusion, and 2) instructor perceptions of norms and interactions in that department and their impact on decision-making. Finally, introductory biology instructors' use of assessment and feedback techniques were characterized in a lecture hall and an active learning classroom to see how innovation adoption translates to specific assessment practice and investigate the impact of the active learning classroom. Results indicate that perceptions and practices vary widely, but that both peer interactions and active learning classrooms may have a positive impact on teaching innovation adoption and practices in a university biology department. In addition, the pattern of interactions within this department allows instructors of varying assessment experience to interact, making it potentially conducive to the spread of teaching ideas. The model and results presented here will assist in understanding the factors involved in instructor decision-making and can be leveraged to help promote the use of formative assessment and other evidence-based teaching practices.

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LIST OF ABBREVIATIONS

COPUS..Classroom Observation Protocol for Undergraduate STEM

EBIP...Evidence-based Instructional Practice(s)

FRAS...Faculty Self-Reported Assessment Survey

HLI..High/Low Index

PCK...Pedagogical Content Knowledge

SCALE-UP ....Student-Centered Active Learning Environment with Upside-down Pedagogies

STEM..Science, Technology, Engineering, Mathematics

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CHAPTER 1: INTRODUCTION

STEM education at the college level

Issues in college-level science education in the US have recently received widespread acknowledgement and attention (AAAS, 2015; Brewer & Smith, 2011; Committee on STEM Education of the National Science & Technology Council, 2018; Olson & Riordan, 2012). Calls to action highlight the need to produce more STEM graduates, which means recruiting and retaining STEM majors (Olson & Riordan, 2012). Additionally, in an increasingly technology-focused world facing many challenges, researchers, tech workers, healthcare workers, and science-educated members of the general public are needed, and each of those groups need to have a solid science education focusing on core concepts and including critical thinking and problem solving (Bradforth et al., 2015; Committee on STEM Education of the National Science & Technology Council, 2018; Cooper et al., 2015). The quality of undergraduate STEM education is of utmost importance in educating and retaining students.

As part of reforming undergraduate STEM education, increased attention is being paid to developing and using evidence-based instructional practices which improve student learning (AAAS, 2015; Bradforth et al., 2015; Deslauriers et al., 2019; Freeman et al., 2014). Often described as "active learning", one substantial category of such practices involves students working actively with the course material, which has been shown to lead to better student learning outcomes than an instructor-focused lecture teaching style in which students passively listen and take notes (Deslauriers et al., 2019; Freeman et al., 2014). The chapters in this volume refer to evidence-based instructional practices (EBIPs) and active learning as examples of innovations, or new (to that instructor) practices an instructor can decide to implement in their classrooms. They also refer frequently to one specific aspect of active learning, formative assessment.

Formative assessment

Formative assessment is the gathering and responding to evidence of student learning in order to improve the learning. It is distinct from summative assessment (such as exams) in that formative assessment is an integral part of ongoing learning rather than a means to evaluate a student's work for grade assignment (Bell & Cowie, 2001; Nicol & Macfarlane-Dick, 2006; Offerdahl et al., 2018). As part of the learning process, formative assessment offers an opportunity for both the instructor(s) and student(s) to diagnose progress toward learning outcomes (Bell & Cowie, 2001). Instructors can use the information gained from formative assessment to adjust instruction or provide feedback that guides students on their journey toward reaching the learning outcomes (Evans, 2013; Nicol & Macfarlane-Dick, 2006; Offerdahl et al., 2018). Optimal feedback should provide students information about their performance, provide goals or benchmarks for success, and facilitate student reflection on how to bridge that gap, rather than simply indicate correctness of an answer (Hattie & Timperley, 2007; Nicol & Macfarlane-Dick, 2006). Robust, beneficial formative assessment involves an iterative feedback loop between instructor and student that generates a dialogue to help both parties see and work toward the learning goals (Nicol, 2010). For these reasons, it is likely that proper implementation of formative assessment, coupled with generation of appropriate and actionable feedback, has the potential to be a crucial element that increases the effectiveness of EBIPs in teaching. Examples of formative assessment include in-class group activities or worksheets, clicker questions, and assignments such as concept maps.

Instructor practices and innovation adoption

Despite recent calls to action and initiatives emphasizing the importance of EBIPs, active learning, and formative assessment in STEM (Bradforth et al., 2015; National Academies of Sciences, 2017; Owens et al., 2018), their use remains limited and infrequent in many college classrooms (Eagan et al., 2014; Stains et al., 2018). Numerous factors may impact an instructor's likelihood of using particular practices in their classrooms, and the process of decision-making they go through can be modeled as an innovation decision process (Rogers, 2003). The major steps of the innovation decision process include finding out about an innovation, forming opinions about it, deciding whether or not to try it, and deciding whether or not to continue using it (Andrews & Lemons, 2015; Rogers, 2003).

Evidence indicates that familiarity with a teaching practice, appreciation for it, and knowledge of the evidence in its favor are not sufficient to ensure effective adoption of that innovation (Andrews et al., 2011; Andrews & Lemons, 2015; Dancy & Henderson, 2010; Offerdahl & Tomanek, 2011). As an instructor experiences the steps of the innovation decision process, they consider (consciously or unconsciously) several aspects of the innovation (e.g. ease of use, trialability, cost) and of themselves (e.g. personality, needs). Satisfaction (or dissatisfaction) with current teaching, level of priority placed on teaching change, and reflection on past classroom experiences are all personal factors that can be taken into account by an instructor making a decision about an innovation (Andrews & Lemons, 2015; Marbach-Ad & Hunt Rietschel, 2016; Mcalpine et al., 1999; Sturtevant & Wheeler, 2019). Further, instructors' choices are heavily impacted by their environment, including departmental and university culture and norms and peer interactions (Grunspan et al., 2018; Landrum et al., 2017; Lund & Stains, 2015; Sturtevant & Wheeler, 2019).

In Chapter 2, the innovation decision process will be discussed further in the context of an expanded model of instructor innovation decision that takes into account social contextual factors. In Chapter 2 as well as the remaining chapters of this dissertation, instructor decisions and practices are explored in the context of three factors in particular: departmental teaching and social norms (Chapters 2-4), departmental peers (Chapters 2-4), and classroom environment (Chapter 5). These factors are often overlapping. For example, the model presented in Chapter 2 indicates that teaching and social norms impact peers, and peers both shape and transmit aspects of departmental norms. Further, classroom environment can be an indicator of departmental culture and norms (Reinholz & Apkarian, 2018). Each of the three factors will be discussed briefly in this introduction, followed by a preview of the contributions of each chapter of this dissertation.

Departmental teaching and social norms

The chapters in this dissertation will frequently refer to the culture, climate, and norms of an academic department. Culture in this context refers to the formal and informal structural factors, norms, barriers, supports, and patterns within a department, specifically in regard to teaching and interactions about teaching. Climate is "the behavioral evidence for culture" (Schneider et al., 2013), or the way that the members of a particular social context experience the environment regarding a particular thing (in this case, teaching, instructional change, and teaching-related interaction) and the meanings that are thereby formed (Schein, 1996, 2010; Schneider et al., 2013). Norms are an aspect of culture that refer to ways of doing, believing, and relating that are typical and expected (Frese, 2015). Norms can be implicit or explicit and are built from structural cultural factors as well as interactions between people in the department (Burt, 2000; Grunspan et al., 2018; Lund & Stains, 2015; Reinholz & Apkarian, 2018).

The climate around teaching and norms about teaching and teaching interaction in a department can have a profound impact on the instructional methods individuals choose to use in their classrooms (Andrews & Lemons, 2015; Grunspan et al., 2018; Owens et al., 2018). For example, factors such as professional identity, perceptions of peers' teaching, and perceptions of student preferences influence the innovation decision process and are themselves heavily influenced by departmental reward structures, resources, and patterns of instructor interaction (Austin, 2011; Brownell & Tanner, 2012; Grunspan et al., 2018; Reinholz & Apkarian, 2018). Further, instructors often may form subgroups or microclimates within a department that can act to reinforce or subvert the prevailing climate or add some nuance to it for participating and adjacent instructors (Roxå & Mårtensson, 2015; Schein, 2010).

Departmental peers

An instructor's peers, particularly those who share the same departmental or university context, are in a position to provide information and encouragement through informal conversation (Sun et al., 2014). Frequent interaction with knowledgeable peers could impact an instructor's innovation decision process, encouraging them to both try and persist in using EBIPs like active learning and formative assessment (Quardokus & Henderson, 2015). Conversely, interaction with peers who provide negative information or share negative experiences with innovations could discourage an instructor from adopting them and reinforce lecture norms (Grunspan et al., 2018). Instructors who receive ongoing support from their peers while implementing pedagogical change are more likely to persist in using evidence-based practices (Guskey, 2002; Henderson et al., 2011; Wieman et al., 2013). This support may or may not be available in a given social context. In addition, instructors who try an innovation may frequently modify it to be less student-centered and potentially less evidence-based (Henderson, 2005;

Henderson et al., 2012; Stains & Vickrey, 2017). Support from knowledgeable peers within their social context may help prevent such undesirable modifications from happening (Chasteen et al., 2015; Wieman et al., 2013). Since interacting instructors can all impact each other's innovation decision processes, practices may spread throughout a department in this way, modeled by the innovation diffusion framework (Quardokus & Henderson, 2015; Rogers, 2003). This will be explored further in Chapter 3 (McConnell et al., 2019).

Classroom environment

A third factor that may impact instructor decision-making is classroom environment. The size, layout, and affordances of a classroom may cause instructors to change their adoption decisions, but may also impact the way they implement innovations and their day-to-day classroom practices (Felege & Ralph, 2019; Foote et al., 2014; Henderson et al., 2011). Although evidence-based practices such as active learning and formative assessment can be adapted to work in most classroom environments, instructors may be more or less likely to try them or persist in using them depending on setting, and they may use them in different ways.

In Chapter 5 of this work, this factor is explored through investigating the impact of a SCALE-UP (Student-Centered Active Learning Environment with Upside-down Pedagogies) classroom on in-class assessment and feedback. A SCALE-UP room is often incorporated in order to mitigate some of the aspects of large classes that make active learning difficult (Allen & Tanner, 2005; Beichner, 2008; Wilton et al., 2019). It does this by seating students at round tables in groups, making whiteboards and screens more readily available, and positioning the instructor station within the tables rather than at the "front" of the room. These design decisions are intended to increase the potential for student participation and groupwork (Beichner, 2008).

Studying instructor innovation adoption and practices to facilitate change

Understanding the factors, including barriers and supports, that underlie individual instructors' decisions to adopt or not adopt instructional change is a fruitful line of inquiry in terms of encouraging more widespread evidence-based teaching practices. This is especially true when an instructor's social context is taken into account. Instructional change in higher education is dependent on individual instructors knowing about and deciding to use evidence-based practices and persisting in using them in an effective way. Yet, their choices occur in the context of particular departmental teaching and social norms and in relationship and interaction with peers who are also themselves instructors (Dancy et al., 2016; Sturtevant & Wheeler, 2019). This dissertation is an attempt to increase the understanding of this complex system - how social, departmental, and environmental factors impact individual instructor ideas and practices in regard to teaching. The hope is that these findings will be leveraged to encourage the use and spread of effective teaching practices in STEM higher education.

A "best case scenario" department

As noted, didactic, lecture-based teaching remains common, with evidence-based practices and formative assessment being used rarely if at all in many university STEM classrooms (Stains et al., 2018). In order to study the use of formative assessment and the adoption of teaching innovations effectively, a relatively innovation-friendly environment is required where there is variety in teaching. Additionally, to study the effects of peers on instructor innovation adoption, interaction about teaching between instructors needs to be observed. These features were found within a particular university biology department in which the investigations for this dissertation were performed.

This dissertation is an exploration into 1) the process of instructors deciding whether or not to adopt evidence-based teaching innovations, 2) the impacts of departmental teaching and social norms peers on that process, and 3) the ways in which implementation varies and changes over time and with environment among instructors who do decide to adopt. The remainder of this chapter will orient the reader with a brief introduction to each of the other chapters of this dissertation.

Chapter 2: A model of social impacts on instructor innovation adoption

The theoretical framework for this dissertation work is developed in Chapter 2 and explores the impact of teaching and social norms and peer interaction on instructor innovation decision. Previous literature regarding innovation decision, instructional change, and peer influence is synthesized to present a model of instructor innovation adoption that draws heavily on an innovation decision framework but takes into account the hypothesized roles of norms and peer interactions. Implications of the model are discussed and form the background for the other chapters, particularly Chapters 3 and 4.

Chapter 3: Meeting the conditions for diffusion of teaching innovations in a university STEM department

The model developed in Chapter 2 represents only one instructor experiencing a process of instructional decision-making. The links with peer interactions in this model imply that multiple instructors making multiple decisions can be conceptualized as an interlocking network of peers through which information and ideas can flow. This network is used in Chapter 3 to characterize the conditions for innovation diffusion. Instructor self-reported assessment experience is used to represent a measure of innovation use, and instructor interactions are also measured, allowing the relationship between instructor interactions and innovation use to be determined. The implications for opportunities for innovations to diffuse are explored. Chapter 3 establishes that the conditions for innovation diffusion exist in that the department contained instructors using innovations at a range of levels, with some using primarily lecture-based approaches and some using frequent active learning. Furthermore, frequent interaction about teaching was occurring within the department.

Chapter 4: Interaction and innovation: A study of the impacts of departmental climate perceptions and peer interaction on adoption of teaching innovations among college biology instructors

Chapter 4 builds on the results of Chapter 3, "zooming in" within the same network to further characterize instructors' processes of innovation decision and their perceptions of peer interactions and departmental teaching and social norms through interviews. The results from Chapter 4 enrich description of the model presented in Chapter 2 and suggest the possibility of peer interactions being harnessed to promote instructional change. Additionally, Chapter 4 points out that departmental climate perceptions can differ in a single department and affect instructor decisions in different ways.

Chapter 5: Build it and they will come? An investigation of formative assessment and feedback in an undergraduate biology SCALE-UP classroom

Chapters 3 and 4 help to establish the setting for Chapter 5: instructors involved in an innovation-friendly departmental climate who collaborate in creating an assessment-rich environment in introductory biology. Yet, Chapter 5 "zooms in" further to characterize the observed day-to-day assessment and feedback practices of instructors in a particular context. Classroom assessment and feedback are measured to discern how stable the instructors' assessment practices were within and between semesters and in the context of different classroom environments (SCALE-UP vs. lecture hall). Even though these instructors had adopted formative assessment and feedback practices, Chapter 5 allows for the characterization of what that adoption means within the classroom.

CHAPTER 2: A MODEL OF SOCIAL IMPACTS ON INSTRUCTOR INNOVATION ADOPTION

Abstract

Understanding and leveraging the factors involved in adoption of instructional innovations is important in the effort to improve undergraduate Science, Technology, Engineering, and Mathematics (STEM) education. While models of innovation decision describe individual instructors' adoption decisions, and institutional change literature emphasizes the influential role of departmental climate, fewer studies have examined the effects of an instructor's social context and peers on their individual adoption decisions. Departmental climate and norms influence the behavior of individuals within a social context. Peers within a department can act to spread awareness, provide various forms of knowledge, impact an instructor's affect positively or negatively, and build and communicate norms of the culture. We present a model of innovation decision for undergraduate STEM instructors that accounts for the roles of social and teaching norms and peer interaction by synthesizing previous literature on instructional innovation decision, peer influence, and institutional change. This work serves as a foundation for future investigations of the role of peers and departmental climate in encouraging and discouraging instructor adoption of teaching innovations and facilitating the spread of effective techniques.

Introduction

In the continuing effort to improve undergraduate science education, the importance of active learning techniques, frequent formative assessment, and other evidence-based instructional practices is often highlighted (Bradforth et al., 2015; Committee on STEM Education of the National Science & Technology Council, 2018; Freeman et al., 2014). Recent calls to action have stressed the need to encourage instructors to use evidence-based practices in undergraduate STEM, and extensive efforts continue to be made toward this goal (AAAS, 2015; National Academies of Sciences, 2017; Owens et al., 2018). Yet, there is still substantial evidence that many university science instructors continue to teach primarily didactically (Eagan et al., 2014; Stains et al., 2018). Even when instructors are aware of evidence-based practices and express positive attitudes and intent to use them (Henderson et al., 2012; Lund & Stains, 2015), they often don't persist in using them (Offerdahl & Tomanek, 2011), or implement the practice with modifications that may decrease their effectiveness (Offerdahl et al., 2018; Stains & Vickrey, 2017).

Ultimately, the predominant instructional approaches observed in undergraduate STEM contexts are the net sum of individual instructors' pedagogical choices over time (Grunspan et al., 2018; Sturtevant & Wheeler, 2019; Tomkin et al., 2019). But individual instructors' choices are heavily influenced by their past and present environment and experiences (Andrews & Lemons, 2015; Frese, 2015; Quardokus & Henderson, 2015; Reinholz & Apkarian, 2018). It has been hypothesized that instructors are likely to teach in the way they were taught. In this manner, the university context within which lecture has been historically normative may encourage perpetuation of lecture-based teaching over time (Grunspan et al., 2018). In addition, instructors may also be constrained by time, professional identity, and departmental reward structures (Austin, 2011; Brownell & Tanner, 2012; Reinholz & Apkarian, 2018). Effective teaching practices can sometimes be complex and require specific knowledge and skills (Henderson, 2005; Offerdahl et al., 2018; Stains & Vickrey, 2017), but access to, and inclination to use, the kind of detailed support necessary to develop those skills may vary (Landrum et al., 2017; Lund & Stains, 2015). Furthermore, instructors' direct and indirect experiences with teaching, and with new teaching methods, are influential in their decisions whether to use or continue using those methods (Andrews & Lemons, 2015; Marbach-Ad & Hunt Rietschel, 2016; Mcalpine et al., 1999).

To understand how individual instructors make decisions about how to teach, it is important to understand the interplay between personal and contextual factors (Dancy et al., 2016; Landrum et al., 2017; Lund & Stains, 2015; Shadle et al., 2017). An instructor's perception of their teaching identity, attitude toward evidence-based practices and confidence in implementing them, satisfaction with their current instruction, and the priority placed on teaching and instructional change are all personal factors that can influence instructional decisions (Andrews & Lemons, 2015; Marbach-Ad & Hunt Rietschel, 2016; Sturtevant & Wheeler, 2019). Contextual factors include instructional or institutional structures (i.e., specific courses taught by the instructor, physical classroom space) as well as the cultural norms of the department and institution within which the instructor functions daily (Gess-Newsome et al., 2003). Of particular interest here is how the departmental climate, or the "behavioral evidence for culture" (Schneider et al., 2013), as a contextual factor influences individual instructor behavior.

Culture has been conceived of as a set of underlying beliefs, values, and norms that guide an organization (Schneider et al., 2013), while climate is defined as the subjective experiences people have within the organization around that culture and the meaning they create from those experiences (Schein, 1965, 2010; Schneider et al., 2013). Climate grows in part out of a department's prevailing culture and history, but also out of the interactions between members of the department (Burt, 2000; Grunspan et al., 2018; Quardokus Fisher et al., 2019; Schein, 1996). Science departments often have cultural norms that play a role of preservation, buffering against extreme changes in teaching or research practice (Grunspan et al., 2018; Knight & Trowler, 2000; Roxå et al., 2011; Schein, 2010). Yet microcultures can exist within departments that reinforce or subvert the prevailing culture (Roxå & Mårtensson, 2015; Schein, 2010). The prevailing climate can also be affected by wider cultural influences, like the university-wide climate and the surrounding culture (Emery et al., 2019; Schein, 2010).

Instructors are embedded within departments and as such have regular interactions with their academic peers about research, teaching, students, departmental activities and obligations, and the like (Andrews et al., 2016; Quardokus & Henderson, 2015). Many different kinds of information can be communicated through these interactions, some of which instructors will interpret as related to their teaching, such as: prevailing norms around teaching, awareness of new teaching techniques, tips on how to implement teaching techniques, and ongoing support (or discouragement) toward instructional change (Andrews & Lemons, 2015; Dancy et al., 2016; Henderson, 2005; Lund & Stains, 2015; Rogers, 2003). Peer interactions collectively build an instructor's perception of the teaching and social norms within a department, and these perceptions are likely to influence instructional decisions. Interactions with peers may also affect teaching decisions more directly by adding to an instructor's knowledge base (e.g., increasing awareness of innovative teaching practices) or providing encouragement and moral support to try new methods.

A robust model that incorporates the potentially substantial impacts of departmental teaching and social norms as well as individual peer interactions on instructor decision-making will be fruitful for understanding and encouraging instructional change. In this paper, we present such a model. We have synthesized literature regarding innovation adoption (Andrews & Lemons, 2015; Marbach-Ad & Hunt Rietschel, 2016; Rogers, 2003), peer influence (Dancy et al., 2016; Quardokus & Henderson, 2015; Tomkin et al., 2019), departmental climate and norms

(Knight & Trowler, 2000; Landrum et al., 2017; Lund & Stains, 2015), and institutional change (Kezar & Holcombe, 2019; Marker et al., 2016; Reinholz & Apkarian, 2018) to produce our model. It provides contextualization of the innovation decision framework to a STEM teaching context in an academic department, incorporating the role of social context (teaching and social norms and individual peer interactions). In this model, peer interactions will refer only to those interactions that are somehow related to an aspect of teaching, or that an instructor interprets as having relevance to their teaching. This model will help conceptualize and describe the adoption of new teaching practices by individual instructors within a community, and will be useful in the encouragement of the use of evidence-based practices by instructors in undergraduate STEM.

A synthesized model of social impact on instructional innovation adoption

We present a synthesized model that helps us to conceptualize the role that climate and peers play in an individual instructor's innovation adoption decisions. Our synthesized model (Figure 2-1) draws from Rogers' (2003) innovation decision model and takes into account adaptations of that model to a university science teaching context (Andrews & Lemons, 2015) as well as literature on peer influences, climate and norms, and institutional change. An individual instructor's decision process is represented within a dashed box, while everything outside the dashed box is an instructor's social context. Both teaching/social norms and peer interactions are represented as directly influencing an instructor's affective state. Affect refers to the emotional situation of an individual, and affective state in this context can refer to such attributes as satisfaction, motivation, and feelings about identity (Andrews & Lemons, 2015; Gess-Newsome et al., 2003; Sturtevant & Wheeler, 2019). Further, peer interactions can provide knowledge, and indirectly perturb an instructor's affective state by influencing prevailing teaching and social norms. At the same time, these norms influence the affective states of other instructors within the department. Both an instructor's knowledge and affective state are activated when deciding to either implement an innovation (with or without some sort of re-invention or refinement), seek further information about an innovation, or reject the innovation (at least temporarily). In instances where information is sought, the newly acquired knowledge can change the affective state as well as impact future decisions. If a decision is made to implement an innovation, knowledge gained from classroom implementation can perturb the affective state and future decisions through the process of reflection.

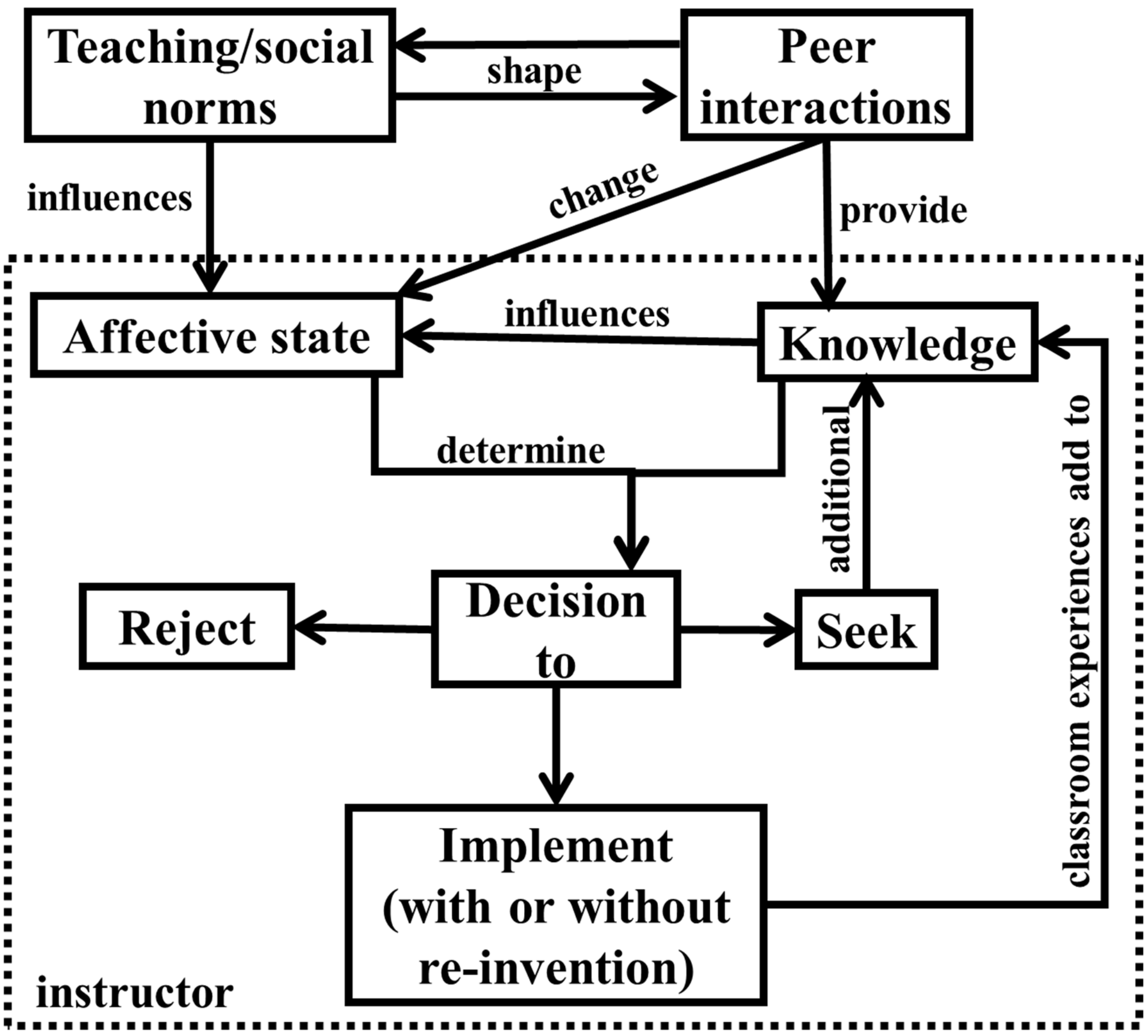

Figure 2-1. A model of the impact of departmental teaching and social norms and peer interactions on instructional innovation adoption

A concrete example of a teaching innovation helps to illustrate the path an instructor takes through this process. Consider the case of a university biology instructor deciding whether or not to adopt an instructional innovation, such as using case studies in their teaching (Andrews & Lemons, 2015). Our model predicts that an instructor's perception of their departmental teaching/social norms and pre-existing personal characteristics (e.g. teaching identity, perceived needs, personality) influence their affective state and thus their entry into the innovation decision process. When the instructor becomes aware of case studies and their utility in teaching (from a peer or another source), they take into account that knowledge and their affective state (influenced by peers and departmental norms) to make one of the three main decisions. They may decide to try out a case study in their classroom without much further research. In that case, the experience trying the case study will result in new knowledge. Reflecting on this knowledge can impact the instructor's affective state (e.g. opinion on case studies) positively or negatively, and they will go on to make a further decision on whether to continue their use. Alternatively, they may decide not to use case studies. This can happen if their affective state is such that they are already predisposed toward a negative opinion on such teaching methods, perhaps because of an unsupportive department with teaching norms in favor of lecture, or for other reasons. Finally, they may be interested in case studies but need to gather more information about them before deciding to try one. In this case, they will make the choice to seek out more knowledge about case studies. They may talk more to peers or seek out other sources. Eventually, that knowledge will lead them to try a case study or to decide against the idea.

In the following sections, we will further explore each of the aspects of this model, discussing the model relationships as well as theoretical and empirical support from the literature that informed this framework. We will start by briefly describing the steps within the dashed box, and then we will go into more detail about the impacts of norms and peer interactions. Then we will discuss potential implications of the model in terms of hypotheses for future research.

Knowledge

Knowledge refers to information an instructor has regarding an innovation, implementing it, or the context in which it is implemented. This can include not only initial awareness of an innovation but also how-to knowledge, principles knowledge (about how or why an innovation should "work"), pedagogical content knowledge (PCK), and knowledge about departmental norms and students (Andrews & Lemons, 2015; Dancy et al., 2016; Henderson, 2005; Lund & Stains, 2015; Pataraia et al., 2015; Van Driel & Berry, 2012). As in previous models, all of these types of knowledge can influence an instructor's decision directly (e.g. practical tips on how to use clickers), but they can also impact decisions through changing an instructor's affective state (see below). Knowledge can be obtained through communication channels (e.g. peers, books, websites), as well as from reflection on classroom experiences (Andrews & Lemons, 2015; McAlpine et al., 1999; Rogers, 2003). Knowledge, including awareness, can be passive or incidental, as when a peer mentions a new technique during a conversation or a teaching method is discussed during a required professional development seminar. Knowledge may or may not lead to further decisions, and instructors often need to actively seek out additional knowledge to implement a technique (Lund & Stains, 2015; Rogers, 2003). It is important to note that all forms of knowledge are dynamic, not static. They continually change based on personal experiences and information obtained from peers and other resources (Lund & Stains, 2015; Marbach-Ad & Hunt Rietschel, 2016; Mcalpine et al., 1999; Rogers, 2003).

Affective state

We define affective state to encompass instructor identity, confidence, motivation, priority placed on teaching, deeply-held values and beliefs, goals, and attitudes (Henderson, 2005; Mcalpine et al., 1999; Rogers, 2003; Sturtevant & Wheeler, 2019). Affective state can also include more situationally dependent personal conditions such as satisfaction with a particular class or innovation (Andrews & Lemons, 2015; Marbach-Ad & Hunt Rietschel, 2016; Sturtevant & Wheeler, 2019). Affective state has previously been modeled as a part of an instructor's prior conditions that can affect their entry into the decision process (Lund & Stains, 2015; Rogers, 2003; Sturtevant & Wheeler, 2019). In contrast, Andrews and Lemons (2015) presented a model which explicitly includes two components of affective state, satisfaction/dissatisfaction with teaching and prioritization of instructional change. Other models emphasize the role of affective state in terms of motivation and satisfaction, both as a starting condition as well as a mediating factor after trying an innovation (Gess-Newsome et al., 2003; Marbach-Ad & Hunt Rietschel, 2016; Sturtevant & Wheeler, 2019). Dissatisfaction is often seen as a necessary but insufficient condition for adopting a change in teaching practices (Gess-Newsome et al., 2003; Henderson, 2005). Instructors who are satisfied with their teaching may update content or incorporate new ideas (Dancy & Henderson, 2010), but they may not be actively seeking out any substantial changes in their teaching practice (Gess-Newsome et al., 2003). In addition, even dissatisfied instructors may not begin the innovation decision process if instructional change is not a high priority (Andrews & Lemons, 2015; Brownell & Tanner, 2012). Priority placed on teaching can vary with individual identity and social context, particularly departmental climate and norms. For example, research is often heavily prioritized and rewarded in STEM disciplines and departments, leading many instructors to minimize the time and effort they spend on teaching (Grunspan et al., 2018).

In our model, the affective state includes satisfaction, motivation, and prioritization of teaching and is depicted as directly impacting an instructor's decision, together with knowledge. Like knowledge, affective state is constantly in flux depending on changes in the instructor's personal situation, departmental climate, new knowledge, and classroom experiences. Affective state can be changed through knowledge gained from peers or other sources (e.g. finding out new information about student learning could lead an instructor to change how they prioritize teaching innovation), directly through peers (e.g. comparing oneself to what a peer is doing in their class could make one feel more or less satisfied with their own teaching), and through the climate and norms an instructor experiences within their department (e.g. motivation to change may be lower in climates that value research over teaching) (Andrews & Lemons, 2015; Bathgate et al., 2019; Knight & Trowler, 2000; Lund & Stains, 2015; Pugh & Hickson, 2007).

Decision

Together, knowledge and affective state determine the decision one makes about an innovation (Mcalpine et al., 1999; Sturtevant & Wheeler, 2019; Trowler & Cooper, 2002). During the decision stage, knowledge plays a persuasive role in that it influences the affective state to form an opinion, thereby initiating the decision-making process (Lund & Stains, 2015; Rogers, 2003). We follow Andrews and Lemons (2015) in not conceptualizing persuasion as a separate step for university STEM instructors, particularly since their process is iterative, forming and re-forming opinions about innovations throughout the cyclical process. Persuasion can thus be thought of as the process of opinion-forming by which knowledge influences affective state and these together initiate decision-making.

Decision-making can take place just once or many times. Attitudes formed about an innovation (including a belief that the innovation is better than current practice) do not always produce changes in classroom practices due to other affective influences and barriers, including departmental climate and norms (Buehl & Beck, 2014; Lund & Stains, 2015; Offerdahl & Tomanek, 2011; Sturtevant & Wheeler, 2019). Our model identifies three possible outcomes of the decision-making step: seeking more information, implementing the innovation in some form, and rejecting the innovation.

Seeking

An instructor's decision-making process may include the step of gathering information, from peers or any number of other sources (Lund & Stains, 2015; Marbach-Ad & Hunt Rietschel, 2016; Rogers, 2003). Seeking information can be motivated by dissatisfaction with teaching and/or a prioritization of change (Andrews & Lemons, 2015; Pataraia et al., 2015; Roxå & Mårtensson, 2009; Sturtevant & Wheeler, 2019) and departmental climates in which talking about teaching is the norm (Owens et al., 2018; Roxå & Mårtensson, 2009; Van Waes et al., 2015). Instructors may seek teaching-related resources or reach out to a peer viewed as possessing expertise in order to get ideas for improving teaching or addressing a particular problem (Henderson, 2005). Active seeking of new knowledge could result in awareness of one or more innovations.

In some cases, initial awareness of an innovation is acquired passively. An instructor may have heard of an innovation and be somewhat familiar with what it entails, but not have enough information to implement it themselves (Lund & Stains, 2015). Before implementation occurs, then, an instructor will typically decide to seek additional information (Lund & Stains, 2015; Rogers, 2003). Instructors may seek additional knowledge while initially considering an innovation or after trying it (Henderson, 2005; Marbach-Ad & Hunt Rietschel, 2016; Rogers, 2003). While this model explicitly recognizes the possibility of seeking behavior, we also recognize that implementation decisions can happen based on initial awareness only, without gathering additional information (Guskey, 2002; Henderson, 2005).

Implementation

A second possible outcome of the decision step is implementation of some form of the innovation. This can mean implementing an innovation exactly as the individual first became aware of it. But instructors also commonly make changes, particularly following their own experiences with implementation and reflection (Henderson, 2005; Rogers, 2003; Stains & Vickrey, 2017). Refinements or whole-scale re-inventions can happen before or after trying innovations in an effort to obtain or preserve instructor satisfaction (Marbach-Ad & Hunt Rietschel, 2016; Mcalpine et al., 1999).

We follow Andrews and Lemons (2015) and Marbach-Ad and Rietschel (2016) in taking into account the iterative nature of an instructor's path by making the innovation decision process into a cycle and including an element of reflection in the feedback arrow from implementation to knowledge. The cyclic aspect is important in an innovation decision model that specifically focuses on university instructors because they have repeated personal experiences in the classroom, both day to day and when teaching the same class repeatedly. Personal experience in the classroom is extremely influential in deciding whether to continue using instructional innovations (Guskey, 2002; Mcalpine et al., 1999; Rogers, 2003). While before implementation instructors may be primarily receiving information from peers or other outside sources, influences can shift after trying an innovation. At that point, an instructor's own classroom experience becomes a primary source of information to evaluate the innovation

(Andrews & Lemons, 2015; Guskey, 2002; Mcalpine et al., 1999; Sturtevant & Wheeler, 2019). However, instructors may seek input from peers who can help them think about their experiences and suggest changes for future implementation (Bandura, 2001; Rogers, 2003; Roxå & Mårtensson, 2009), and departmental teaching and social norms may also influence their perception of their experiences and consequent decisions (Lund & Stains, 2015; Morris et al., 2015).

Reflection can incorporate the results of student learning and implicit or explicit information about student preferences and classroom experience (Guskey, 2002; Kane et al., 2004). Since reflection changes the knowledge available for the next round of decision-making, it can be viewed as a form of self-assessment – instructors are learners who can use feedback from their classroom experience to inform their learning (Mcalpine et al., 1999; Mulnix, 2016). Knowledge from reflection also impacts affective state, particularly satisfaction based on that particular experience (Marbach-Ad & Hunt-Rietschel, 2016). In an ideal case, reflection becomes new knowledge and knowledge then informs future reflection in a continuous cycle (Andrews & Lemons, 2015; McAlpine et al., 1999). Confirmation (Rogers, 2003) or continuation (Henderson, 2005), in the context of instructional decision-making, then ideally consists of instructors continually deciding to implement an innovation iteratively, making refinements as necessary based on reflection on the results of previous iterations and on new information they obtain (Andrews & Lemons, 2015; Henderson, 2005; Henderson et al., 2012; Marbach-Ad & Hunt Rietschel, 2016; Mcalpine et al., 1999; Trowler & Cooper, 2002).

Rejection

The third and final potential decision is to reject the innovation, which can happen with or without first trying the innovation (Henderson et al., 2011, 2012; Rogers, 2003). Rejection means a temporary or permanent end to the innovation decision process for that innovation, although rejected innovations can be reconsidered at a later date, particularly if an instructor's circumstances or attributes change (Rogers, 2003). However, it is important to note that even rejected innovations can lead to changes in an instructor's initial knowledge and/or affective states. This happens because there is awareness of the rejected innovation and some kind of opinion was formed of it (Andrews & Lemons, 2015; Rogers, 2003). If the innovation was tried before being rejected, then reflection on classroom experiences also leads to changes in knowledge and affective state (Marbach-Ad & Rietschel, 2016).

Teaching and social norms

Departmental climate is an emergent property of a department's prevailing culture, disciplinary history, interactions between members of the department, and outside influences (Emery et al., 2019; Grunspan et al., 2018; Schein, 2010; Schneider et al., 2013). Norms (about teaching and about social interaction within the department) are an aspect of an instructor's climate that can change and constrain their affective state, including teaching and research identities, satisfaction with teaching, priority placed on teaching, and attitude toward teaching innovations (Grunspan et al., 2018; Knight & Trowler, 2000; Quardokus Fisher et al., 2019; Schein, 2010; Walter et al., 2016). Often in terms of undergraduate STEM education, departmental norms and climate are explored in the context of encouraging widespread instructional change. For example, the four frames model of organizational change (Bolman & Deal, 1991) has been adapted to a university STEM context by Reinholz and Apkarian (2018) to describe departmental culture in the process of a change initiative. They conceptualize the four frames as: Structures (formal procedures and norms, such as teaching evaluations, tenure review policies, procedures for choosing teaching assignments, and even physical teaching spaces);

Symbols (the vision underlying the structure and the cultural artifacts that demonstrate it – a set of shared values within the department); People (the members of the department and their social capital, individual identities, goals, and agency); and Power (the ways in which people are connected that illustrate power and status differentials and formal and informal departmental politics). These interdependent frames produce a department's cultural norms and climate, and each frame has aspects that can act as drivers or barriers for effective teaching and for instructional change (Reinholz & Apkarian, 2018; Shadle et al., 2017; Walter et al., 2016). Each academic department will have its own complement of drivers and barriers, and thus its own unique departmental climate for teaching and instructional change, and its own norms around teaching and social interactions (Lund & Stains, 2015; Reinholz & Apkarian, 2018; Roxå et al., 2011; Walter et al., 2016). Variation in climate and norms between departments results in different departments having differential impacts on both individual instructor change and the potential for cultural change (Lund & Stains, 2015; Reinholz & Apkarian, 2018; Shadle et al., 2017; Sturtevant & Wheeler, 2019). Recent studies indicate that a supportive department is essential for the adoption of teaching innovations (Bathgate et al., 2019; Carbone et al., 2019) and that outcomes of change initiatives are dependent on departmental climates and norms (Chasteen et al., 2015; Sturtevant & Wheeler, 2019).

For the model presented here, we focus mainly on norms around teaching and social interaction. Although other aspects of a departmental climate and culture could also impact instructors, norms are intimately connected to the social environment we are studying. Our model indicates that teaching and social norms influence instructor decisions through perturbing an instructor's affective state (see above), including satisfaction (with teaching in general, with a particular course or innovation, or generally their job satisfaction in the department), the motivation or priority placed on teaching, feeling of identity as a teacher and/or a researcher, curiosity or confidence about trying new teaching techniques, and beliefs about teaching (Landrum et al., 2017; Lund & Stains, 2015; Schneider et al., 2013; Sturtevant & Wheeler, 2019; Wieman et al., 2013; Woodbury & Gess-Newsome, 2002).

It is important to note that many afore-mentioned aspects of the climate for instructional change, like resources for teaching, the presence of pedagogical development, and departmental expectations are impactful not only because they provide a practical benefit, help, or incentive for instructors to change, but also because they serve as a signal about the department's underlying values and norms in regards to teaching, even if instructors never make use of a particular support (Landrum et al., 2017; Schein, 2010; Sturtevant & Wheeler, 2019; Walter et al., 2016). Instructors may conform to the prevailing norms, taking cues about how to prioritize or value teaching from their context. Alternatively, there may be a mismatch between how they value teaching and their departmental norms around teaching, causing dissatisfaction and conflicts with identity (Schein, 1996, 2010; Sturtevant & Wheeler, 2019). Departmental norms interact with each instructor's personality and perceived identity, leading to increased or decreased satisfaction and motivation, depending on their own experiences and disposition toward teaching (Brownell & Tanner, 2012; Grunspan et al., 2018; Sturtevant & Wheeler, 2019).

Peer interactions

Peers are known to be an influential factor in human behavior; the decisions an individual makes are heavily dependent on the relationships they have with their peers (Dancy et al., 2016; Lane et al., 2019; Van Waes et al., 2015). In an academic STEM department, instructors likely regularly interact about a variety of topics including research, teaching, and current administrative, service, or social events at the departmental or university level. These interactions facilitate the exchange of information, ideas, awareness of innovations, and encouragement/discouragement, and they are influenced by the departmental teaching and social norms as well as helping to shape those norms and communicate them to each other (Pataraia et al., 2015; Roxå & Mårtensson, 2009; Thomson & Trigwell, 2018).

Peers have previously been modeled as one of many communication channels that can affect nearly any step of the innovation decision process (Lund & Stains, 2015; Rogers, 2003; Sturtevant & Wheeler, 2019). In this model, we assert that peers act on an instructor's innovation decision process in three specific ways: 1) they provide knowledge (Dancy et al., 2016; Henderson et al., 2011; Pataraia et al., 2015), 2) they perturb an instructor's affective state (Marbach-Ad & Hunt Rietschel, 2016; Roxå & Mårtensson, 2009; Sturtevant & Wheeler, 2019), and 3) they shape and communicate norms of the department, which can indirectly impact an instructor's affective state (Landrum et al., 2017; Lund & Stains, 2015; Shadle et al., 2017). All downstream impacts of peers (decisions by an instructor to implement or reject an innovation or seek more knowledge) are the result of one or more changes in either knowledge or affective state, or both.

The impact a peer has on an instructor's decision-making process can be innovation-positive, innovation-negative, or innovation-neutral. This depends not only on what the peer does or says but also the receiving instructor's perception of prevailing departmental norms, the receiving instructor's personality and prior knowledge and affective state, and features of the innovation itself. An instructor interprets and processes peer input before using it to make decisions. For example, an instructor may hear a peer talking about using case studies to stimulate group discussion. Even if the peer is positive about their experience with case studies, the instructor hearing it may interpret that information in an innovation-negative way, e.g. if they do not have a favorable view of group discussion or already feel they have enough group discussion.

Peers provide knowledge

An instructor's peers can be an effective communication channel due to proximity, homophily, shared knowledge of a system and culture, and ability to provide multiple forms of information (Dancy et al., 2016; Lund & Stains, 2015; Quardokus & Henderson, 2015; Rogers, 2003). Peers can communicate a range of information, including awareness of specific innovations , practical knowledge about implementation of innovations (how-to knowledge), knowledge about how and why an innovation "works" or the principles behind it (principles knowledge), pedagogical content knowledge (PCK), troubleshooting or help with reflection, and guidance based on personal experience using an innovation (Dancy et al., 2016, 2014; Henderson, 2005). Individuals draw on their peers to gather information and opinions and make decisions; instructors who are well-connected and have access to peers who can provide a productive variety of resources have more social capital and may be equipped to be more successful in their teaching (Benbow & Lee, 2018; Burt, 2000; Seibert et al., 2001; Van Waes et al., 2015).

Peers are a significant source of awareness of new teaching ideas (Dancy et al., 2016; Rogers, 2003), either passively or actively. Instructors may hear their peers talking about something or a peer may share something they tried or heard about (Andrews & Lemons, 2015). A peer may convey a positive or negative value judgement of the innovation, potentially impacting an instructor's affective state. Or, an instructor may make the decision to talk to peers in active search of an idea that will help them with a specific problem they are having as part of their teaching (Rogers, 2003). Instructors who decide to actively seek information will likely turn to peers as a source, especially when those peers are perceived as knowledgeable about the particular innovation or someone with whom the instructor has an affinity (Quardokus Fisher et al., 2019; Rogers, 2003; Roxå & Mårtensson, 2009). Instructors may seek how-to knowledge, technical help or troubleshooting when trying the innovation, or after trying it and reflecting on what needs to change (Marbach-Ad & Hunt Rietschel, 2016). Knowledge can be acquired through active seeking, or passively through casual conversation with peers (Quardokus Fisher et al., 2019; Thomson & Trigwell, 2018).

The information provided by peers is a potential mechanism for innovation diffusion within a department (McConnell et al., 2019; Rogers, 2003), as it could trigger a start to the innovation decision cycle in an instructor and/or perturb the cycle (Andrews & Lemons, 2015; Dancy et al., 2016; Rogers, 2003). Additionally, the instructors who are proceeding through the innovation decision process can affect others' processes (Dancy et al., 2016; Rogers, 2003). Information in a social system can flow to and from each instructor as they are experiencing the innovation decision process. Thus, each instructor's decision process can be conceptualized as intersecting with the innovation decision processes of their peers to form a social network through which innovation diffusion can take place (Greenhalgh et al., 2004; McConnell et al., 2019; Quardokus & Henderson, 2015; Rogers, 2003).

Peers perturb each other's affective states

In addition to knowledge about an innovation or about other aspects of teaching, peers can affect each other's goals, beliefs, satisfaction, and attitude, in both innovation-positive and innovation-negative ways, through conversation and implicit or explicit comparison (Benbow & Lee, 2018; Mcalpine et al., 1999; Owens et al., 2018; Seibert et al., 2001; Thomson & Trigwell, 2018). Peers within the same institutional and/or social context are well positioned to provide each other ongoing support before, during, and after implementing new innovations. Such support has been shown to be important for sustained change (Guskey, 2002; Henderson et al., 2011; Sirum & Madigan, 2010; Wieman et al., 2013). Support can take the form of sharing of personal experiences, acting as a sounding board to assist with the decision-making process, or assistance with the reflection process after an instructor tries an innovation (Marbach-Ad & Hunt Rietschel, 2016; Mcalpine et al., 1999).

Collaboration and frequent interaction can reinforce positive teaching behaviors within a community of like-minded peers, whether such groups are formal or informal (Ma et al., 2018; Olmstead et al., 2019; Sirum & Madigan, 2010). Communities of practice can provide not only knowledge but emotional and practical support as instructors undergo a change in teaching practices (Owens et al., 2018). Conversely, peers can be a persistent barrier to innovation when they reinforce ideas about teaching norms that are not conducive to implementation of such innovations (Emery et al., 2019; Henderson et al., 2012; Lund & Stains, 2015; Rogers, 2003). Individuals may find it difficult to change if those around them are not interested or are antagonistic toward that change.

Peers influence and are influenced by departmental norms

It is important to note that interactions with peers often shape an instructor's perception of the prevailing teaching and social norms within a department. The influences between an instructor and their peers and between the departmental norms and each instructor are mutually dependent. The interactions between instructors within a department form a network by sharing information and opinions, and this network of interactions is one aspect that shapes an instructor's perception of departmental climate and norms (Bandura, 2001; Borgatti & Cross, 2003; Burt, 2000; Pataraia et al., 2015). In turn, teaching norms can have a profound impact on the types of teaching that take place within a department (Emery et al., 2019; Grunspan et al., 2018; Lund & Stains, 2015; Roxå et al., 2011; Schein, 1996), and social norms impact the pattern of interactions that happen in regards to teaching and other topics (Chasteen et al., 2015; Ma et al., 2018; Owens et al., 2018; Quardokus & Henderson, 2015; Smolla & Akçay, 2019). Thus, peer interactions are both a product and a producer of the prevailing departmental norms, and also communicate those norms to each other, moderating the effects of departmental climate and norms on each instructor (Dancy et al., 2016; Grunspan et al., 2018; Lund & Stains, 2015; Pataraia et al., 2015).

Hypotheses for future work

A vast literature base already indicates that the rates of innovation adoption vary with environment (Lund & Stains, 2015), instructors' perceptions of departmental culture and norms impact their willingness to use innovations (Bathgate et al., 2019; Landrum et al., 2017; Shadle et al., 2017), and persistence in using innovations is enhanced by a supportive community (Tomkin et al., 2019; Wieman et al., 2013). We have developed a model that explicates the role of departmental norms and peer interaction in facilitating (or inhibiting) university STEM instructors' innovation adoption. Importantly, this model will be useful in understanding how instructors with identical classroom experiences and knowledge could reach different conclusions about an innovation because of differences in their prevailing departmental norms and peer interactions. In this section, we identify four hypotheses that stem from the model that can be used for future validation studies.

Hypothesis 1: Instructor adoption decisions are impacted more by their perceptions of departmental climate and norms than by individual peer interactions

Interactions with a peer can affect an instructor's decision-making process directly by providing new information that increases their knowledge (e.g., tips for integrating a new teaching strategy) or support that changes the affective state (e.g., encouragement or acting as a sounding board). Peer interactions can also have an indirect effect by shaping an instructor's perception of the teaching and social norms within a department. These perceptions are likely to influence instructional decisions through the instructor's affective state. Thus, affective state is influenced by both norms and individual peer interactions. Hypothesis 1 posits that social and teaching norms may carry more weight for an instructor's decisions than individual interactions with peers. Social and teaching norms likely have a larger impact on motivation, priority, identity, and general attitude toward teaching and teaching innovation than any individual interaction with a peer because they are in part an emergent property of many peers, and because of the relative power aspects of the two situations (Reinholz & Apkarian, 2018). While departmental norms affect an instructor and all of their peers, individual peer interactions only impact one or a few instructors at a time. Additionally, these norms have a long-standing historical cultural element that helps shape the identity of an instructor, which a single peer typically does not (Grunspan et al., 2018; Lund & Stains, 2015). When an instructor seeks out information from a peer, the decision they make with that information will be mediated by their perceptions of departmental norms. Thus, we would expect instructors' perceptions of departmental norms to be more predictive of their innovation adoption than any single peer interaction in a typical department. This hypothesis could be invalidated by showing that instructor decisions are typically traced to interactions with specific peers irrespective of prevailing norms. However, social and teaching norms and peer interactions are also intertwined. Within a supportive department with norms encouraging peer interaction, we expect that peers could become a much more relevant influence. In this situation, norms and peer interactions may have a synergistic, mutually reinforcing impact, and groups of peers may be more influential toward initiating change.

Hypothesis 2: Social norms mediate peer interactions, potentially constraining innovation adoption

Social and teaching norms impact the affective state of all members of a department. Therefore, they will impact how instructors interact with each other and the structure of the network (Chasteen et al., 2015; Smolla & Akçay, 2019), which will have an impact on how instructors receive both information and support. Seeking behavior, for example, is expected to be mediated by the social and teaching norms in a department. Peers likely demonstrate seeking behavior when they are interested in an innovation they've heard about (Lund & Stains, 2015), or when they are dissatisfied with their teaching and/or have a high priority regarding instructional change. However, in addition to mitigating those variables of an instructor's affective state, norms around teaching and collegial interaction have the potential to moderate an instructor's propensity toward seeking information. Strong norms of academic freedom and individuality, for example, would likely depress interactions among colleagues and discourage seeking behavior. An alternative hypothesis may be that seeking behavior is primarily the result of individual instructor personality attributes and will not be impacted as much by departmental norms.

Formally, a department or change agent could find ways to encourage teaching interaction and collaboration, such as communities of practice (Owens et al., 2018; Roxå &

Mårtensson, 2009; Tomkin et al., 2019). When collaboration is encouraged, peers who work together would more readily share pedagogical content knowledge, how-to tips, and ideas and would be able to support each other through changes. We expect that departments and change initiatives which find ways to incorporate more community around teaching would experience positive results with instructor innovation adoption, which would be enhanced if reinforced by social and teaching norms. Conversely, if departmental history, norms, and reward structures strongly favor lecture, incorporating communities of practice alone may not have as much of an impact, and such communities would need to be carefully designed to overcome the impacts of these deep-seated cultural norms.

Hypothesis 3: Increased peer interaction leads to increased innovation adoption

Even though implementation decisions can happen without seeking additional information, we expect this outcome to be relatively uncommon. In contrast, rejecting an innovation on the basis of limited information may be the easier decision to make for instructors, unless they have very high levels of confidence and/or motivation. Rejection without seeking is thus expected to happen much more often than implementation without seeking. Since peers are a likely source of teaching information for instructors due to proximity and homophily (Rogers, 2003), and because there is likely little implementation without an instructor first seeking out some kind of further information, we hypothesize that departmental norms which encourage teaching interaction and seeking behavior would produce more innovation adoption. In addition, peers within a supportive microclimate or community of practice would be more likely to both try and continue using innovations than peers without this support. Peers can provide the information or perspective necessary to make an informed decision regarding trying an innovation as well as help instructors reflect on their experience after trying it. Furthermore, peers can increase initial opportunities to adopt innovations by providing awareness of new ideas to each other. We predict that instructors who talk to peers more frequently, and/or are in environments which encourage this type of interaction, would implement more innovations. There is some possible evidence of this in instructional settings already (McConnell et al., 2019; Middleton et al., 2015; Van Waes et al., 2015). Alternatively, if this hypothesis is incorrect, we would expect to see little relationship between peer interaction and innovation adoption, or see that those who adopt few teaching innovations still have frequent interaction with their peers about teaching.

Hypothesis 4: Microclimates mitigate the impacts of departmental norms for some instructors

The prevailing departmental climate has substantial influence due to components such as reward structures, codified norms and expectations of leadership, and the presence and absence of supports and pedagogical improvement opportunities (Landrum et al., 2017; Reinholz & Apkarian, 2018). Yet, subgroups can form within a department that may have different norms than those that prevail in the surrounding departmental climate (Roxå & Mårtensson, 2015; Schein, 2010). In fact, organizational cultures actually consist of many overlapping cultures (Henderson et al., 2011; Schein, 2010). Such subgroups are predicted to impact instructor affective state, just as do prevailing norms from the department. Some departmental norms could be reinforced by subculture norms, while others are subverted. For example, within a department in which the primary instructional norm is lecture, a subgroup of instructors who are interested in active learning may form, interacting with each other to share ideas and support each other in trying active learning techniques. We would expect that instructors in that subgroup and adjacent to it would be more likely to implement innovations even though their department is unsupportive, since they are receiving social support to do so from the subgroup. However, they might be less likely to persist in using the innovations than if they were in a supportive departmental climate, since they are lacking the norms and institutional structural supports that would come with such a climate. Conversely, a department in which the primary instructional norm is active learning may contain a pocket of resistant or skeptical instructors who reinforce each other's decisions to continue using lecture, or not to try new teaching innovations. Such instructors may be less likely than those outside that subgroup to be implementing innovations, even though they teach within an innovation-friendly department, because they are receiving social support not to use innovations.

Conclusions and future directions

The model presented here is focused on departmental and peer effects on the innovation decision process. As such, the potential utility of this model will be for change agents seeking to support instructional change in undergraduate STEM education as well as researchers of instructional change. This model should be tested and validated in a variety of situations and contexts and used to more fully elucidate the specific impacts of norms and peer interactions on an instructor's decision-making process. This can be done by 1) studying how peers interact with each other, the types of information they exchange, and how departmental norms influence interaction patterns, and 2) studying individual instructor decisions and the impacts they perceive from peers and their departmental teaching and social norms.

Due to the focus on social context, the model does not explicitly take into account other impacts on an instructor such as non-peer sources of knowledge. Some instructors may make use of books, websites, and professional development seminars to change their teaching in the presence of an unsupportive department and with no peer input, or to justify not changing their teaching even in a departmental context supportive of change. Likewise, attributes of the innovation (e.g. trialability, ease of use; Rogers, 2003) that may affect likelihood of implementation are not considered explicitly in the model. The presence of these attributes may be ascertained by conversation with peers, by trying the innovation, or by other means.

The model awaits empirical testing and validation to confirm and further elucidate the role of peers and explore the impacts of teaching and social norms in different departments, university contexts, and disciplines (Lund & Stains, 2015; Sturtevant & Wheeler, 2019). Further, the set of peers and the scope of climate and norms taken into account may vary among those who make use of this model and could affect the utility. For example, limiting peers to those within a single department or social context may simplify a study and allow it to be placed in the context of a particular departmental culture, yet it risks excluding influential peers encountered elsewhere by instructors.

Synthesizing previous literature on instructional innovation decision, peer influence, and institutional change in higher education has produced a framework for studying innovation adoption in a social context within undergraduate STEM education. This comprehensive model incorporates the effects of departmental teaching and social norms and peer interactions on instructor innovation decision and has allowed us to make predictions about how they impact an instructor's decisions. After empirical validation, the model can be used as a framework for researchers to more fully elucidate and extend the effects of peers, determining the relative importance of different peer interactions and outcomes and the departmental conditions under which they have certain impacts. Additionally, researchers can predict and explain how different sets of departmental norms may mediate the impact of change initiatives on individual instructors. Administrators, professional development coordinators, and other change agents can also use the model to encourage interventions that will maximize positive impacts of peers and social context and minimize negative ones in order to encourage the spread of evidence-based practices in university STEM instruction.

As we continue to seek widespread change in STEM education, it will be important to fully consider the context an instructor is working within and how that affects their decision-making. We will then be able to suggest beneficial changes at the institutional, departmental, and individual level that will help instructors adopt student-centered instructional practices in an evidence-based way. This model will be a useful framework for administrators, peer change agents, and individual instructors to maximize adoption of beneficial instructional innovations and minimize potential negative effects of departmental norms and peers. Administrators and change agents can use this model to think about the types of peer interactions that are likely to be beneficial and how those can be encouraged within a given departmental culture, as well as how to leverage departmental cultures or subcultures in the service of instructional change. Professional development programs can take into account the social context and suggest ways instructors can succeed in pedagogical change, and work within institutions to incorporate communities of practice that will maximize beneficial interactions and the spread of effective teaching innovations. In sum, understanding the role of departmental norms and peers in fostering instructional innovation adoption will help change agents continue to transform the landscape of undergraduate STEM education.

CHAPTER 3: MEETING THE CONDITIONS FOR DIFFUSION OF TEACHING INNOVATIONS IN A UNIVERSITY STEM DEPARTMENT[1]

Abstract

Recommendations to improve university Science, Technology, Engineering, and Mathematics (STEM) education often emphasize the role of classroom assessment in supporting student learning. Despite extensive efforts to support instructors in reforming their practices, many continue to teach didactically with limited classroom assessment. Instructors' decisions to adopt new practices have previously been characterized with the innovation decision model, and the spread of such practices can be explored through an innovation diffusion lens. Innovation diffusion of high-impact assessment practices requires interaction between experienced assessment users and less-experienced users. Within a university STEM department, instructors' assessment experiences were documented through the Faculty Self-Reported Assessment Survey (FRAS), and interactions between instructors were characterized with social network analysis. Results show that instructors with higher self-reported assessment experience had more teaching-specific peer interactions within the department, and that instructors of all assessment experience levels interacted more often with more experienced instructors. This study demonstrates and characterizes the conditions for innovation diffusion in a university STEM department and

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highlights the potential role of peer interactions for supporting the spread of innovative teaching ideas.

Introduction

Educators in Science, Technology, Engineering, and Mathematics (STEM) face many challenges in meeting the critical demand for science-educated workers and a scientifically literate populace (Committee on STEM Education of the National Science & Technology Council, 2018). Initiatives to improve STEM education often include calls to decrease lecture-based instruction in favor of increased use of evidence-based instructional practices that actively engage students in higher-order activities and incorporate frequent, ongoing assessment of in-progress learning (Brewer & Smith, 2011; Cooper et al., 2015; Freeman et al., 2014; Handelsman et al., 2007). These practices have been shown to increase retention, improve learning, and decrease achievement gaps (Eddy & Hogan, 2014; Freeman et al., 2014; Haak et al., 2011). Yet the majority of university science teaching remains didactic, even when instructors participate in extensive professional development (Dancy & Henderson, 2010; Ebert-May et al., 2011; Stains et al., 2018).

Why is it so difficult for science instructors to change their teaching practices? Previous scholars have described the myriad personal, contextual, and social factors that influence the pedagogical choices of individual instructors (Andrews & Lemons, 2015; Dancy & Henderson, 2010; Gess-Newsome et al., 2003; Lund & Stains, 2015). These factors have also been used to generate models to predict the conditions and mechanisms for adoption of new teaching innovations (Andrews & Lemons, 2015; Lund & Stains, 2015; Rogers, 2003). While much of this work has sought to describe the evolution of individual teaching practices, it focuses much less on discerning and describing the roles of peers in that process. Instructors socialize routinely with department colleagues about research, teaching, and other scholarly activities. Particularly in STEM departments, peers may communicate norms that include an emphasis on research at the expense of teaching, which may be a factor that inhibits the adoption of innovative teaching practices. Alternatively, they may communicate new and effective teaching ideas.

The spread of innovative teaching ideas or techniques, referred to as innovation diffusion, is likely to be enhanced through peer interactions that are supportive of such ideas and inhibited by negative interactions (Rogers, 2003). Diffusion of innovations through a community requires interactions between members of the community who use an innovation and those who do not (Rogers, 2003). Therefore, within the context of university-level teaching, new teaching techniques are more likely to spread through a department when there is communication between more and less experienced instructors (Rogers, 2003). Indeed, experienced departmental colleagues may play a critical role in shaping peer motivations as well as signaling a positive climate (Andrews et al., 2016; Bush et al., 2016; Sun et al., 2014). Yet the role of peer relationships and social interactions in shaping instructional practices within STEM departments has yet to be well characterized (Dancy, Henderson, & Turpen, 2016).

Given the seemingly slow spread of evidence-based instructional practices in university STEM contexts (Stains et al., 2018) and the potential role of peer support in adoption and diffusion, we sought to understand the opportunities for diffusion of teaching innovation in relationship to peer interactions within academic STEM departments. The innovation of interest for this study was the routine implementation of diverse assessment practices by faculty within a single STEM department (a biology department). Specifically, this study sought to answer the following questions:

1. What differences in self-reported assessment practices exist in a university biology department?

2. To what degree do departmental colleagues interact with instructors who report high use of assessment practices?

3. To what degree do instructors with different levels of assessment use interact with one another?

In the following narrative, we begin by rationalizing the choice to examine assessment practices as a teaching innovation, followed by a brief description of the innovation decision process (deciding whether or not to adopt an innovation such as assessment) and how peer effects on this process could lead to innovation diffusion. We then introduce social network analysis as a tool to characterize peer interactions within academic departments. Finally, we describe how we characterized the conditions for innovation diffusion, and conclude by discussing the implications of this work, including the role of peer interactions between STEM instructors in the adoption and spread of teaching innovation. The results of this work will be useful to professional development designers and department/university leaders in their efforts to improve university STEM teaching.

Background

University STEM education reform includes improving assessment practices

Recent calls for improving university STEM education have recommended increasing the frequency with which student learning is assessed and provided feedback on during learning (AAAS, 2015). By increasing both the quality and quantity of classroom assessment, instructors can improve STEM learning by monitoring progress toward student learning outcomes and providing relevant feedback during the learning process (AAAS, 2015; Hanauer & Bauerle, 2015; Handelsman et al., 2007; Offerdahl et al., 2018). When designing and implementing classroom assessment, instructors consider many factors such as defining student learning outcomes, writing appropriate assessment items, evaluating the quality of an assessment, and providing feedback to students (Hanauer & Bauerle, 2015). Summative assessments are common because of the necessity to assign course grades, but meaningful and effective assessment practices that help students learn often do not come naturally to instructors and may be lacking in classes that are taught in a didactic, lecture-heavy style (Stains et al., 2018; Wu & Jessop, 2018). Since formative assessment is likely to be less frequent in lecture-heavy courses, and university STEM instructors continue to rely on didactic teaching methods, implementation of a diverse array of assessment practices that includes both formative and summative measures can be thought of as a teaching innovation, and their spread as an innovation diffusion process. In this study, the innovation of interest was measured using the Faculty Self-Reported Assessment Survey (FRAS) (Hanauer & Bauerle, 2015; https://www.lifescied.org/doi/10.1187/cbe.14-10-0169), which reveals the frequency of self-reported use of, attitude toward, and confidence in using various assessment practices (e.g. creating formative assessments, giving feedback to students). High FRAS scores indicate the frequent implementation of diverse assessment practices (Hanauer & Bauerle, 2015).

Innovation decision: instructors try and adopt new ideas

An instructor's adoption of effective assessment practices can be modeled as an innovation decision process (Andrews & Lemons, 2015; Henderson, 2005; Henderson et al., 2012; Rogers, 2003). In this model (Figure 3-1), dissatisfaction is a prerequisite condition that is necessary but not sufficient for an instructor to begin changing their teaching (Andrews & Lemons, 2015; Gess-Newsome et al., 2003; Mcalpine et al., 1999). Dissatisfaction must be accompanied by prioritization of change, both of which can be affected by departmental context and peers. Prioritization of change then leads to seeking knowledge about an innovation (Knowledge stage; Andrews & Lemons, 2015).

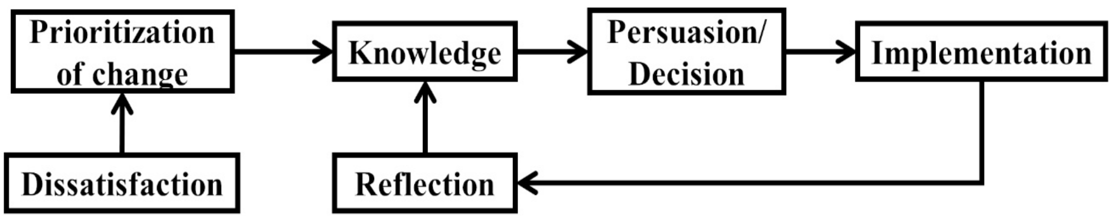

Figure 3-1. An innovation-decision model for instructional decisions. Adapted from Andrews and Lemons (2015)

Knowledge shapes opinions and ultimately the decision (Persuasion/Decision) to try the innovation (Implementation). Instructors can obtain knowledge from peers, professional development, reading, or other sources. Knowledge is also generated through reflection on classroom experiences (Reflection; Andrews & Lemons, 2015; McAlpine et al., 1999). Reflective instructors will consider their experience within the context of their own 'corridor of tolerance' – a range of cues within which instruction is perceived to be acceptable (McAlpine et al., 1999). The outcome of this reflection generates new understanding of the innovation that then shapes the decision to re-enter the cycle, and whether or not to continue using the innovation, or to refine it in some way (Andrews & Lemons, 2015; Henderson et al., 2012). Refinement of an innovation (often termed re-invention) (Henderson et al., 2012; Rogers, 2003) may repeat, often leading to multiple iterations of the innovation-decision process for a single innovation (Andrews & Lemons, 2015). Each step of the innovation decision process can be affected by features of the innovation (e.g. ease of use), instructor (e.g. personality, goals), and environment (e.g. peers, departmental context, time and resources available, professional incentives) (Brownell & Tanner, 2012; Dancy et al., 2016; Dancy & Henderson, 2010; Lund & Stains, 2015; Rogers, 2003).

Innovation diffusion: social interactions affect adoption and spread of innovation

Peer effects are known to be important influences on human behavior and the spread of ideas in any social system (Christakis & Fowler, 2013; Kezar, 2014; Valente, 2012). In the context of transforming university teaching, the role of departmental and social contexts is recognized as a factor in need of more exploration (AAAS, 2015; Dancy et al., 2016; Lund & Stains, 2015). Indeed, recent research has focused on the role of peers in encouraging faculty instructional change (Andrews et al., 2016; Knaub et al., 2018; Lane et al., 2019; Ma et al., 2018).

Departmental peers are a potential source of information for an instructor who is proceeding through the innovation decision process and may assert influence on the process in a number of ways. Peers can communicate and reinforce social norms within a departmental culture, thereby affecting an instructor’s teaching (Dancy et al., 2016; Rogers, 2003; Sun et al., 2014; Thomson & Trigwell, 2018). This can be especially important in university STEM contexts, which can have cultures focused on research with less priority on effective teaching (Brownell & Tanner, 2012; Lund & Stains, 2015). Peers can influence an instructor’s level of satisfaction with teaching and the priority they place on teaching (Andrews & Lemons, 2015; Dancy et al., 2016; Gess-Newsome et al., 2003). They can provide information in the Knowledge stage (e.g., awareness of an innovation, how-to tips, personal experience) thereby influencing an instructor’s decision about whether to try the innovation (Andrews & Lemons, 2015; Dancy et al., 2016; Rogers, 2003). Similarly, during the Reflection stage, input from a peer may help an instructor process implementation of an innovation, and in doing so shape perceptions of success (Andrews et al., 2016; Dancy et al., 2016; McAlpine et al., 1999).

Through these mechanisms, peers have the potential to perturb the innovation decision processes of individual instructors. In turn, those instructors who have gone or are going through an innovation decision process may communicate information to others about their experience, thereby asserting influence on the innovation decision processes of others (Dancy et al., 2016; Rogers, 2003). In this way, information about innovation can spread through a department, impacting multiple instructors at different points in their innovation decision processes (Rogers, 2003). These interlinked, iterative innovation decision processes collectively create a social network where innovation diffusion can take place.

Social networks: studying social influences in higher education

Peer interactions between department colleagues produce a social network and can therefore be elucidated through social network analysis (Kezar, 2014; Lane et al., 2019; Quardokus & Henderson, 2015), a technique that allows analysis of the structure of ties (i.e., self-reported interactions) between nodes (i.e., instructors within the department). Social network analysis has recently been used to study both student (e.g. Grunspan et al., 2014; Siciliano, 2016; Zwolak et al., 2017) and faculty interactions (Andrews et al., 2016; Ma et al., 2018; Middleton et al., 2015) within university science contexts.

In the departmental social network, ties can be directed – incorporating information about who reported the interaction – or undirected, implying a two-way relationship or that direction does not matter. In this study, we used both directed and undirected ties. The large teaching, research, and social networks in Figure 3-2 illustrate undirected ties, while the subset network on the left illustrates directed ties. The number of ties a node has is known as degree centrality

(Grunspan et al., 2014). In a directed network (Figure 3-2, left), there are two types of degree centrality: out-degree and in-degree. Out-degree centrality is the number of ties a participant reports to other individuals, while in-degree centrality is the number of participants who report a tie to an individual (Grunspan et al., 2014; Thiele et al., 2018). For example, in Figure 3-2, node 4 has an out-degree centrality of 3 and an in-degree centrality of 1. Although it can be assumed that node 1 also interacted with node 4 due to the tie reported by node 4, perhaps the communication was more impactful for node 4 or there is another reason that node 1 did not recall it or consider it important to mention. In some cases, an interaction is one-sided because the interaction partner did not answer the survey (node 2 in Figure 3-2). A high centrality may indicate that a node is a 'hub' that could be influential in spreading information to a large portion of the network (Quardokus & Henderson, 2015). In this study, in-degree centrality was used as a measure of potential influence (Knaub et al., 2018; Thiele et al., 2018) because it was determined by others in the department (the number of individuals within the network reporting an interaction with another person).

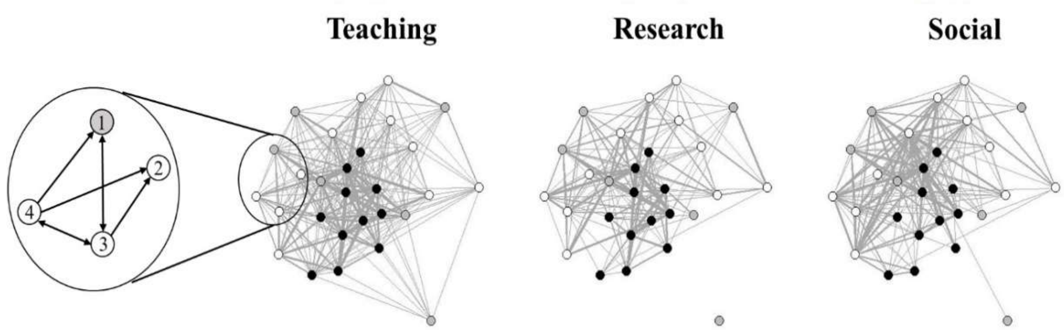

Figure 3-2. Network diagrams for three types of interactions within the department, fixed in position based on the teaching network with ties weighted by number of semesters reported. A subset of the teaching network illustrates in-degree and out-degree. Nodes represent instructors with high (black), low (white), and mid (grey) self-reported assessment practices

The relationship between peer interactions and teaching has been studied previously. It has been shown that K-12 teachers who interact more about teaching also implement more student-centered practices (Judson & Lawson, 2007). Similarly, university instructors classified as learner-centered or expert are reported to have more extensive social networks (Middleton et al., 2015; Van Waes et al., 2015).

Departmental colleagues who conduct education research are perceived by themselves and their peers as contributing to change in their peers' teaching practices (Andrews et al., 2016; Bush et al., 2016). Collectively, these studies suggest that individual instructors will be well positioned to encourage diffusion of teaching innovations if they a) are a hub in the department (i.e., have a position of high centrality in the network), b) have a high level of expertise or experience using a particular teaching innovation, and/or c) interact with others who have less experience (Knaub et al., 2018; Quardokus & Henderson, 2015; Rogers, 2003).

Communication is more common among individuals who share some characteristics (known as homophily), yet the spread of ideas is better facilitated by heterogeneous interactions – communication between individuals who differ in ways relevant to those ideas (Grunspan et al., 2014; Rogers, 2003). Therefore, the current study investigated the potential for diffusion of assessment as a teaching innovation by determining the extent to which instructors with high self-reported experience in assessment also had a position of high centrality, and to what extent more experienced individuals interacted with those who had less experience. The existence of these conditions would meet Rogers' criteria for innovation diffusion: a) the presence of an innovation, b) members of the social system who have experience using the innovation, c) members without this experience, and d) communication between the two types of members (Rogers, 2003, p. 18).

Methods

Diffusion of assessment ideas and practices within a STEM department requires instructors with differential assessment experience (i.e., expert-like experience, entry-level experience) and communication between these instructors. To determine if these conditions existed, a survey was conducted to measure two attributes for each instructor: self-reported assessment experience (including frequency of use) and interactions with other instructors within the department. The survey was administered within a single department over five semesters, thereby allowing for characterization of informal peer interactions and the potential for innovation diffusion through these interactions.

Context of the study

This study took place in a biology department at a doctoral-granting land grant university in the upper Midwestern United States. The university and department cultures valued teaching, as evidenced by the presence of large-scale education reform initiatives, monthly Provost-sponsored pedagogical luncheons, and an undergraduate learning assistant program (Otero et al., 2010). State-appropriated funding had been dedicated to faculty with education research specialties within the department. The chair of the department allocated funds for pedagogical professional development and actively encouraged all instructors to reflect on their teaching. At the time of this study, ~60% of instructors within the department had participated in substantial (more than a one-day seminar) professional development focused on teaching. Instructors attended prominent national professional development workshops and seminars, and also participated in local programs including faculty learning communities and a long-term university-wide professional development initiative.

Participants

All research faculty members, post-doctoral researchers with teaching appointments, and instructional staff were solicited to complete the survey, regardless of teaching assignment at time of solicitation. Participants were solicited by email near the beginning of each semester. All research was conducted in accordance with university IRB protocols.

A total of 37 people met the inclusion criteria over the five semesters of the study. The demographics of potential participants in the department included 19% tenure-track faculty, 41% tenured/full or emeritus professors, 24% teaching-focused faculty, and 14% postdoctoral researchers with at least some teaching responsibilities. Potential participants were 59% female, and actual participants were 57% female. The department chair was removed to avoid conflation of administrative responsibilities with potential roles in casual interaction.

There were 28 participants who answered the survey at least once (76% participation). Most who completed the survey were consistent in their participation – 16 instructors (57% of participants) completed the survey each semester for which they were solicited, and 22 (79%) missed two or fewer semesters. Participation rates varied between semesters, decreasing over the course of the study from 75% (Fall 2015) to 45% (Fall 2017).

Survey

The survey included two sections, one eliciting each participant's self-reported assessment experiences and the other documenting peer interactions (teaching, research, and social). The first section consisted of three subsections from the FRAS (Hanauer & Bauerle, 2015) instrument: practices (how often participants reported engaging in a variety of assessment activities such as developing an assessment plan for a course and providing feedback on formative assessments), confidence (self-reported confidence in implementing these assessment activities), and attitudes (positive vs. negative feelings about assessment activities). Each FRAS subsection consisted of five or more five-point Likert scale items.

Participant responses on each item ranged from 1 (Never/Strongly disagree/Extremely negative) to 5 (All of the time/Strongly agree/Extremely positive). A composite score was calculated for each subsection by averaging item responses. Each composite score (Practices, Confidence, and Attitudes scores) represents a facet of an instructor's self-perception of their assessment experience (Hanauer & Bauerle, 2015). For example, a high Practices score indicates an instructor who felt they regularly implemented a range of classroom assessment practices. The Practices scores for each participant were subsequently used to identify two groups of instructors: those with high assessment use and those with low assessment use (see Analysis).

In the second section of the survey, instructors' peer interactions were reported by selecting the names of individuals with whom they interacted from a list. The list included names of all faculty members and post-doctoral researchers in the department, as well as a 'none' and 'other' option. The 'other' option allowed participants to identify colleagues outside the department; only interactions between department members were analyzed for this study. Department culture influences the nature of peer interactions. In STEM departments with high expectations for research, peer interactions might focus on how to improve, find support for, and disseminate research. In departments with a strong undergraduate education mission, one might expect a greater number of peer interactions centered on high-impact teaching practices. Smaller, tight-knit departments might exhibit colleagues who socialize frequently on and off campus. All of these peer interactions have the potential to influence the innovation diffusion process. Therefore, instructors were asked to report three types of peer interactions: those individuals with whom they interacted 'about teaching', 'about research', and 'socially'. It was indicated that ‘interact about teaching’ could include anything from talking about teaching to sharing resources to receiving and giving feedback (see Andrews et al., 2016).

Analysis

Innovation diffusion is unlikely if all members of a social system have the same experience or knowledge, or if there are no interactions between more and less experienced users of the innovation. Therefore, our first task was to determine that groups of instructors with varying levels of assessment experience were indeed present within the department. Hanauer and Bauerle (2015) report a mean Practices score of 4.35 (SD = 0.86) for advanced instructors and 2.69 (SD= 1.6) for novice instructors. In the next two paragraphs, we describe how these values were used to delineate two groups of instructors with distinctly different levels of self-reported assessment practices (‘high’ and ‘low’). Although Confidence and Attitudes scores may also affect the process of diffusion, Rogers’ criteria require differences in use of innovations; therefore, Practices score was used as the variable of interest for categorizing participants.

The high category (‘highs’) included participants with Practices scores greater than 3.5 every semester in which the survey was completed. Additionally, participant Practices scores needed to be greater than 4.0 in at least one semester. This ensured that individuals in the high group always reported scores in the upper half of the overall distribution of Practices scores and reported at least one score in the top ~15%. All Practices scores in the high group were within one standard deviation of the mean advanced score from Hanauer and Bauerle (2015). The resulting high group contained 11 individuals. The mean Practices scores of highs in each of the five semesters were: 4.34 (SD 0.34), 4.24 (0.28), 4.45 (0.4), 4.4 (0.31), and 4.4 (0.26), comparable with Hanauer and Bauerle’s values. In the results section, primarily medians are reported rather than means to minimize outsize effects of extreme individuals (Piovesana & Senior, 2018). See Table 3-1 for more details on each group.

Table 3-1. Medians (and ranges in parentheses) of the biology department participant scores on the three sections of the FRAS by assessment use group for each semester. These data exclude the department head. Note that the numbers of highs, mids, and lows who participated in each semester varied; the Ns in the column headers are total participants in each category across all semesters.

	High (N=11)	**Mid (N=6)**	**Low (N=11)**	**Overall means (SD) (N=28)**
		Fall 2015		
N	9	6	9	24
Practices	4.3 (3.9-5.0)	3.65 (3.3-4.6)	1.6 (1.0-3.1)	*3.33 (1.21)*
Confidence	4.0 (3.2-4.5)	3.8 (2.5-4.6)	3.6 (2.0-4.1)	*3.65 (0.62)*
Attitudes	4.0 (3.6-5.0)	3.8 (2.8-5.0)	3.2 (2.8-3.8)	*3.65 (0.62)*
		Spring 2016		
N	7	4	8	19
Practices	4.3 (3.7-4.6)	3.15 (2.6-3.3)	3.0 (1.6-3.4)	*3.33 (0.88)*
Confidence	4.1 (3.5-4.8)	3.6 (3.0-4.0)	3.45 (2.4-4.0)	*3.68 (0.56)*
Attitudes	4.0 (3.6-5.0)	3.9 (3.0-5.0)	3.3 (2.8-4.0)	*3.83 (0.69)*
		Fall 2016		
N	10	4	5	19
Practices	4.5 (3.6-5.0)	3.05 (3.0-3.3)	2.9 (2.6-3.1)	*3.74 (0.84)*
Confidence	4.4 (3.5-5.0)	3.7 (3.2-3.9)	3.55 (3.2-3.9)	*4.03 (0.59)*
Attitudes	4.2 (3.2-5.0)	3.2 (2.4-4.6)	3.5 (2.6-4.0)	*3.86 (0.78)*
		Spring 2017		
N	9	3	7	19
Practices	4.4 (4.0-4.9)	3.4 (2.7-3.7)	2.6 (1.4-3.0)	*3.53 (0.99)*
Confidence	4.4 (3.8-5.0)	3.6 (3.5-3.9)	3.5 (2.4-4.0)	*3.89 (0.7)*
Attitudes	4.0 (3.0-5.0)	3.0 (3.0-4.0)	3.4 (2.8-4.0)	*3.71 (0.69)*
		Fall 2017		
N	8	3	4	15
Practices	4.5 (3.9-4.7)	3.1 (2.4-3.6)	2.7 (2.0-3.1)	*3.65 (0.93)*
Confidence	4.5 (3.6-5.0)	3.7 (3.6-3.9)	3.5 (2.3-4.1)	*4.03 (0.71)*
Attitudes	4.6 (2.8-5.0)	3.2 (2.6-4.0)	3.3 (2.6-4.2)	*3.83 (0.85)*

The low use group ('lows') consisted of participants with Practices scores less than 3.5 for every semester in which the survey was completed. Additionally, inclusion in the low group required at least one semester with a Practices score of less than 3.0. These inclusion criteria ensured that participants in the low group always reported scores in the lower half of the overall distribution of research participants and reported at least one score in the bottom ~15%, making the criteria symmetrical for highs and lows. The resulting low group contained 11 individuals. All Practices scores in this group were within a half standard deviation of the mean novice score reported by Hanauer & Bauerle (2015), or lower. Again, average scores were comparable to or lower than Hanauer & Bauerle's novice range scores within each semester. Mean Practices scores in the low group were 2.02 (SD 0.78), 2.68 (0.66), 2.84 (0.17), 2.51 (0.52), and 2.63 (0.49) (see Table 3-1 for more information).

Six individuals who completed the survey at least once did not meet either set of inclusion criteria (high or low). These individuals are classified as "mid", although this should not be construed to mean that in any given semester, all mids had scores between all highs and all lows. However, as a group, mids tended to fall between the low and high groups in Practices score. Most (4) mid individuals reported Practices scores of less than 3.5 in some semester(s) and greater than 3.5 in others. The range of reported Practices scores for mids was 2.4-4.6, and the means and standard deviations were as follows: 3.77 (SD 0.48), 3.05 (0.29), 3.1 (0.12), 3.27 (0.42), and 3.03 (0.49) (see Table 3-1 for more information). Nine other individuals are classified as unknown since they did not take the survey at all.

The FRAS data were examined across questions and all participants to look for any patterns potentially indicative of anomalies or evidence of respondent carelessness. While it was relatively common (up to ~15% of responses) for individuals to answer at the same Likert level across a dimension (i.e., Practices, Confidence, or Attitudes), no respondents answered at the same level across the entire questionnaire. Because each dimension was measuring a facet of instructor assessment experience, we did not consider a consistent answer within a dimension to be indicative of respondent carelessness or dishonesty. Rather, we understood it as their actual self-perceived attitude or confidence level. It was less common for Practices to show this pattern (0-2 respondents per semester).

Due to our interest in the possibility of diffusion, we endeavored to create two clearly separate groups with different levels of assessment experience (highs and lows). Thus, mid and unknown individuals will be described, but will be excluded from some analyses. Teaching-focused faculty and faculty with education specialties were over-represented in the high group compared to the rest of the department, as were female faculty. Tenure-track faculty were somewhat under-represented in the high group. With these exceptions, the high, mid, and low use groups did not dramatically differ in demographics from the department as a whole. See Table 3-1 and the first section of Results for additional detail on the Practices, Confidence, and Attitudes scores of the different groups.

The second section of the survey was used to identify both directed and undirected ties (teaching, research, and social) between instructors. Directed ties were used to determine the in-degree centralities needed to address Research Question 2. In-degree centrality values were calculated for each participant for each of the three types of peer interactions. Each instructor thus had a measure of teaching in-degree centrality, research in-degree centrality, and social in-degree centrality. In order to determine if participants reported interacting with members of the high use group (about teaching, research, or socially) more often than those in the low group, Mann-Whitney U tests were conducted using the wilcox.test function in R to compare in-degree centralities of the high and low use instructors within each semester. Benjamini-Hochberg corrections were performed for multiple tests with a false discovery rate of 0.05. In other words, p values of tests were ranked and compared to the threshold value for that rank (the rank times the false discovery rate divided by the number of tests). The highest p value less than the threshold and all p values lower were considered statistically significant (Benjamini & Hochberg, 1995).

Innovation diffusion requires interaction about the innovation between high and low use individuals. For any reported interaction on the survey, the direction of information flow is unclear. Therefore, teaching-related ties between participants were treated as undirected to determine the potential for innovation diffusion between members of the high and low use groups (Research Question 3). The undirected ties were categorized by group membership (high, low, mid, or unknown) of the instructors involved in each reported interaction. For example, if a member of the high use group reported interacting with an instructor in the low use group, this heterogeneous tie was assigned to the "high-low" category. Similarly, two participants of the low use group reporting an interaction was considered a homogeneous "low-low" tie. The proportion of heterogeneous vs. homogeneous ties within the department as a whole was determined.

We also calculated the high/low index (HLI) for each instructor using the undirected teaching-related ties to that individual. The HLI is defined as the number of undirected interactions each individual had with highs divided by the number of undirected interactions with lows. An HLI of 1.0 indicates that a participant communicated with an equal number of highs and lows. Values less than 1.0 indicate interacting with mostly lows while values of greater than 1.0 indicate interacting with mostly highs. HLI values for individuals, combined with other data such as centrality, may provide insight into the potential role of individual instructors in facilitating innovation diffusion. For example, HLI values less than 1.0 for highs may indicate more opportunities to facilitate diffusion, while higher values for lows may indicate more exposure to innovations.

All network attributes and statistics were computed using the R programming language (R Core Team, 2017) in RStudio (RStudio Team, 2016), including the igraph (Csardi & Nepusz, 2006) and pastecs (Grosjean & Ibanez, 2018) packages. Visualizations were created in RStudio using the ggplot2 package (Wickham, 2016).

Results and discussion

Diffusion of assessment innovations is possible when high use individuals have interactions with other members of a social system, especially less experienced users. We found that these conditions were present in the department we studied. Biology instructors (both highs and lows) reported interacting more often with high assessment use instructors about teaching, and interactions were present between highs and lows.

Differences in assessment experience

The first criterion for diffusion of innovation (in this case, frequent diverse assessment practices) is the presence of both high and low use individuals. The FRAS instrument (Hanauer & Bauerle, 2015) was used to measure biology instructors' self-reported assessment experience. Practices, Confidence, and Attitudes scores varied between semesters (Table 3-1). Median scores overall ranged from 3.3-3.9 for Practices over the five semesters, 3.6-4.1 for Confidence, and 3.6-4.0 for Attitudes. Means and standard deviations for the department as a whole are shown in Table 3-1, which also shows the median and ranges for each assessment use group. Medians were used in the groups rather than means since extreme values can easily skew means within a small sample (Piovesana & Senior, 2018). These values are likely overestimates of the actual assessment experiences in the department as a whole, due to a probable response bias (unpublished data). Yet these data consistently reflect ranges previously reported by Hanauer and Bauerle (2015) and allowed for the highs and lows to be identified as two groups with distinctly and consistently different levels of self-reported experience (see Analysis).

While self-reported practices were used to delineate the two groups, confidence and attitudes likely also affect an instructor's continued use of an innovation and their interactions with others about it (Rogers, 2003). The distributions of Practices, Confidence, and Attitudes scores for members of the three practice use groups are visualized in Figure 3-3. While in some semesters members of the high use group tended to report higher Confidence and Attitudes scores than lows, the Confidence and Attitudes scores could not be used to discretely delineate two groups in the same way as the Practices score. These data indicate that many biology instructors who report frequently using assessment practices also report feeling relatively confident and positive about those practices compared to their lower use peers. However, the data also show that there is sometimes little or no attitude gap between those who use assessment practices frequently and those who do not. Some who use assessment practices less frequently may have a positive attitude about those practices which may impact their desire to change, while some who use assessment practices very frequently may nevertheless view them less favorably.

A positive attitude may affect the process of change by influencing the priority an instructor places on teaching, and confidence likely influences willingness to seek knowledge, implement new ideas, and mention experiences positively in conversation. In addition, confidence and positive attitude are often visible to peers and may facilitate diffusion by serving as a signal that an instructor is either receptive to or a potential source of information or advice.

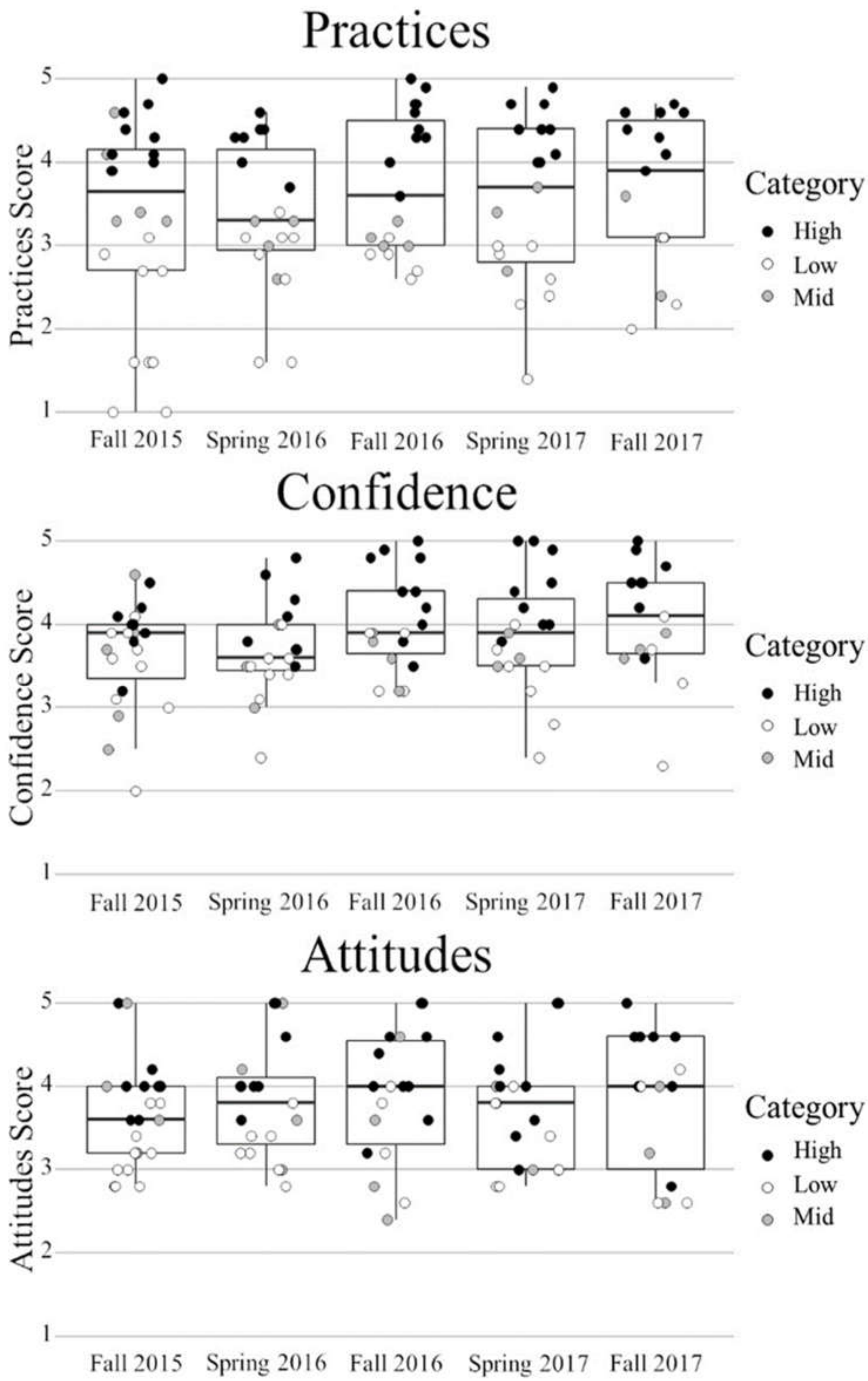

Figure 3-3. Practices, Confidence, and Attitudes scores of high (black), low (white), and mid (grey) individuals over five semesters

While it was expected that individual FRAS scores would vary over time, and potentially increase due to experience and innovation adoption, inspection of individual FRAS scores revealed only a few individuals who demonstrated a sustained increase or decrease in Practices score. For others, there was not enough data to demonstrate a pattern. One mid and one low showed sustained decreases in Practices score (from 3.9 to 2.4; from 2.7 to 2.3). One low and two highs showed sustained increases (from 1.6 to 3.0, from 4.0 to 4.6; from 3.9 to 4.6). In no instance did an individual move from the low group to the high group over the course of the semesters included in this study (see Supplemental Figure 1).

Biology instructors more frequently interact with high-use instructors about teaching

Together, participants reported an average of 174 total teaching-related interactions in each semester, 112 research-related interactions, and 142 social interactions, or roughly 3-5 connections of each type per instructor per semester (Figure 3-2). The teaching in-degree centralities for highs (overall mean 8.7; SD 2.3) tended to be greater than for lows (overall mean 4.3; SD 2.4), indicating that individuals with high self-reported assessment use were reported more frequently by their peers as teaching-related connections (Figure 3-4). Mann-Whitney U tests with Benjamini-Hochberg corrections (false discovery rate of 0.05) show that teaching in-degree was significantly different between highs and lows in each semester (Table 3-2).

Interestingly, research and social in-degree values did not consistently differ between high and low use instructors in either direction. Overall mean research in-degree values were 4.7 for highs (SD 2.2) and 3.6 for lows (SD 2.0). The corresponding social in-degree centralities were 4.7 for highs (SD 3.3) and 5.2 for lows (SD 2.8). Table 3-2 shows the results of comparisons of in-degree centrality of all three types. While we did not expect the three different types of interactions to be mutually exclusive (i.e., during a research or social interaction,

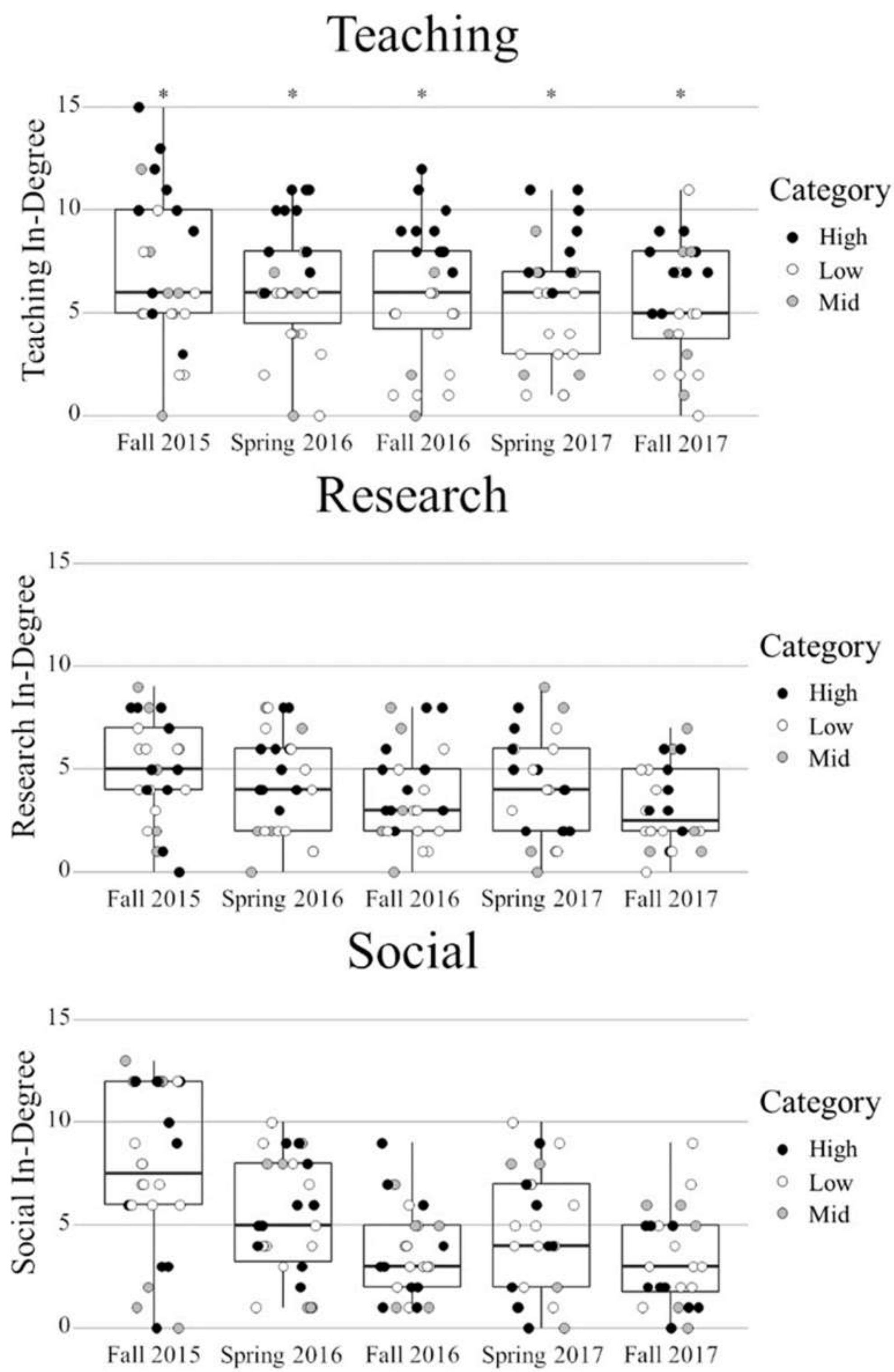

Figure 3-4. Teaching, research, and social in-degree centrality values of high (black), low (white), and mid (grey) individuals over five semesters. *Mann-Whitney U test has significant results after Benjamini-Hochberg correction with false discovery rate of 0.05

conversation might shift to teaching, or information regarding the relative value of teaching or departmental norms could be communicated), the interactions reported more toward those with high assessment use were specifically teaching-related. This indicates that the relationship we found is not indicative of a generalized pattern of interaction within the department. This can also be visualized more qualitatively by comparing the structure of the networks in Figure 3-2; while in the teaching network many ties are clustered around the highs, the pattern is more dispersed in the other two networks.

The in-degree centrality results are consistent with previous work demonstrating that university instructors with high levels of teaching expertise have larger social networks (Middleton et al., 2015; Van Waes et al., 2015). Our work differed from these in that we used in-degree centrality within a specific pre-determined social context (the biology department) rather than out-degree centrality based on interviews with instructors of interest. Since in-degree centrality was reported by other participants, it more reliably indicates the instructors' potential influence on innovation diffusion within the department. Our results also support the results of Judson and Lawson (2007), who found that teachers with student-centered practices in two small high school STEM departments had a greater in-degree centrality, especially in regards to interactions about content and pedagogy. Our work further delineated types of peer interactions (i.e., research, teaching, social), showing that only teaching-specific interactions were more common among high-use instructors. Recent work in a university STEM context (Knaub et al., 2018; Lane et al., 2019) has found that teaching in-degree centrality does not necessarily correspond to academic rank or nomination as a leader; however, our work and other work cited above indicates that the teaching-focused conversations instructors report are important in a university STEM context. It also underscores that instructors may not always talk about teaching to the same peers with whom they converse about research or other topics.

Table 3-2. Median teaching in-degree centrality values for highs and lows, and results of Mann-Whitney U tests comparing in-degree centrality values for highs vs. lows in each semester

	Median: highs	**Median: lows**	**W**	**p-value**	
Teaching in-degree centrality					
Fall 2015	10	5	82	0.0156	*
Spring 2016	10	5	95	0.0007	*
Fall 2016	9	5	107.5	0.0002	*
Spring 2017	8	3	97.5	0.0003	*
Fall 2017	7	4.5	74.5	0.0161	*
Research in-degree centrality					
Fall 2015	5	5	56.5	0.6456	
Spring 2016	5.5	3	69.5	0.1463	
Fall 2016	4.5	2	85	0.0348	
Spring 2017	5	4	56.5	0.6169	
Fall 2017	3	2	59	0.2605	
Social in-degree centrality					
Fall 2015	8.5	7	50.5	1	
Spring 2016	5.5	4.5	53.5	0.8192	
Fall 2016	3	3	52	0.8578	
Spring 2017	4	5	35	0.2822	
Fall 2017	2	3	29.5	0.2129	

*Statistically significant with Benjamini-Hochberg correction (false discovery rate 0.05).

There seems to be an overall pattern of more experience with teaching innovations correlating with higher centralities in regards to teaching interaction, in this and other studies (Judson & Lawson, 2007; Middleton et al., 2015; Van Waes et al., 2015). There are two plausible explanations for this observation. Intuitively, it is probable that highs are viewed as experts and as such are sought out by others for teaching advice (i.e. high experience causes high centrality). However, it could also be that these instructors became more expert by seeking out information from a variety of sources, including peers, and then implemented assessment innovations (i.e. high centrality causes high experience). Furthermore, it is possible that a self-reinforcing combination of these factors contributed to the pattern we see.

While our study cannot assess causality and did not show many instances of definitive change in Practices score, the two high individuals who had positive changes in Practices score showed patterns that may be consistent with the second explanation. One instructor had Practices scores more reminiscent of the mid-range for the first two semesters (3.7-3.9) which increased to the high range in the last three (4.0-4.6). This instructor's teaching in-degree centrality was already relatively high during the first semester (9), closer to the mean in-degree centrality of the high group (9.4) than to that of the mid (7) or low (5.3) groups. It remained comparable to other highs (6-10) throughout the study. In the other case, the instructor began the study with the second highest teaching in-degree centrality in the department (13). As this individual's Practices score increased from 4.0 to 4.6 over the course of the study, their teaching in-degree centrality decreased, but still fell within the range of other highs (7-11). Both of these instructors already made use of assessment techniques, as indicated by their higher Practices scores, but this pattern could indicate that these instructors' initial high centralities facilitated their continued adoption of innovations and increase in Practices score. We see no evidence in these data of high Practices scores being followed by increasing centrality, nor of lows or mids changing categories before or after an increase in centrality. It should be noted that with the decrease in participation over time, increasing centrality would be an unexpected result in this study.

Teaching-related interactions occur within and between assessment use groups

Our data indicate that instructors who report higher Practices scores (highs) were interacted with by more of their peers about teaching. This is encouraging for the possibility of innovation diffusion, since those with more experience may be better able to spread beneficial information and provide helpful support. High assessment experience peers can provide knowledge or share experience about using an innovation, or affect an instructor's satisfaction level, the priority placed on teaching, or the width of the "corridor of tolerance" (Andrews & Lemons, 2015; Dancy et al., 2016; Gess-Newsome et al., 2003; Mcalpine et al., 1999; Rogers, 2003).

Yet, innovation diffusion is thought to only happen when interactions bridge different experience levels. The finding that highs had higher teaching-related centrality does not in itself tell us whether interactions with highs were primarily homogenous (with other highs) or heterogeneous (with lows). We investigated the extent to which teaching-related interactions occurred within and between experience groups. Both homogeneous and heterogeneous interactions occurred within the biology department (Figure 3-5). Not including ties with unknown individuals, interactions involving at least one high made up 73-83% of the interactions each semester (mean 78.4%, SD 4.1%). Of those, 35-52% of interactions were with other high individuals (mean 43.4%, SD 5.4%), while 29-35% were with lows (mean 32%, SD 2.6%).

Lows had somewhat fewer interactions overall, but a higher proportion of those interactions were heterogeneous. Of the interactions (again, excluding ties with unknowns) which involved at least one low individual, 47-64% were with highs (mean 57%, SD 5.8%), while only 14-23% were with other lows (mean 18%, SD 3.1%). These results suggest that communication about teaching within the department happened more frequently among highs than among lows, but that opportunity existed for innovation diffusion; when interactions included lows, they also often included highs.

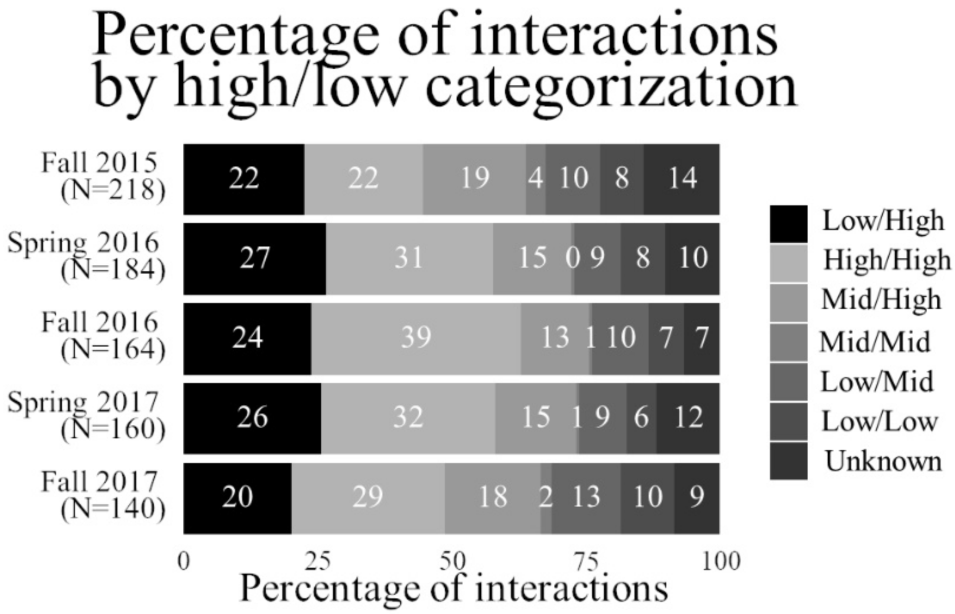

Figure 3-5. Percentage of teaching interaction ties within each semester that were reported within and between assessment experience categories. Total number of teaching interaction ties for each semester are shown on y axis

Homophily could be one reason for frequent interaction among highs (Quardokus & Henderson, 2015; Rogers, 2003). It is intuitive that instructors who are more interested in teaching would talk about teaching more often, and that they would talk with others who were also interested in teaching. Another consequence of this interest might be an increased propensity to implement new teaching techniques. It is important even for those who have already committed to using an instructional technique to have consistent support from others who use it (Cox, 2004; Henderson et al., 2011). For these reasons, frequent communication between high use individuals is expected and might be important for sustained adoption of innovations.

Although these data show us that interaction occurs between the high experience and low experience groups, a mechanism for innovation diffusion is the interactions of individual pairs of instructors. Thus, it is also informative to consider the interactions reported with high and low individuals. The proportions of interactions with an individual that involve participants from the different use groups could influence their ability to spread or adopt innovations.

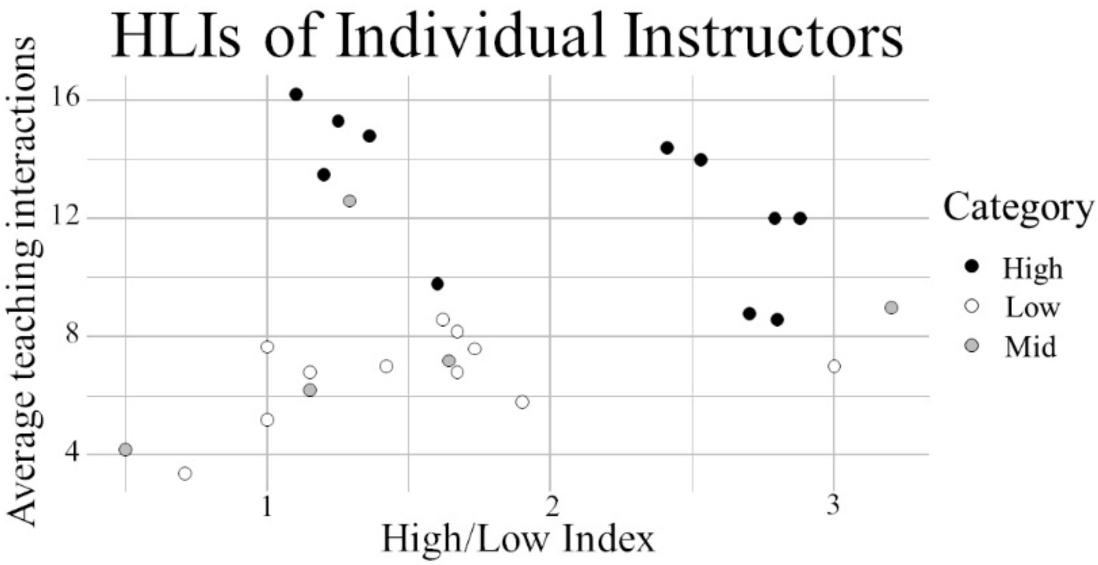

Figure 3-6. Variation of HLIs and total average teaching-related interactions per semester of high (black), low (white), and mid (grey) individuals. One mid outlier (average interactions per semester 6, HLI 10) was removed from the graph to better visualize the rest of the participants.

HLIs (ratios of communication with highs to communication with lows) varied widely depending on the individual (Figure 3-6). The mean HLI for highs was 2.06 (SD 0.71; median 2.41), indicating that they interacted with at least twice as many highs as lows on average. Yet, HLIs ranged from 1.1 to 2.88 among highs, indicating that some highs talked to almost the same number of highs and lows while others talked to nearly three times as many highs. Regardless, highs interacted with an average of more than 8 other instructors each semester. Lows tended to have fewer total reported interactions in each semester, but their range of HLIs was wider. One low had an HLI of less than 1, indicating interaction with more lows than highs, while another had an HLI of 3. The mean HLI among lows was 1.53 (SD 0.59; median 1.62), with most lows between 1 and 2. This underscores that when interactions with lows were reported, they often involved a high, allowing an opportunity for diffusion of teaching ideas (Rogers, 2003). These data also reiterate that interaction with highs was common, and it was rare to interact with more lows than highs (only one low and one mid reported an HLI of less than 1.0). In summary, highs had more interactions than lows overall, both highs and lows tended to interact with more high use individuals than low use individuals, and individual instructors varied in their HLIs.

While homophily encourages interaction (i.e., people interact with those who are similar to them; Quardokus & Henderson, 2015; Rogers, 2003), change is encouraged by heterogeneous interactions (Rogers, 2003). In this study, the opportunity existed for information about effective assessment techniques to diffuse from high use to low use individuals, and we can make several hypotheses about how specifically this information might flow. First, we can hypothesize that highs with lower HLIs will more effectively facilitate diffusion because of their greater contact with lows. However, it could also potentially be more impactful for highs to simply have many total interactions, allowing individuals of all assessment use groups to further spread ideas. This may also depend on the cultural norms of the department, university, discipline, and/or subgroups within the department. Cultural norms can have an impact not only on individual instructor behavior but on the structure of interactions within a group and the nature of those interactions (Lund & Stains, 2015; Roxå & Mårtensson, 2015; Smolla & Akçay, 2019; Sturtevant & Wheeler, 2019).

Secondly, we expect that lows with higher HLIs may be more likely to adopt assessment innovations, eventually increasing in Practices score. This is expected since beneficial information is likely to come from high use individuals. However, recent work suggests that instructional change may reflect a network disturbances model, indicating that change of practices among discussion partners may be a more important factor than their initial level of practices (Lane et al., 2019). Thus, we can also hypothesize that instructors who communicate with peers who are increasing their assessment use would likewise increase their assessment use, and vice versa. We have insufficient data within this study to establish whether high-HLI low instructors increased in Practices score.

Finally, some individuals, whether high, low, or mid, may serve as a connection between those with high assessment experience and others with less experience. For example, highs appeared to fall into two distinct clusters along the HLI axis (Figure 3-6): six highs with HLIs of greater than 2.0 (mean 2.68; SD 0.16) and five highs with HLIs of less than 2.0 (mean 1.3; SD 0.17). It is possible that some individuals in the lower-HLI group of highs who have interaction with higher-HLI highs as well as mids and lows could pass ideas to individuals from multiple groups. In addition, interaction between the two groups of highs could lead to each group adopting specific practices used by the other group. Similarly, mids and lows who have interactions with both highs and lows could act to encourage innovation diffusion (Lane et al., 2019). For example, the mid who had an HLI of over 3 interacted with highs frequently. Even if this individual's practices were more mid-range, they could potentially pass ideas from highs on to others they talk to. Mids and lows could even be more well-positioned for this task since their classroom practices seem more similar to other mid or low peers, increasing perceived homophily. Since assessment is a category of instructional innovations that can encompass a variety of techniques, diversity in expertise and HLI could be advantageous for the spread of innovations. If a continuum exists from those who use many innovative assessment practices to those who are just starting to think about adopting one idea, many levels may exist with relatively high perceived homophily, yet differences in the amount and type of assessment experiences.

Interestingly, the two highs who showed positive changes in Practices score both had relatively low HLI scores among highs (1.1, 1.36). They also had two of the highest numbers of average total teaching interactions. These individuals were interacting with many highs and many lows regarding teaching. This brings up another interesting hypothesis that communication with lows in addition to highs may be beneficial for adoption of innovations (see also, Lane et al., 2019). Perhaps lows express curiosity about new techniques that drives the adoption process forward for the higher individual, or provide some other form of motivation. Alternatively, this may be a reflection of those who are highly motivated to change their teaching seeking out conversation about teaching from many of their peers at a variety of assessment experience levels.

It is important to note the effect of disciplinary context and research-focused academic culture. The impact of peers and the structure of interactions is likely to vary in different departmental contexts (Lund & Stains, 2015; Sturtevant & Wheeler, 2019) and if the most influential peers and the departmental cultural norms are negative toward teaching or teaching innovation, the impact may be very different. However, our study indicates that even in a department with a strong research focus, teaching-specific interactions show their own pattern separate from research-focused and social interactions, and teaching-focused interactions skew toward instructors with higher innovation use.

Implications for instructional change

This work highlights the possibility for peers within a STEM department to influence one another, potentially leading to the sustained adoption of teaching innovations within the department over time. On a larger scale, peer impact on diffusion of teaching innovations could have a widespread effect on the quality of university science education. Adoption of effective assessment techniques is expected to increase student learning and retention and address achievement gaps (AAAS, 2015; Eddy & Hogan, 2014; Freeman et al., 2014), yet adoption has been slow even with professional development and other dissemination efforts; incorporating the role of peer support in these efforts may be beneficial (Ma et al., 2018).

Since homophily encourages interaction and sustained adoption of innovations while heterogeneous interactions encourage diffusion (Rogers, 2003), it would seem that administrators could encourage the diffusion of teaching innovations by fostering an inclusive department with a sense of community around effective teaching (increasing perceived homophily), while providing opportunities for heterogeneous teaching-related interactions. Although brown bag seminars and colloquia focused on research are common in STEM departments, often fewer formal opportunities exist to talk with peers about teaching; increasing these opportunities could be beneficial. This could include teaching-focused lunches or coffee hours, intentional pairing of high experience with low experience individuals for team teaching or small teaching collaborations, or having participants in teaching-focused professional development events report out about what they learned. Professional development experiences could incorporate the opportunity for long-term interactions and/or 'outreach' to departmental colleagues. Our research suggests that increasing opportunities to interact about teaching would likely give both high and low assessment use STEM instructors more access to effective teaching ideas through more exposure to high use individuals. This would both encourage diffusion of innovations and support those already using the innovations. These recommendations mesh well with suggested action steps and implications of other recent research in the field (e.g. Lund & Stains, 2015; Ma et al., 2018; Sturtevant & Wheeler, 2019).

Our results could also inform the selection of individuals for change initiatives and peer leadership (Knaub et al., 2018). Peers have the potential to be influential when they have a high teaching in-degree centrality, but also when a comparatively larger share of their interactions are with non-users of a particular innovation (Rogers, 2003). If those peers are targeted with professional development and trained in the use of a particular innovation, they may more easily spread it to non-users. Additionally, including one or more less experienced peers in a professional development group with such an individual would provide homophily for the less experienced individuals, allowing them to support each other through the change process.

Implications for research

This study demonstrates the presence of prerequisites for diffusion of teaching ideas among university instructors in a STEM department and informs future research into the effects of peers and the conditions under which diffusion may occur. Whether particular interactions result in innovation adoption depends on characteristics of the innovation, the instructors, and the interaction(s) (Rogers, 2003). If adoption of a specific innovation can be tracked, future work could investigate the relative impact of the various factors involved in this study: centrality, assessment experience, and contact with low use individuals. Our study shows that variability existed in Confidence and Attitude within groups; these variables could also be further explored to see how they moderate adoption and spread of innovation. Investigating specific discrete assessment innovations would also help us understand the effects of members of the different levels of assessment experience on each other. For example, in this study, some members of the community were mid-range (neither consistently high nor low) in order to examine the most likely conditions under which diffusion could happen. However, mid-range and other uncategorized individuals could play a substantial role in innovation diffusion. Some may be in the process of adoption, while others may have tried and rejected assessment innovations. With such recent experience, they may be in a position to offer realistic advice about adopting assessment innovations and relate better to lower experience instructors. Thus, mid-range people may either act as a buffer between high and low use instructors, or as a catalyst in spreading information and encouraging change.

Understanding more about the mechanisms by which peers perturb the innovation decision model and support (or discourage) innovation diffusion will both guide future research and inform efforts by change agents to encourage adoption. Interview studies could continue to investigate how instructors think their teaching practices and ideas are impacted by interaction with colleagues. Instructors who are in the process of adopting an innovation could be studied to see how their iterative innovation decision process is affected by peers but also if and how it leads to a change in the way they approach and are approached by peers – i.e., as they become a more high experience individual themselves.

Finally, this study did not directly investigate instructors' perceptions of their peers' expertise, nor did it track which instructors, if any, were specifically sought out for teaching help by their peers. Future work could investigate the reasons instructors have for talking to peers about teaching, what they talk about, and how teaching in-degree centrality and assessment experience relate to the subjective judgement of expertise by peers.

Limitations

The departmental context of this study was one characterized by high research activity but was also supportive and encouraging to teaching innovation, incorporating teaching reform initiatives and a number of faculty with education expertise. It is unknown to what extent departmental, university, and disciplinary context affected the results, or to what extent these results would apply in a less supportive culture (Lund & Stains, 2015; Sturtevant & Wheeler, 2019), where innovation diffusion may be an even more urgent problem. These results should be confirmed in other such contexts. It is possible that in some STEM departments, assessment experience would be universally low, due to minimal teaching experience and training of beginning instructors and/or a substantial focus on research with a lack of focus on evidence-based teaching. In these departments, it may be more important to first increase the level of assessment experience of a few key instructors.

The study did not include peer interactions or use of other resources from outside the department. This was intentional because we wanted to study the department as a cohesive unit, but outside resources can play an important role in fostering change for individual instructors. Additionally, the nature of this study relied on gathering information from a limited, self-contained group of people. This constraint led to a fairly small sample size, limiting our ability to draw broader conclusions about sub-groups or investigate the role of demographics. Furthermore, although social network analysis allowed us to gather information about instructors who did not fill out the survey, our dataset was incomplete in regards to participation. Participation rates were comparable to other studies of this type (Andrews et al., 2016; Knaub et al., 2018), but those who completed it may be more likely to report high FRAS scores.

Finally, instructors were not observed in their classrooms in order to determine or categorize their use of various assessment techniques. Our measure of assessment experience relied fully on a self-report survey. While this allowed us to measure confidence and attitudes as well as practices, both inside and outside the classroom, it also constrained our ability to make objective claims about instructors' assessment practices. Based on our informal knowledge of the department and instructors' courses, we detected no systematic under- or over-estimation of classroom assessment practices, and previous studies have indicated that self-report patterns match with other measures (Durham et al., 2017; Owens et al., 2018).

Conclusion

This research demonstrated a relationship within a university STEM department between an instructor's self-reported experience with a particular category of teaching practices – assessment techniques – and the number of peers who reported teaching-related interactions with them. The relationship did not hold for research-related or social interactions. Additionally, we demonstrated that a subset of these interactions was between instructors with high levels of assessment use and those with lower levels of use. Thus, the conditions for innovation diffusion of assessment ideas within a university STEM department were met. Instructors with both high and low self-reported assessment use levels reported interacting with more high assessment use instructors. Administrators and professional development coordinators can use these results to help them harness the power of peer influence in academic departments by identifying potential targets for innovation diffusion and providing environments conducive to teaching-related interaction and the resultant diffusion of ideas. When these ideas include beneficial assessment practices such as formative assessment and feedback, learning and retention of the college students who will become tomorrow's science leaders and citizens are set to improve.

CHAPTER 4: INTERACTION AND INNOVATION: A STUDY OF THE IMPACTS OF DEPARTMENTAL CLIMATE PERCEPTIONS AND PEER INTERACTION ON ADOPTION OF TEACHING INNOVATIONS AMONG COLLEGE BIOLOGY INSTRUCTORS

Abstract

Despite continued efforts to increase adoption of teaching innovations (e.g. student-centered practices, active learning, formative assessment) in undergraduate STEM (Science, Technology, Engineering, and Mathematics) education, adoption in many situations remains limited. A variety of factors may contribute to an instructor's decision to use or not use a teaching innovation, including their social context. This paper explores the impacts of two aspects of social context, departmental teaching/social norms and individual peer interactions, on instructors' decisions about adoption of teaching innovations. Interviews were conducted with 11 instructors who all taught within the same biology department. Results indicate that though prevailing teaching norms were perceived as being innovation-positive, these norms were interpreted differently, with some instructors experiencing them negatively. In addition, some instructors perceived a collaborative, interactive environment with frequent teaching interaction, while others perceived a much more solitary environment. Perception of a collaborative environment was associated with reporting greater use of teaching innovations, while instructors who perceived a solitary environment also tended to be less enthusiastic about teaching innovation adoption. This suggests that interaction among peers may generally support teaching innovation, particularly when occurring within a context where teaching and social norms are innovation-positive. Further details about how peer interactions impact the innovation adoption process are described.

Introduction

Undergraduate STEM (Science, Technology, Engineering, and Mathematics) education has recently been the target of multiple initiatives to incorporate more evidence-based instructional practices (EBIPs) that are expected to improve student learning and retention (AAAS, 2015; Committee on STEM Education of the National Science & Technology Council, 2018). Teaching with the use of such EBIPs, and staying current with changing best practices, requires instructors to adopt a series of innovations (Andrews & Lemons, 2015; Rogers, 2003), or new practices that change how they teach in some way. Yet, the process by which instructors decide whether or not to use an innovation or to continue using it is complex and influenced by many factors (Ajzen, 1991; Gess-Newsome et al., 2003; Henderson, 2005; Rogers, 2003). Many university instructors do not make the decision to adopt EBIPs, instead continuing to teach using primarily lecture-based methods (Eagan et al., 2014; Stains et al., 2018). Being aware of the existence of a teaching innovation and the evidence in favor of it is not enough to persuade instructors to adopt a practice (Kane et al., 2004). Positive attitudes and intentions are not necessarily enough either, and even when instructors try an innovation, they may not continue using it (Offerdahl & Tomanek, 2011), or they may use the innovation in a way that fails to best support student learning (Henderson et al., 2012; Lund & Stains, 2015; Stains & Vickrey, 2017). Due to the widespread efforts to help instructors try new innovations as well as the difficulty in getting them to persist in using them, it is important to understand the process by which instructors make decisions about teaching innovations. It is also important to consider the complex factors that may impact the decisions they make.

In this paper, we focus on how an instructor's social context affects their decision-making about teaching innovations. We know that individual instructors' decisions can be heavily influenced by their departmental climate, specific barriers and supports present in their departmental environment, input from their peers, and their past social experiences (Andrews & Lemons, 2015; Dancy et al., 2016; Quardokus & Henderson, 2015; Reinholz & Apkarian, 2018; Sturtevant & Wheeler, 2019; Walter et al., 2016). In addition, an academic department is a good setting to provide the kind of ongoing support required for instructors to be consistent in implementing innovations (Chasteen et al., 2015; Henderson, 2005; Wieman et al., 2013). Instructors within the same department likely regularly interact about teaching and other topics, offering the potential to share information and ideas (Andrews et al., 2016; Dancy et al., 2016; Quardokus & Henderson, 2015).

The effects of two aspects of social context (departmental norms and individual peer interactions) on the instructor innovation decision process are explored here. Departmental norms are the set of explicit and implicit standards and expectations within a social group (Frese, 2015; Lund & Stains, 2015; Schneider et al., 2013). Each instructor has their own perception of the departmental norms, which they can discern through formal structures and policies such as tenure review requirements and physical classroom space as well as the pattern and content of social interactions within the department (Landrum et al., 2017; Sturtevant & Wheeler, 2019). In this study, we focus only on departmental norms around teaching and social interaction within the department. Likewise "peer interaction" in this study refers to any interaction in which information is received from another instructor that is perceived by the participant to relate to teaching. Peer interactions are a mechanism through which norms are both shaped and communicated (Burt, 2000; Schein, 2010). Here, we consider two roles of peer interactions. An individual interaction with a peer may provide specific "micro-level" information or impact that directly affects an instructor. Additionally, multiple peer interactions will shape an instructor's perception of a department's climate and norms, which will affect their feelings about teaching and teaching innovation in a more general, "macro-level" way. In this manner, the innovation decision process can be influenced by perturbations of an instructor's affective state (through perceptions of teaching/social norms and/or specific peer interactions) and/or additions or changes to the instructor's knowledge (from peer interactions). In the current work, we explore these impacts on instructor affect and knowledge further through detailed interviews within a single STEM department.

A note on terms: innovation, active learning, and assessment

In this paper, we use the term "innovation" broadly to describe any change in teaching practices, which can range from including videos in lecture-based instruction to completely flipping the classroom. An innovation, then, does not need to be something completely new, but only different from what that particular instructor has done in the past. We assume that the overall innovation decision process is similar regardless of innovation but that features of the innovation itself may differentially impact the various steps of the process and therefore the likelihood of implementation. Framing innovations in this way made it easier for instructors to think of and describe changes in their teaching, which we can then further characterize.

The most beneficial innovations for STEM instructors to adopt to positively affect student learning are those which would: 1) increase student-student and student-instructor interaction, 2) increase the extent to which students actively think and work with the material, and 3) increase the opportunity for formative assessment – collecting evidence of student learning for the instructor and providing feedback for the learner (Bell & Cowie, 2001; Evans, 2013; Freeman et al., 2014). Such instructional practices have been referred to in a variety of ways (e.g., student-centered, EBIPs, DBER-based, evidence-based pedagogies). Yet, one of the most common and easily recognizable terms for instructors is “active learning” and we will therefore be using that term throughout this paper as a catch-all for evidence-based innovations.

However, since active learning is a broad term and can mean different things to different people, we focused on instructors’ assessment (and specifically formative assessment) practices as an example of an active learning innovation. Formative assessment has the potential to improve student learning as it allows instructors to gather and act on evidence of that learning while the learning is still occurring (Offerdahl et al., 2018). While we typically did not use the words “formative assessment” in interviews with instructors, we asked specific questions that probed the extent to which they used formative assessment and feedback, allowing us to more accurately characterize their teaching and the innovations they referred to. In addition, instructors have had their assessment experience broadly quantified based on a related study (McConnell et al., 2019), which will be discussed in more detail in the Methodology section.

Background

A model of instructor innovation adoption

In this study, we developed (McConnell et al., in prep) that draws on an innovation decision framework (Andrews & Lemons, 2015; Rogers, 2003) and incorporates the roles of departmental teaching and social norms and peer interactions (Figure 4-1). Peers can influence the innovation decision cycle in various ways and trigger innovation diffusion, the spread of ideas through a social system (Andrews & Lemons, 2015; Dancy et al., 2016; Quardokus & Henderson, 2015; Rogers, 2003). Additionally, the norms of the department in which the instructor and their peers practice can have a substantial impact on if and how an instructor’s behavior is affected and how they choose to teach (Lund & Stains, 2015; Walter et al., 2016).

These norms can also impact whether and how peer interactions take place (Lund & Stains, 2015; Quardokus & Henderson, 2015; Smolla & Akçay, 2019; Sturtevant & Wheeler, 2019).

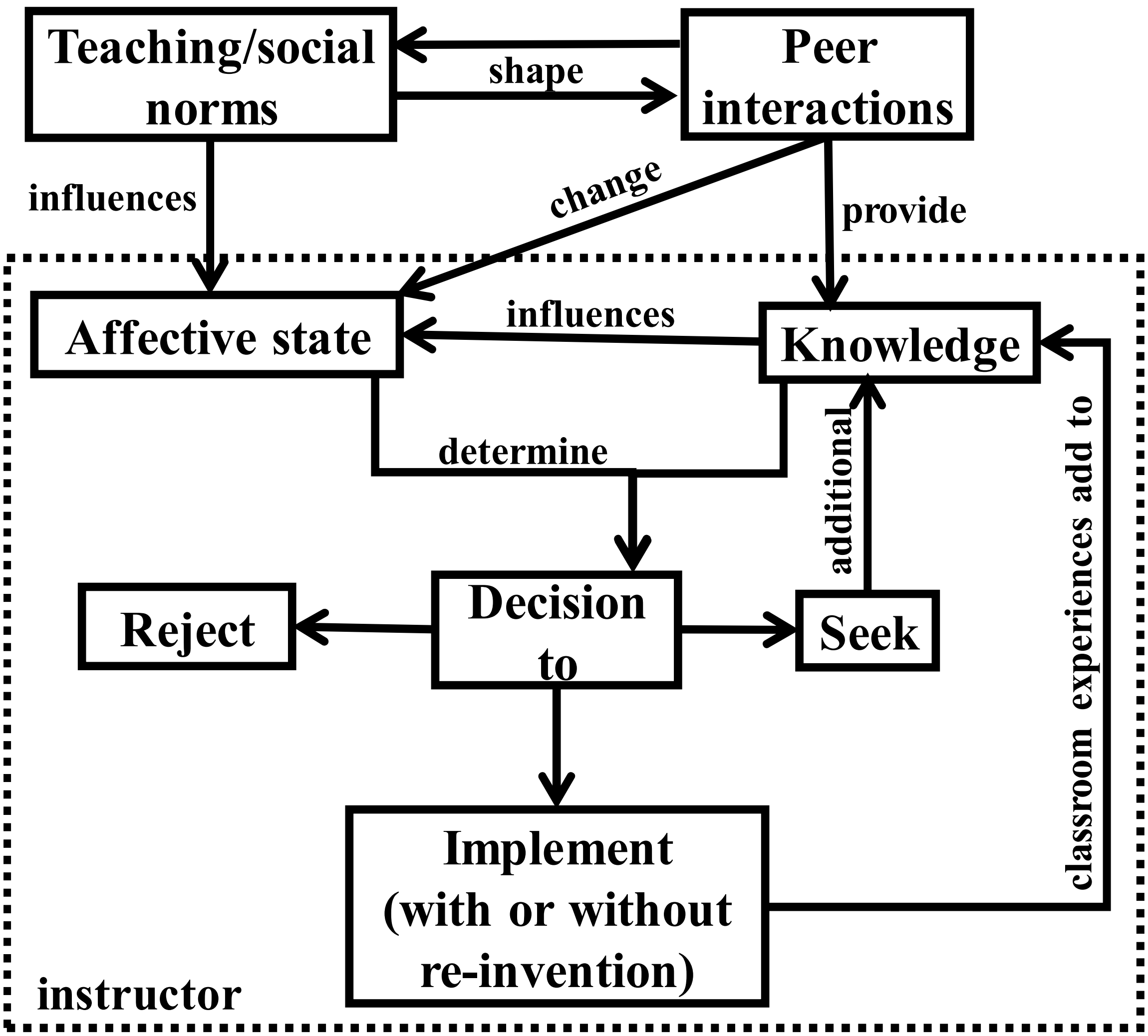

Figure 4-1. A model of the impact of departmental climate and peer interactions on instructor innovation decision. From McConnell et al., in prep (Chapter 2)

In this model, knowledge refers to an instructor's knowledge base about innovations, content, teaching, and students (Andrews & Lemons, 2015; Dancy et al., 2016; Rogers, 2003), and affective state refers to non-knowledge attributes that may affect decision-making (including personality, confidence, beliefs, values, goals, and satisfaction with a particular innovation or class) (Andrews & Lemons, 2015; Marbach-Ad & Hunt Rietschel, 2016; Sturtevant & Wheeler, 2019). Both knowledge and affective state can change through time, experience, and new information. For example, individual peer interactions can directly impact both an instructor's knowledge and affective state, and through that, an instructor's decision regarding whether or not and how to adopt innovations (Mcalpine et al., 1999; Trowler & Cooper, 2002). The norms of an instructor's department or social group constrains or perturbs their affective state, influencing such attributes as motivation and satisfaction (Sturtevant & Wheeler, 2019; Walter et al., 2016). Norms are communicated, in part, through interactions among peers.

Outcomes of an instructor's decision-making process can include implementing an innovation (with or without making changes), rejection of an innovation, and choosing to seek additional information, often from peers (Pataraia et al., 2015; Roxå & Mårtensson, 2009). One implication of our model is that interaction with peers in a department with innovation-positive norms should lead to increased innovation adoption because of the availability of more information about teaching innovations as well as the ways in which peers can influence the choices (Implementation, Rejection, or Seeking) involved in the innovation decision process (McConnell et al., in prep). While other factors such as the environment in which an instructor is embedded or characteristics of the innovation have previously been shown to influence adoption of an innovation (Henderson et al., 2011; Rogers, 2003; Shadle et al., 2017; Trowler & Cooper, 2002), we focus here on the role of peer interactions and teaching/social norms. To that end, we explore the following research questions:

Research Question 1: In what ways do perceptions of departmental teaching and social norms affect the process of innovation decision in a department known to be innovation-positive?

Research Question 2: Beyond shaping and communicating teaching and social norms, in what ways do individual peer interactions affect the process of innovation decision?

In the remainder of this paper, we begin with a brief overview of the model and its predictions about the impact of departmental norms and peer interactions on instructor innovation decision (see also, McConnell et al., in prep). The relationships illustrated in the model indicate the need to pay attention to: 1) impacts of departmental norms on instructor affective state, 2) the relationship between departmental norms and peer interactions, and 3) the impacts of peer interactions on instructor knowledge and affective state.

Departmental teaching and social norms will predict outcomes of innovation decision processes

The departmental environment within which an instructor is situated is like an ecosystem which can have a profound effect on their teaching (Emery et al., 2019; Grunspan et al., 2018; Lund & Stains, 2015; Roxå et al., 2011; Schein, 1996), as can smaller microclimates made up primarily of a subset of peer interactions within the department (Roxå & Mårtensson, 2015; Schein, 2010). The model indicates that teaching and social norms within a department can influence an instructor's affective state – perhaps constraining or changing it. Priorities, goals, attitudes, satisfaction, and research and teaching identities are all subject to an instructor's perception of their prevailing departmental norms and the microculture(s) they perceive themselves as belonging to (Knight & Trowler, 2000; Landrum et al., 2017; Schein, 2010; Schneider et al., 2013; Sturtevant & Wheeler, 2019; Walter et al., 2016).

Different departments have different complements of potential drivers and barriers which can impact the perceived norms and the extent of innovation adoption (Lund & Stains, 2015; Reinholz & Apkarian, 2018; Roxå et al., 2011; Shadle et al., 2017; Walter et al., 2016). A supportive environment may be even more impactful for implementation of teaching innovations than the lack of barriers (Bathgate et al., 2019; Carbone et al., 2019; Chasteen et al., 2015; Sturtevant & Wheeler, 2019). Such a supportive environment is experienced as the sum total of a variety of factors, such as peer interaction, norms, supports offered, and official policies such as tenure review procedures (Reinholz & Apkarian, 2018; Walter et al., 2016). Our model focuses on interactions and norms, indicating a mechanism by which differences in departmental teaching and social norms can impact instructor decision-making: perturbing their affective state. Because departmental norms carry implicit expectations and often reflect priorities of leadership in the department (Reinholz & Apkarian, 2018; Shadle et al., 2017), we expected that an instructor's experience of prevailing departmental norms would have a greater impact on their affective state than any individual peer interaction and would be predictive of their innovation adoption decisions (McConnell et al., in prep).

Departmental norms impact peer interactions and the flow of information

Interactions between peers play a role in the shaping of departmental norms, but the number, type, and structure of those interactions are also affected by the norms within the department (Bandura, 2001; Pataraia et al., 2015; Roxå et al., 2011; Roxå & Mårtensson, 2009; Thomson & Trigwell, 2018). In addition, peers signal or communicate prevailing departmental norms to each other (Andrews et al., 2016; Ma et al., 2018; Owens et al., 2018). We hypothesize that departmental norms can moderate the relevance of peers to an instructor's decisions. Social and teaching norms impact the affective state of each instructor, and as such may change the nature and/or content of the interactions that instructor takes part in, thereby affecting the structure of the departmental social network and the kinds of information that are received from peers (Lund & Stains, 2015; Quardokus & Henderson, 2015; Smolla & Akçay, 2019; Sturtevant

& Wheeler, 2019). Norms of when, where, and even whether to talk about teaching and what aspects of teaching to discuss may vary considerably by department, affecting the structure of networks and the information and interactions that occur within them (Chasteen et al., 2015; Lund & Stains, 2015; Ma et al., 2018; Owens et al., 2018). Thus, the importance of peers in affecting instructor decisions may be increased in departments in which teaching innovation is supported and interaction and collaboration about teaching is encouraged. Conversely, departments in which interactions about teaching are not the norm, and/or teaching innovation is not supported, would be less likely to foster peer interactions that are positive toward teaching innovation, and thus lessen the impacts of peer interactions on an instructor's decisions. For example, we know that ongoing support (such as from knowledgeable peers) is an important factor in an instructor's continued implementation of teaching innovations (Guskey, 2002; Henderson et al., 2011; Sirum & Madigan, 2010; Wieman et al., 2013), and departmental norms around teaching and interaction can have a substantial impact on whether and how such support is normative and allowed to flourish (Chasteen et al., 2015; Owens et al., 2018; Walter et al., 2016).

The impact of peer interactions on innovation decision

We have already discussed the potential impacts of perceived departmental norms around teaching and social interaction. These norms are in part an outgrowth of the sum total of an instructor's interactions. Yet, individual interactions with peers can play an additional role in terms of providing information to perturb an instructor's knowledge and/or affective state (McConnell et al., in prep). As such, we hypothesize that peer interactions in an innovation-positive department will reinforce decisions to implement teaching innovations. Our model indicates that one decision an instructor can make about an innovation is to seek out more information about it, and peers are expected to be a common target of such seeking behavior (Lund & Stains, 2015; McConnell et al., in prep; Quardokus Fisher et al., 2019; Rogers, 2003; Roxå & Mårtensson, 2009). We expect that peers would provide knowledge, including awareness of teaching innovations and techniques, how-to tips and troubleshooting, and information about students and content (Dancy et al., 2016; Henderson et al., 2011; Pataraia et al., 2015). We also expect that peers would impact instructor affective state (including priority, motivation, satisfaction, goals and attitudes toward teaching and particular innovations) as they share experiences, commiserate about frustrations, and compare their teaching with each other, either explicitly or implicitly (Marbach-Ad & Hunt Rietschel, 2016; Owens et al., 2018; Roxå & Mårtensson, 2009; Sturtevant & Wheeler, 2019; Thomson & Trigwell, 2018; Van Waes et al., 2015). Through these types of interactions, peers can affect an instructor's downstream decisions (implementing or rejecting an innovation or seeking more information) in innovation-positive, innovation-negative, or neutral ways. The impact a peer has depends not only on a specific interaction with that peer but also the norms of the department that an instructor perceives and their previous affective state, including personality and prior knowledge about the innovation (McConnell et al., in prep).

Methodology

Study context

This study was conducted in a biology department in a research-intensive, doctoral-granting institution in the upper Midwestern United States. The department was chosen in part because it displayed several indications of a culture that valued teaching and a climate that was supportive of instructors using teaching innovations such as formative assessment, active learning, and other non-exclusively lecture approaches. For example, funding was allocated toward faculty lines for those with education research specialties and toward teaching-focused professional development for faculty. Instructors were actively encouraged to spend time reflecting on and developing their teaching and were provided with opportunities and funding to attend workshops about active learning techniques. More than 60% of the instructors in the department had done so. Additionally, initiatives at the university level further supported pedagogical development. These included monthly pedagogical luncheons sponsored by the Provost, undergraduate learning assistants (Otero et al., 2010), and a large-scale education reform initiative supported by the National Science Foundation. These various formal supports signal a culture that values teaching and teaching innovation and may make it easier for instructors to adopt new teaching practices (Reinholz & Apkarian, 2018; Shadle et al., 2017).

The department contained about 37 faculty members, post-doctoral researchers, and instructional staff. Demographics included 19% tenure-track faculty, 41% tenured/full and emeritus professors, 24% teaching-focused faculty (lecturers, professors of practice), and 14% post-doctoral researchers (with at least some teaching responsibilities). Interaction about teaching was frequent, and colleagues with expertise in education were talked to frequently about teaching (McConnell et al., 2019).

Participants

Since we were studying the impact of peer interaction on innovation adoption, interviewees were chosen to maximize variation in two variables solicited on surveys in a related study. These variables were self-reported assessment experience and number of teaching-related interactions with departmental peers. The two variables were correlated with each other in that instructors who reported higher assessment experience tended to interact with more of their peers (see McConnell et al., 2019 for details).

As part of a related study which explored student-centered assessment practices as an example of an innovation, instructors were asked to self-report their level of assessment experience by indicating how frequently they used various student-centered assessment practices on a Likert scale using the Faculty Self-Reported Assessment Survey (FRAS; Hanauer & Bauerle, 2015). Results showed a range of assessment experience in the department, from those who reported rarely or never using practices such as formative assessment and feedback to those who reported usually or always doing so (McConnell et al., 2019). Because we wanted to interview instructors who represented the full range of innovation adoption views present in the department, we used self-reported level of assessment experience as one factor in choosing potential interviewees. Instructors were classified into groups having high, mid, or low assessment experience as described previously (McConnell et al., 2019), resulting in eleven "high" individuals, six "mid" individuals, and eleven "low" individuals. When choosing instructors to interview, stratified purposeful sampling (Palinkas et al., 2015) was used to select multiple instructors representing each assessment experience group. Our sampling resulted in interviews with four instructors with "high" assessment experience, three with "mid" assessment experience, and four with "low" assessment experience.

Eight interviewees were tenured or tenure-track professors and three were teaching-focused faculty (lecturers or professors of practice). The department population was 55% female, and, since assessment experience was skewed by gender, interviewees were only 36% female (4 of the 11). One instructor (a "low" tenure-track professor) did not respond to requests for an interview; all others who were solicited for the interview participated (92% response rate). The department head was included among those interviewed – this subject was additionally able to provide a different perspective on administrative supports for teaching innovation and how they saw the climate for teaching in the department and its intentional cultivation over time. To preserve participant privacy, we do not identify quotes from the department head as different from those of any other interviewee.

Interview protocol

All research was conducted in accordance with the Institutional Review Board of the university (IRB Protocol #SM16031). Interviews occurred between October 2015 and February 2018. Interviews were conducted by one of the authors (MM), who was a graduate student in the department at the time of the interviews. Participants were solicited by email and a mutually agreeable time was arranged. At the beginning of the interview, participants were briefed on the types of questions they would be asked and on how their identities and the identities of people they mentioned would be kept confidential. Interviews were audio recorded and subsequently transcribed. Immediately following each interview, an interviewer memo was audio recorded in order to capture the interviewer's initial impression of the main expressed by the interviewee. Although these memos helped the interviewer make sense of the interviews and begin to become familiar with the data (Gibbs, 2018), they were not used for analysis themselves.

The aim of the interviews was to gather information about instructors' reported teaching practices, including innovations tried, considered, and rejected, as well as their social interactions about teaching within the department. We expected that gathering information about both would allow us to see how they related to each other, allowing us to understand more about the role of norms and peer interactions in instructional innovation decision. To that end, interviews were semi-structured (Brown & Danaher, 2019) with three main conceptual categories of questions regarding: 1) The instructor's teaching style and how, if at all, it had changed over time, 2) How and why the instructor made decisions about how to teach and whether to adopt innovations, and

3) The interactions the instructor had with peers in the department. A fourth line of questioning (regarding whether the instructor had observed resistance to active learning) was asked of 8 of the 11 participants after it came up organically in earlier interviews. The interview protocol is available in Appendix B and is discussed in more depth in the following paragraphs.

As is common with semi-structured interviews (Brown & Danaher, 2019), each main question from the protocol was asked if it hadn't already been answered, in order to ensure that the interviewee addressed all avenues of investigation listed above. However, often the first question asked ("Can you tell me a little bit about your teaching style?") led naturally to numerous follow-up questions regarding their decision-making that addressed one or more of the other avenues organically. Interviews were thus allowed to proceed as naturally as possible as a conversation about instructional decision-making and peer interaction, while ensuring that each line of questioning was addressed at some point during the interview. In order to increase validity and mutual understanding, during the interview the interviewer frequently rephrased a participant's response and repeated it back to them to ensure it reflected their meaning.

Interviews began by asking participants to describe their teaching style. Due to variation in teaching styles, some participants provided substantial detail about different types of activities and formative assessments used, while others primarily described the type of content they taught. Those who described content rather than techniques were then asked more specifically whether they used mostly lecture, and if they did any group work or active learning. Any teaching techniques that were mentioned were conceptualized as an innovation and further probed in terms of why the instructor had chosen to teach in that way. If interviewees mentioned changing their teaching over time, they were asked to describe why they made those changes. Even if interviewees did not talk about a change over time in their teaching, they were asked if and how their teaching had changed (or was changing) and then asked to describe their process of making those changes. Care was taken to also ask about any teaching techniques that had been heard about or tried but ultimately rejected, and why those innovations were rejected.

All participants were familiar with the term "active learning"; this term was thus used frequently in the interviews and is referred to in the results as a general teaching innovation that represents evidence-based, student-centered approaches. However, since interpretations can vary greatly and interviewees themselves used a variety of terms to describe innovations they used, tried, or considered, follow-up questions also typically established details about the methods to which they referred. Additionally, formative assessment was specifically probed for in the interviews (without necessarily using the term formative assessment) to get more detailed information about this important aspect of active learning. The detailed conversations that unfolded with the interviewees provided insight into what "active learning" and other innovations they referred to meant to them. Except as part of a participant quote, we will use these terms in the researcher-defined way already described in this paper.

Participants were also asked what types of interactions they tended to have with peers in the department. They were asked about giving advice and getting advice separately. When interviewees brought up specific peers and their impacts on instructional decision-making, follow-up questions typically focused on categorizing the interactions (e.g. did the participant think it was advice giving, advice receiving, collaboration, etc.) and the results of those interactions (including decisions about innovations). The questions about peer interactions helped us to characterize the types of input instructors were receiving from peers, which could have impacts on their knowledge and/or affective state.

The first three interviewees noted that the department was very supportive of teaching innovation and active learning. The fourth interviewee spoke at length about undercurrents of defensiveness and resentment they perceived (and participated in) within the department and that lecture methods were being, in their view, "disrespected". Due to varying perceptions of climate in early interviews, a fourth line of inquiry was added that probed more specifically the perceptions interviewees had about the climate for teaching and active learning within the department. Many interviewees also continued to bring up the topic unprompted. Follow-up questions mainly consisted of clarification requests and paraphrases to check for consistency in understanding between the interviewee and interviewer.

Data analysis

Interviews were coded and analyzed repeatedly in an iterative process concurrent with the development and refinement of a three-layer coding scheme (Brooks & King, 2014; Gibbs, 2018). A priori codes originated from previous work on innovation decision (Andrews & Lemons, 2015; Rogers, 2003) and reflected the structure of our theoretical model of climate and peer impacts on innovation decision (McConnell et al., in prep). The coding scheme was applied and then refined iteratively, in that codes which were seldom used were removed, emergent codes were added, and the coding scheme was restructured to better reflect the interview data and more informatively relate the data to the model (Brooks & King, 2014; Gibbs, 2018). More detail about the iterative coding and analysis steps as well as decisions about the coding scheme development are found in the following sections.

The three layers of the final coding scheme were: 1) the steps of the innovation decision process; 2) the impacts of peers, and 3) perceptions of climate and peer/climate interactions. The final coding scheme is available in Appendix C.

Process of coding and analysis

Coding and analysis were primarily done by the same author who did the interviews (MM), with assistance of a second coder and regular conversations with the co-authors and second coder (Gibbs, 2018; Luker, 2008). The coding and coding scheme construction was an iterative process (Brooks & King, 2014; Gibbs, 2018). First, paper copies of the interview transcripts were read through, and portions of the transcript which discussed innovation decisions or opinions were noted. In a second pass, portions which mentioned interactions with peers were noted. Preliminary emergent codes were applied, which included mentions of departmental climate and norms. After becoming familiar with the data in this way, an initial coding scheme was developed with codes informed by the data and reflecting primarily: 1) steps of the innovation decision process as interpreted by Andrews and Lemons (2015) and Rogers (2003): Priority, Satisfaction, Awareness/Knowledge, Persuasion/Decision, Implementation, Re-invention, Reflection, Confirmation, and Rejection; 2) interactions and services hypothesized to be provided by peers based on Rogers (2003) and other literature: How-to knowledge, Pedagogical Content Knowledge (PCK), Principles Knowledge, Advice, Support, Materials, and Climate (indicating a communication of departmental norms and perceptions of culture or climate).

Two rounds of coding were done by the primary coder using Dedoose (Dedoose Version 8.0.35, 2018), with edits of the coding scheme in between rounds. Each round of coding consisted of reading through and applying codes to each interview twice – once focusing on steps of the innovation decision process and another time focusing on peer interactions and impacts. Edits of the coding scheme were undertaken based on data emerging from the interviews, constant comparison among interviews, and conversations with co-authors and the second coder (Gibbs, 2018; Luker, 2008; Saldaña, 2009).

To establish consistent code application, two rounds of coding were then undertaken in a similar fashion that incorporated the second coder, another graduate student in the department. The second coder had been briefed on the theoretical model being used, and both coders had engaged in extensive discussions about the coding scheme. During the process of joint coding, the third layer (perceptions of climate) was added. Climate had previously been coded only as an interaction with peers, and our data indicated a more nuanced and expanded role for climate perceptions that were only rarely tied with specific peer interactions. Each interview was thus read through and independently coded by each coder three times, once for each layer. Excerpts in transcripts were unitized for all three layers by the first coder by highlighting and commenting a section in a word processing document, which both coders then coded independently (Campbell et al., 2013). Consensus was then reached between the two coders by discussing each excerpt, clarifying and refining the code application and coding scheme together. Two interviews were coded initially, leading to a refinement and restructuring of the coding scheme after discussion between the coders. Subsequently, two additional interviews were completed by both coders in the same way, as well as selections of excerpts from multiple other interviews which were chosen to ensure that the entire coding scheme was applied and discussed. Consensus was reached through discussion at each step.

The final refined coding scheme was applied by the first coder to all interviews using Dedoose, following the same procedure as before. Analysis was completed using Dedoose by the same investigator using several complementary and iterative methods (Brooks & King, 2014; Gibbs, 2018; Ragin, 1999; Saldaña, 2009). Throughout the coding and analysis process, constant comparison was done between interviews and the data was considered in the light of the theoretical model of peer impacts on innovation adoption and prior literature. Excerpts labeled with each particular code were read through, categorized, and summarized, which allowed the development of themes that shed light on the research questions. Extensive memos were written during this process, and counter-examples were sought in the interviews. Codes that occurred together frequently were investigated in the same way to see what ideas were expressed in the excerpts in which they occurred together. Excerpts (3-10 each) which represented categories and themes were gathered and independently labeled by the second coder to ensure they were being consistently interpreted. Side-by-side comparison of themes expressed (or not expressed) by different interviewees enriched the analysis, and tables were constructed to analyze relationships between responses (Gibbs, 2018; Ragin, 1999). Finally, when results were taking shape, each interview was read through another time for each major result, focusing on how that participant's thoughts and ideas shaped that result and searching specifically for counter-examples and emergent ideas that may have been missed.

Coding scheme decisions

As part of the iterative process of applying codes, discussing, and restructuring and refining the coding scheme, some codes were removed entirely, some codes were added, and other codes were reconceptualized and reorganized to better reflect the interview data as well as relate it to the structure of the model (Brooks & King, 2014; Gibbs, 2018). Important aspects of innovation decision, peer interaction, and climate that emerged were incorporated into the coding scheme. This included a code for seeking more information, along with several aspects of seeking which were ultimately categorized with it, including seeking new ideas and consultation or "bouncing" ideas off peers. Sharing behavior was added as a possible impact on Affective state – although it is a behavior rather than an impact, we considered that sharing experiences are likely to result in implicit comparison and trigger reflection, impacting affective state. The climate portion of the coding scheme was expanded to reflect instructors' descriptions of the climate and teaching/social norms as Collaborative or Independent and as Positive (supportive toward teaching innovation) or Pushy, as well as how peers tried to influence those norms.

We removed codes that had a low number of instances or did not provide useful insight into the impact of norms and peer interaction on innovation decision. These removed codes included the Priority and Satisfaction codes. Although instructors did occasionally indicate that they were satisfied or dissatisfied with their teaching, or imply prioritizing certain things, there was a low number of instances of these codes and little clear connection with either peers or departmental norms. Priority and satisfaction can still be conceptualized as components of the affective state, which may be impacted heavily by departmental norms and peers and influence downstream decisions, but the mechanism(s) of these potential impacts are not specifically addressed as such in this study. Decision was removed as a code, as we chose instead to focus on the particular decision that resulted (Implementation, Re-invention/Refinement, Rejection, or Seeking). Reflection was also ultimately removed as a code of its own, since any aspects of reflection that incorporated peer input or norms would also be coded as such. Confirmation likewise was removed, as it was difficult to distinguish from implementation in our data and is conceptualized simply as repeated implementation of the same innovation, with or without refinement.

The final structure of the coding scheme closely reflects our theoretical model (McConnell et al., in prep). Layer 1 (steps of the innovation decision model) includes codes reflecting the decisions of Seeking, Implementation (with Refinement as a subcode), and

Rejection. Layer 2 (peer impacts and interactions) was significantly expanded to include both Knowledge and Affect codes, each with subcodes. Awareness was reconceptualized as a type of Knowledge received from peers, as was Materials. Although awareness of innovations can frequently come from sources other than peers, we are focused on departmental peer impacts and ignore other sources for the purpose of this work. Final subcodes of Knowledge include Awareness, How-to knowledge, Principles knowledge, PCK, and Materials. Affect subcodes include Support, Influence (incorporating guidance, advice, and pearls of wisdom), and Sharing. Layer 3 (climate impacts and peer-climate interaction) was added to characterize the impacts of norms and climate perceptions on instructor affective state. Codes include Collaborative, Independent, Values (with subcodes of Positive and Pushy), and a Peer*Climate code (peer and instructor impacts on the climate).

Minimizing researcher bias

As previously mentioned, the primary researcher in this study was a graduate student within the same department where faculty were interviewed, and was known by most or all of the participants prior to interviews. Additionally, the research team had a connection to DBER and a commitment to active learning practices which was well-known within the community. Finally, the researcher was involved in instruction within the department, as well as interaction about instruction, with the participants, which is the very phenomenon which was being studied. This puts the primary researcher, and to some extent the rest of the research team, in the role of participant-observer, which may provide some benefits (e.g. increased rapport, prior knowledge and background context for what interviewees say), as well as challenges (e.g. hesitancy of participants to talk freely within their own department, researcher preconceptions and biases). While these challenges and potential biases could not be completely overcome in this research context, several steps were taken to minimize bias and maximize the validity of the data collection and analysis. Some of these steps have already been described; we also summarize them briefly here.

During interviews, the interviewer often rephrased or interpreted participant's responses for the participant and asked if that is what they meant. This practice often resulted in agreement or further elaboration, but sometimes resulted in disagreement (always with further elaboration). Doing this helped ensure that the true meaning of the participant's responses was captured. During the analysis stage, counter-examples were actively sought within the transcript data for each emerging theme, category, and assertion to consciously work against confirmation bias. Alternative explanations were considered and will be discussed in the results section. Finally, the role of the second coder has already been described. Although this coder was familiar with the theoretical framework and model and was heavily involved in conversations about the codebook as it developed, they were not informed of developing themes and assertions before their coding. This independence helped ensure that interpretations were consistent; however, it should be acknowledged that a prior relationship with the department studied may still introduce biases in the process.

Results

The teaching-positive and innovation-positive nature of the department was confirmed in interviews, with many participants also noting a perception of autonomy in teaching. The climate was perceived by some as pushy or judgmental in regard to active learning, while others disagreed. Additionally, while some interviewees perceived and participated in a collaborative environment with frequent teaching-related interactions that influenced their teaching, others indicated that their teaching decisions were primarily solitary. All participants indicated ways in which their instructional decisions were impacted by other instructors within the department, and instructors who frequently interacted with peers reported more innovation adoption and a positive attitude toward active learning. In this section, we will report a) how perceptions of departmental norms led to different impacts on instructor affect, b) how peer interaction, perceptions of norms as collaborative, and innovation adoption were related, and c) specific ways instructors reported interacting with and being impacted by peers.

A note on interview quotes

Instructor wording is preserved as much as possible in all interview quotes we provide here. In some cases, edits were made to preserve anonymity (e.g. classes taught, names of colleagues), and in those instances, the interviewee's words are replaced with bracketed words that communicate the meaning without compromising interviewee privacy. Pseudonyms are also used when an interviewee refers to themselves by name. When instructors paused or interjected, dashes are used to communicate a break in speech. By contrast, ellipses are used to indicate that we have removed wording from the excerpt. Ellipses are used sparingly, and in all cases, the removed words were extraneous in relation to the theme being described and do not change the meaning of the passage. In a few cases, additional wording is added in parentheses to provide context that is present in the interview but not clear from the quote provided.

Interview quotes are provided that represent the range of participant responses expressing a particular idea. Clarity and succinctness were taken into account when choosing quotes. Unless otherwise indicated, interview quotes are not presented as the only example of an idea, but as representative of that idea. When applicable, we include discussion of contrasting ideas, including relevant quotes, or indicate that there were no participants who expressed contrasting ideas.

Teaching norms and their impact on instructor affective state

Common norms expressed in the department included encouragement of teaching innovation such as active learning and an ideal of autonomy in teaching. These norms were perceived and experienced differently by different instructors and had different impacts.

The department was supportive of teaching innovation

Since all participants worked within a single academic department, many perceptions of climate and norms were expected to be common among instructors. The interviewed instructors and the department head all agreed that teaching was valued in the department, and active learning approaches were encouraged. This sampling of interviewee quotations indicates the value of teaching within the department and the perception that active learning was the norm:

> Well, I feel like our department has always valued great teaching, and always valued – it was always expected that you were going to teach, and that you would do a good job and you enjoyed teaching, so they've always hired people who were committed to – that was always a big part of job interviews, always. And so I think the biggest changes in the environment that have happened, sort of getting people who, now feel like it's not just that you are a good teacher and you value teaching, but that you are using sort of what evidence we know about good practice in your classrooms.
> - Yara

> I have a lot of respect for, really, everybody on our faculty. We're, you know, we're still an institution and our department in particular, we value education, and so we're all - I think we're all really dedicated to our work with students.
> -Jorah

> I would say that there is almost no one in our department that doesn't do even, you know, at least a little bit of active learning or more student-centered pedagogy…the degree with which they implement active learning I mean I think there's still variation.
> -Catelyn

> It's just the - the culture here right? I've always enjoyed teaching and I've always tried to be the best instructor I can be, but I think before - you know before I came here I was involved in [professional development program], and so I started to get an idea of some of these concepts and pedagogies. But I hadn't really been immersed into it that much and then coming here and being immersed in the culture and seeing the evidence to support these pedagogies, you know to see it in practice in multiple classrooms and then just to - to try it myself and see how it not only improves my experience in the classroom but I think - I feel that it's improved the students' experience in the classroom.
> -Davos

These data, and other indications discussed in the study context above, indicate that the overall climate within the department was one relatively favorable to teaching innovation. None of the interviewees disagreed with the ideas that teaching was valued and departmental norms favored active learning.

Instructors experience autonomy in their teaching

Another common theme regarding the teaching norms in the department was autonomy to teach in the way one saw fit, without interference from departmental administration or peers. Though it was clear that active learning was encouraged within the department, this was moderated by the "live and let live" ethos expressed by many within the department.

> That being said, I'd be the last person to judge someone who does it (flipped class). I have this feeling that the gestalt of my education has to do with the diversity of ways in which I was taught. And so I - I'm kind of a - let everybody teach to how they feel comfortable. That's how I've looked at it. I don't think there's one size fits all.
> -Stannis

> And the department's philosophy is, we're not going to micromanage you.
> -Jorah

> (Describing general cultural norm) I really don't give a shit what [anyone] is doing, I mean he's responsible for his class, and I trust that he's going to use sound judgement, I mean, why did we hire him?
> -Jorah

Instructors perceived an encouraging environment toward teaching innovation and active learning, and also perceived autonomy to teach in the way they wanted. These are two important aspects of an innovation-friendly climate (Landrum et al., 2017; Walter et al., 2016). Yet, as the next section will show, instructors' perceptions of these norms had different outcomes.

Instructors experience and interpret teaching norms in positive and negative ways

While some participants felt encouraged to experiment with innovations due to their perceptions of an innovation-positive climate, others experienced it as a form of pressure against using lecture. A few interviewees indicated that they perceived some sort of judgement for using lecture techniques or for not using enough active learning, and over half of all interviewees indicated being aware of members of the department who expressed feeling such judgement (Table 4-1). This perception influenced the affective state of some negatively:

> There does seem to be a sentiment from the gung-ho active learning group that any sort of - if you spend more than 10 minutes on in-class instruction then you're not doing it right. And that is - it makes some instructors including me feel like they're not doing what they're supposed to do, but they're doing what works for them but also seems to be working for the students.
> Interviewer: So you think some instructors feel a little bit defensive, or -?
> J: I think - yes. Yeah. I think they feel looked down upon.
> -Jaimie

> I think that the reticence or reluctance is that at times, any new field, and especially when you put a push in your department, if all of a sudden there was a push for biomedical genetics or genomics there might be people who say well wait a second wait a second, we now, those of us who are doing ecology or physiology, are we second class citizens?
> -Bran

> To have that discussion, to stimulate it, I don't think anybody is against that. But to force that and you know repeat it like an advertisement that you might see on the TV over and over again, at some point people go like yeah enough. You know? So I think that is kind of the feeling at least among people that I interact with.
> -Samwell

> And so when I look at it from a research perspective, oh yeah it makes sense. But when I look at it from a perspective of faculty members judging each other, then it becomes less - it seems - it seems like if you aren't employing certain methods you might be judged in a different way than if you are.
> -Stannis

> It's not even judgment - so that's the thing, I don't know that it's personal judgment, it's judgement of the technique, but since people use the technique and it's personal to them, it becomes personal.
> -Stannis

A single perception (i.e., departmental norms support teaching innovation and active learning) can be interpreted in multiple ways, both positive and negative, leading to different impacts on the affective states of the instructors within a department. Likewise, interviews revealed that a norm of teaching autonomy could be experienced differently by different instructors. As noted above, autonomy was referenced in a neutral way, but it was also brought up both to support using active learning approaches and to justify not using active learning approaches. Some interpreted it as a freedom to try new innovations without pushback from colleagues or administration:

> So you definitely in this department have no feeling of, that there’s any like push back from other faculty or, you know the department as far as what I can do so that’s been really great and like no matter what crazy idea I come up with I just, I feel like I can do it if I want to do it, nobody’s ever going to stand in the way or say that you shouldn’t do that.
> -Catelyn

> And I would say that my peers are really supportive of anyone doing whatever they want in the classroom.
> -Daenerys

Others referred to the idea of teaching autonomy as part of their explanation for why they weren’t doing or shouldn’t have to use active learning. In some cases, autonomy seemed to mitigate their sense of pressure from the department in this way. Bran and Samwell in particular discussed the idea of teaching autonomy in reference to departmental norms of active learning.

Table 4-1. Summary of participants' assessment experience (based on FRAS) and expressed practices, attitudes, and perceptions of norms

Pseudonym	Assessment experience	Collaborative/ Solitary	Feel pressure or resentment?	General attitude toward active learning	Adopted or trying	Rejected
Catelyn	High	Collaborative	No	Positive	activities; clickers	
Daenerys	High	Collaborative	No	Positive	activities and worksheets; clickers	flipped classroom
Davos	High	Collaborative	Others	Positive	flipped classroom; clickers; case studies; muddiest point; concept map; alternative assessment	
Yara	High	Collaborative	Others, but it's a "false dynamic"	Positive	project-based learning; alternative assessment; flipped classroom	
Jaimie	Mid	Collaborative	Self and others	Positive "to a point"	clickers; writing assignments	muddiest point
Cersei	Mid	Aspects of both	No	Positive	activities; course structure changes; flipped classroom; clickers	
Bran	Mid	Mostly solitary	Self, mitigated by autonomy	Negative	contract grading; one-on-one meetings; tutorials	"active learning"
Joffrey	Low	Aspects of both	Others	Positive	specific activities and simulations; examples; small projects; case studies	clickers
Jorah	Low	Aspects of both	No	Positive, but not strongly	online courses, writing assignments, discussions	certain labs and activities
Samwell	Low	Solitary	Others	Apathetic to negative	take-home tests; exercises; writing assignments; online courses	flipped classroom
Stannis	Low	Solitary	Self and others	Negative	one-on-one meetings; specific activities; examples; group projects; peer review	flipped classroom; specific activities

> No one can make you teach a certain way. Now I mean unless you are being abusive to students. As long as you are keeping your good faith and effort and you are doing something.
> -Bran

> [The] culture is you're kind of the king of your own kingdom, and yes there's interaction with other people but in the end you're kind of focused on your own field if you know what I mean.
> -Samwell

Some instructors were unaware of alternative interpretations of norms

Interestingly, though everyone in the department agreed and was aware of prevailing teaching norms favorable toward active learning, some interviewees were unaware that they had colleagues with negative attitudes toward active learning or who experienced the norm as a form of pressure:

> I've never felt like there was anybody who said anything that showed that they were like, resistant (pause)
> Interviewer: or against active learning?
> D: or against this whole program. So there may be some who are not participating or implementing, but those people are not stopping or hindering or being outwardly negative to the other people who are, and in the absence of information maybe everybody's excited to do it. That could be possible.
> Interviewer: OK. So you don't experience a lot of negativity about teaching? Teaching ideas or anything like that.
> D: No, definitely not.
> -Daenerys

> I would be really confident in saying there's nobody in our department who totally, you know, disdains learner centered pedagogies, I think there's just people that, you know, that still don't quite maybe know how to implement it or haven't found the time to develop materials that they could implement so it's kind of a trade-off like they, they feel their time is better spent on other activities than developing things to make their classes more learner centered, yeah.
> -Catelyn

These participants did not specifically address whether they had heard of colleagues with feelings of pressure to align with the active learning norm. Other interviewees seemed more aware of this dynamic. One downplayed the impact:

> So there are some people who are resistant, perhaps, to - they feel like what they've been doing is maybe disrespected from the past, so the more lecture approaches, but I think if you look at what they're doing, they're often lab classes, and they've naturally come to some of these best practices, just by being an experienced teacher.
> -Yara

Meanwhile, another acknowledged negative interpretations of the active learning norm in the department and tried to find ways of interacting that could help overcome it:

> So there are certain faculty members in our department that I know are not real excited about scientific teaching and I would venture that they feel a little threatened by it, intimidated that they're perceived that they haven't changed their teaching. So I tend not to broach the "types of teaching" subject with those people as I do with others, but I have had some very good conversations with those people about specific topics and teaching activities, and I think since it was framed as what we can do for this topic, that was perceived much differently then let's talk about active learning, formative assessment. So I had really good conversations with people who probably aren't jazzed about the same types of teaching strategies that I am.
> -Davos

Frequent interaction, social norms of collaboration associated with innovation adoption

In addition to impacting the affective states of individual instructors, our model predicts that departmental teaching and social norms can impact the patterns of interaction between instructors. We have previously found that instructors in this department who reported higher levels of assessment experience also were reported as interacting with more of their peers about teaching (McConnell et al., 2019). During the interviews, instructors who mentioned peer interaction frequently also tended to mention using and trying many different student-centered innovations. They tended to perceive the social norms of the department as favoring frequent teaching interaction and collaboration – as one interviewee dubbed it, an "intellectual community of teaching". By contrast, some instructors perceived much more solitary norms around teaching-related interaction and reported less frequent teaching-related interactions in their interviews. These instructors tended to be ones with more negative attitudes toward active learning who embraced lecture. Many of the innovations they mentioned were presented as either small additions or enhancements to their lecture-based style or fairly typical for a lecture-based college class (e.g. adjusting aspects of grading or a group writing assignment). Interviewees' assessment experience (from McConnell et al., 2019) and attitudes expressed in the interviews regarding departmental norms and active learning are collected in Table 4-1, along with lists of classroom innovations the participants reported trying or rejecting.

High interaction, high adoption

All four participants with high assessment experience (Catelyn, Davos, Daenerys, and Yara) perceived a general collaborative sense of community in the department regarding teaching and reported frequent interaction with their peers. This happened both in the context of teaching the same or similar classes as well as across the curriculum and in general.

> Part of my responsibility to the department is to be somewhat of a resource for teaching so I would hope that other people would see that, because I love to talk about teaching with other people, you know, even if it's a class that I'm not teaching, if they just have ideas and want to just talk about how this works. So I try to make that known to the department and I hope others feel that way.
> -Catelyn

> And I would say we have a really great environment for talking about teaching and sharing and like cross-pollination, not that [other departments] don't, I mean they do talk about teaching, but, we have a lot of people who are innovating and then a lot of people who are also really receptive to adopting new things. So we have like experts in adopting new things and people who are excited to adopt those, and I think that that really is a great environment. They definitely care about teaching a lot in those other departments, but it's just this kind of like synergy thing I think that we have that makes it really great.
> -Daenerys

> I would call that the intellectual community around teaching. That community, those conversations are part of the intellectual - that we approach it from an intellectual standpoint, and those conversations are part of that. You also have the intellectual community that's centered around our research, that we talk in the hallway about, and it's nice that we have both of those, and people are comfortable doing both, you know? There's a real community there for people to talk about their teaching, and a real community for people to talk about their research.
> -Yara

Each of these four participants also reported doing frequent in-class activities and exploring a variety of student-centered practices including regular formative assessment (Table 4-1). They reported implementing activities as part of a teaching team (e.g. teaching similar classes) as well as collaborating with others who taught courses across the curriculum. For example, the groups of instructors who all taught the introductory classes and CUREs had tight-knit communities with frequent meetings and sharing of materials. A group of instructors who sometimes taught one of the upper-level classes had a similar but less formal collaboration.

> [Instructor] and I do this [outreach] where we've taken some of the activities that either one of us have developed in [upper-level class] and made them a day long workshop and so as part of that, [the other instructor] and I really develop things together and revise them in a way in that you wouldn't normally do as individual instructors, and so - and then often I take that improved thing and put it back in my undergrad class. And so that's a really big thing for me.
> -Daenerys

> [The other instructors who teach that class] and I talk all the time about what we do in class, depending on who's teaching it, we share materials very readily, and we think about misconceptions and how to address them.
> -Daenerys

> Now that [other instructors] have also developed their own CUREs, you know, all five of us definitely communicate with ideas for rubrics, for grading proposals and papers and trying to make sure that even though all those courses have different themes to them that the skills that students should be picking up are consistent across them.
> -Catelyn

Many (though by no means all) of the peer interactions reported during interviews by this high interaction group were with other high assessment experience instructors, providing for mutual reinforcement of active learning strategies.

Low interaction, low adoption

One instructor with “mid” assessment experience (Bran) and three with low assessment experience (Jorah, Samwell and Stannis) represent the opposite side of the spectrum. These participants indicated that they did not talk frequently about teaching, preferring to figure things out themselves:

> But for the most part, I probably don't talk that much about teaching. Probably because I have, you know, my [various other] responsibilities and unless somebody asks me, I'm not going to go out of my way to say what did you do or what's working?
> -Stannis

> Because here's the other side of it, academics are individualists. Yeah, we work as a team but we're loners.
> -Samwell

> I wouldn't necessarily say I seek people out. And I don't - seek people out - I seek people out when I - last resort.
> -Jorah

Additionally, these instructors tended to describe their teaching more in terms of course content as opposed to specific instructional techniques. Some indicated it would only be useful to talk about teaching with those who shared their research interests:

> Part of it is that what I teach, particularly [subject] and [other subject], there's nobody who does that. I'm kind of an odd one out.
> -Samwell

Instructors in this group sometimes needed to be asked specifically if they used any active learning. The innovations they mentioned implementing tended to be focused on outside-of-class projects such as writing assignments or on small adjustments to how the material was presented. They had students do longer-term projects in upper-level classes and made adjustments to those as well. One interviewee (Stannis) did mention using pair-and-share activities and other small activities in class, yet also strongly emphasized that they were primarily to focus student attention and interest and to "take a break" from the lecture content, not primarily to drive learning. This interviewee also repeatedly emphasized trying not to spend too much time on such activities:

> The biggest challenge I see for in-class activities is governance, and I think it's pretty easy to give them too much time. I've observed this when I've observed other faculty. It's

> pretty easy for groups to go off task pretty fast, or they feel like they've answered it.
> -Stannis

Many of the peer interactions mentioned by instructors within the low interaction, low adoption group were with others within the group or other low assessment experience individuals, potentially reinforcing lecture norms. However, it should be noted that every instructor in this group still mentioned at least one instance of receiving information or influence from a peer, and they also reported adopting innovations that were used by the previous instructor in a class, or that were used by others teaching the class (this will be developed more later).

Mid-range and counter-examples

Although a general association between frequent, collaborative peer interactions and adoption of active learning techniques appears to hold true, there were three participants who did not fit neatly into either a high interaction/high adoption or low interaction/low adoption category. Of these three interviewees, two (Cersei and Joffrey) can be conceptualized as being in between. They each expressed some indications of a collaborative environment, indicating times they had worked with other instructors to improve instruction as well as seeking out help from peers. Yet, they did not talk about it as much as the group of highs, they mentioned a small number of people, and they also had moments where they lamented a lack of interaction:

> It would also be nice to have somebody nearby that I could talk to all the time and say, this problem came up, how do you deal with that? You know.
> -Joffrey

> I don't have - I don't actually feel like I have a large group of people to work with on stuff like that.
> -Cersei

Cersei and Joffrey each had a very positive viewpoint of active learning. They had “bought in” completely to the idea, in terms of attitude if not day-to-day implementation:

> That (professional development) convinced me that active learning is the way to go, actually having the students, with a bit of guidance, the right amount of guidance, work things out. Now the trick, well that's the way to go, and it works really well and the students get a lot more out of it, but then the trick since then has been how the hell do you fit it into a 90 minute class or an hour long class… just sort of different ways to do it, but I also think it's kind of fun to try to come up with new ways of doing that sort of thing.
> -Joffrey

> And if you're going to take it on, you will. And I want to because otherwise I just get bored. I mean, just straight lecturing I find - I really find boring now. I didn't use to but I do now. I'm looking forward to getting rid of most of that.
> -Cersei

Cersei reported a mid level of assessment experience while Joffrey reported low. Each had adopted active learning approaches to a certain extent and was in the process of trying other teaching innovations.

A third participant, Jaimie, had very frequent interaction with many in the department, about teaching and other things. Jaimie expressed a somewhat positive viewpoint toward active learning, with deep reservations about content coverage.

> So I worry that it - I think there's just a trade-off in what you can cover and how much time you spend on different activities. I don't know. So I think the group work and the active learning and forcing students to think and working with their peers IS good - to a point.
> -Jaimie

Jaimie reported actively trying to implement several new innovations, yet also spoke strongly about lecture being discouraged and negative feelings and perceptions related to the discouragement of lecture (see “Instructors experience climate factors in positive and negative ways” in previous section). Jaimie indicated having frequent interaction due to often seeking out advice about many aspects of life as a faculty member in the department, with teaching often coming up along the way:

> Oftentimes if I have something that I don't like or if I have a concern, and it could be grad students, it could be undergrad curriculum, it could be grad curriculum, it could be dealing with the grants and contracts office here. Yeah. So there are a lot of issues that - of the job that yeah I do go out and seek advice, often from people that I think may have the most experience.
> -Jaimie

Jaimie also indicated frequently "commiserating" with others who shared similar concerns about the teaching norms and perceived pressure around active learning in the department. Jaimie would seek out one set of people (high assessment experience individuals) for teaching advice and commiserate with another set of people (primarily low assessment experience individuals).

> So [ideas/help for teaching] does come from some people that I don't commiserate with. Because I'll seek them out partly because they seem to be doing a lot more of the active learning and they seem to be more into it, so I wouldn't commiserate with them, but I know that they have good ideas.
> -Jaimie

Impacts of specific peer interactions on innovation decision

In the department studied, peer interaction was frequent (particularly among the high interaction/high adoption group of instructors) and the prevailing norms favored active learning and innovation. Our model predicted and our data indicate that frequent interactions within a supportive departmental environment may foster the adoption of teaching innovations. We present here some different types of individual peer interactions reported by participants the impacts of these interactions on the innovation decision process.

Instructors seek new ideas and consultation from peers

One way in which instructors received information from each other was through seeking behavior. Many participants sought help from peers for specific problems they were facing in their teaching. Some also described being sought out by others for help. Seeking behavior was sometimes prompted by dissatisfaction about how class was going:

I give advice to [peer]. [That peer] really likes advice. (laughs) [They're] often having - kind of crises or whatever….you know, [they'll] be like, oh my students are doing so poorly in class. And so then I have to be like, well, you know, here's what you could do, here's why it's ok, here's why you don't need to worry, here's how your grade distribution compares to my grade distribution, that kind of thing
-Daenerys

I mean, if something seems to not be working, then I commiserate. And that's usually when I - that's when I get the informal feedback I guess. Yeah you talk about what you're doing and then you get some ideas.
-Jaimie

Instructors who reported seeking behavior received three main types of input from their peers: awareness, consultation, and expertise. When they reached out to a peer with a teaching problem or issue but with no clear idea of their own for how to fix it, peers often gave them ideas of innovations or activities to try (Awareness). Some instructors spoke generally about the getting ideas from others…

I know that if I ever want to introduce something new, or want new ideas, I can go to a certain number of people and they can help me out
-Davos

I've found for actual ideas on things that I can do in class, [peer] is perfect. [They're] great, [they have] lots of ideas
-Jorah

And that's where I do spend time talking to other people, if something's coming up and I'm like, well this didn't really work, so what do you do, or how do you - there was one time, I think my first semester, my first exam was just like, well they really didn't get it, and so then I talked to several other people, is this normal, or...?
-Jaimie

…while others gave more specific examples:

I knew that I wanted to still have a writing component, but I didn't want the weekly writing, so you know, I asked [peer] what [they do] in some of [their] classes, and [that peer] had students do mini-grant proposals and so I incorporated that with [my class] this past semester
-Jaimie

> [Peer], also, [they] and I talk a good bit. [They're] also in [professional development], so that's kind of where I guess that teaching based relationship comes from, but [that peer] came in here the other day asking me about…primary literature and how to integrate it best in the classroom, and so I guess I gave [them] some advice on that
> -Daenerys

Sometimes the seeking behavior was initiated when an instructor already had an idea and approached peers as a sounding board to "bounce" the idea off (Consultation). These instructors made reference to getting general input from a peer regarding what they thought about an idea rather than specific advice or expertise:

> Usually thinking through ideas. You know, I have this crazy idea that I want to try….Yeah, usually it's just ideas. I'm thinking about this, how do you think this would work?
> -Yara

> Actually when I was going to do the tragedy of the candy I went….and talked to [peer]. I said, what do you think of this idea? Cuz I had read it on the web, or something like it, and I had thought - I was gonna - so we talked about it for - I said, "is this going to take, like-" because I was worried about how much time, you know, I should spend on it. And so we talked for, it was - it was almost just having someone to bounce it off. And of course [peer] was enthusiastic. That was the little bit I got from [them].
> -Stannis

> And because of that I think you know I have to get someone else's input. So, I talked to a friend of mine who is a physician and [they] said well that's like a case based study that we try and do in medical school. I think that would be really useful and that you would get a lot out of it.
> -Bran

Often an instructor had an idea of something to do in their class but wanted to get specific advice or information from a peer they perceived as possessing specific expertise, or experience using a particular innovation (Expertise). Knowledge received from these peers included how-to knowledge, technical help, troubleshooting, and sometimes principles-based knowledge.

> My first semester, my students just weren't getting how pieces fit together, and so I talked to [peer] about concept modeling type stuff.
> -Jaimie

> Yeah, it's like we're all learning, learning the way these things go, but I need to sometimes talk to the people who do it more, because they'll have ideas - they've already - I'm re-inventing the wheel I guess is what it feels like sometimes, and they will have already figured out, oh no you need to do it this way or that way, or something like that.
> -Joffrey

> Yeah. Just something logistical like that, it's like, oh. OK. I know this can work, but I probably need to find out from somebody else how to do it. Who else has experienced this?
> -Cersei

> I also go to [peer] a lot for help. With Blackboard - And clickers. Because [they] - yeah. Yeah. [They're] my technical - And so I'm always like, [peer]! How do I do this in Blackboard?
> – Daenerys

Seeking behavior was most commonly associated with the instructors who reported perceiving collaborative norms around teaching interaction. These data support the assertion that teaching and social norms and peer interactions impact the affective state, thereby influencing an instructor's propensity to seek help from their peers. Alternatively or additionally, repeated seeking behavior may create or reinforce a community of collaboration around teaching. Instructors who are not immersed in a microclimate of teaching community and interaction may not necessarily be on the lookout for new ideas, especially if they are satisfied with their teaching (Andrews & Lemons, 2015; Marbach-Ad & Hunt Rietschel, 2016). Additionally, due to their perceptions of the climate of autonomy, they may feel the need to figure things out on their own. Thus, it is likely that perceptions of norms and interactions were mutually reinforcing for instructors in this high interaction/high adoption group, encouraging both interaction and innovation adoption.

However, even some of the instructors in the low interaction/low adoption group gave examples of times when they exhibited seeking behavior, especially consultation or "bouncing" on an idea they already had. Interestingly, two of these interviewees indicated consulting others outside the department rather than those within the community (e.g. see Bran's quote above).

Perhaps this indicates that their perceptions of solitary and autonomous teaching norms reduce seeking behavior within the department but not necessarily in general.

Sharing and commiserating results in transfer of information

In many situations, interactions were reported between instructors in which none of the instructors involved were necessarily seeking advice or information, to help them solve a problem or otherwise. Often, these interactions involved sharing of classroom experiences, feelings, and ideas rather than explicitly seeking help. All instructors reported some form of sharing and commiserating interactions. These interactions fell into four main categories: 1) talking to peers about an experience using an innovation, 2) talking to peers about concepts and student misconceptions (PCK), 3) commiserating about difficult classroom experiences, and 4) sharing advice or pearls of wisdom.

Instructors who tried an innovation sometimes shared their experience with others:

> So the why is often because I hear about what other people are doing.
> Interviewer: OK. And it sounds good to you?
> J: It sounds worth giving it a try.
> -Jaimie

This type of sharing results in transfer of knowledge regarding the innovation and may or may not lead an instructor to be interested in trying it. Instructors shared both positive and negative experiences with innovations:

> If I have, you know, if I have a tool that I'm like "oh this worked really well" there's maybe a close group, people that I'm - colleagues that I'm especially close with, that I may mention to them, "oh this worked out really well", whatever.
> -Jorah

> If they ask me, some things, I can tell them, "yeah I tried that, oh my god it was a disaster." That doesn't mean you don't try it, it may just have been a disaster because of the way I did it.
> -Jorah

> I talked to one of my former students about it (flipped classroom). Because he was doing it, and he's a quantitative person, and he hated it.
> -Stannis

Sometimes, rather than an innovation, the topic of sharing was a particular piece of content or student understanding around a concept. While instructors who were teaching similar classes talked often about these ideas, sharing also occurred between instructors teaching different levels of courses that shared content. This type of sharing can result in transfer of pedagogical content knowledge or knowledge about the students in a program.

> I do talk about evolution for instance, it features in [a class I teach]. And some of the quirks that we've had to deal with with students who don't understand it or don't believe it, with people like [peers], but in general not that much.
> -Samwell

> Obviously having [peers] teaching intro bio, we do talk a lot about what they're covering with [topic I teach] in intro bio to kind of help with curricular alignment. Because I find out all the time, like oh they're now covering [specific content], which they weren't a few years ago, how does that change how I address the topic, what kind of pre-knowledge can I assume, or what kind of misconceptions are still remaining after that?
> -Daenerys

A third category of experience sharing was commiseration, or complaining about the frustrations regarding students and teaching:

> The typical complaints about whether or not the students are paying attention to this, that, or the other, I probably have just casually talked to people like [peer] and maybe [other peer] in the department.
> -Joffrey

Multiple peers indicated that such complaining could sometimes turn in to seeking-like behavior, in that it could lead to a discussion about how teaching could be changed or advice on how to approach it (see also Seeking):

Well, you know, when you're teaching a class for the first time, there's often this, like "I have no idea what I'm going to do in class tomorrow, how do I do that? Like how do I handle this challenge of prepping a whole class from nothing?" And then you want to do it in advance but it ends up being the night before. And then in the context of that, how do I - what's a fast and easy way to make activities, right? Or where can I get ideas for activities. Does that make sense? And then how do I handle the almost inevitable poor grades on exams, right? Or - you know, I guess every instructor wishes that all their students would eagerly earn A's, right? But then when that doesn't happen, there's a moment of feeling really like, debilitated and ineffective. And then you kind of - it's a good time for an experienced instructor to say, "look, you know, it's not all about you, they have to do some work too, and yes students do poorly and here's something you can do.
-Daenerys

In addition to advice and ideas, such expressions of frustration could lead to instructors providing emotional support and encouragement to each other (i.e. changing instructor affective state):

And probably with [peer] and [other peer] maybe I am a little more like, "Well, the first time you teach a class its tough, the second time is a little better, but I don't feel like I've got it down until the 4th or 5th time." I've probably said things like that to them. Because they are younger, and they are newer.
-Bran

Yeah. And so I feel like 80% of what I do is encouraging other people. I don't know. I guess I try to put some advice in there, but like I don't know.
-Daenerys

Some instructors recalled a statement or piece of advice that was particularly impactful to them, and may have stuck with them for years:

But I mean, I remember a colleague of mine in [former place] saying, well you know we're not training scientists but we're training people that have proven that they can find information and that they have a certain level of education that helps them in their future jobs. But most of them become bankers and business people and what have you and I agree, it's true.
-Samwell

And [peer] said something to me a long time ago and I think there's some truth in that, he says, "It's not what you teach them, Stannis, it's how you make them feel" and I think that's - so whenever I'm lecturing I try to tell stories.
-Stannis

While seeking behavior is directly represented as an instructor behavior in our model, sharing behavior originates from a peer. Both seeking behavior and sharing behavior can result in information being transferred and thus lead to changes in knowledge and/or affective state, impacting future instructor decisions. We did find evidence of instructors adopting ideas they heard about from their peers and receiving tips and help from their peers that influenced their adoption, many of which are detailed in the quotes above, particularly in regard to seeking behavior. Another aspect of peer impact on instructor innovation decision is collaboration or adopting with or directly from peers teaching a similar class. We explore this in the next section.

Adopting together and adopting by class

In the department studied, despite the autonomy ideals, it was common practice for instructors to share materials and entire course plans with other instructors teaching the course. This happened regardless of an instructor's assessment experience or indication of perceived climate. Adopting by class emerged as an important form of interpersonal interaction that was influential particularly as a starting point for instructors just beginning to teach a particular course. Sometimes all the materials used in the class would be passed on to the next instructor to use and modify as they saw fit, while other times it was an ongoing process of sharing and collaboration among instructors who taught the class. Some examples of collaboration have already been given (see "High interaction, high adoption"). Following are some examples of adoption of particular ideas based on the practices of the previous or other current instructors:

> Of course, where the [course] is concerned, I interacted at the time with [peer] a lot. That was in a different situation…but it was certainly a team effort. I mean, actually it was [peer's] baby more than mine, so there I wasn't the king in the kingdom, [they were]. You know what I mean? [They were] the leader certainly setting that up.
> -Samwell

> I've done contract grading before in [class]. That's what people adopted for the course in the department before I got here. I don't have a problem with that.
> - Bran

> So now this year I went back to [clickers] largely because my colleagues who also teach other sections were really wanting to go back and we thought we should all be consistent, so I was kind of drug back into them, and I am using them now
> -Catelyn

> So especially with [peer], [that peer] and I have each created a drop box where we have made all our materials available to all the other [instructors] and umm, and so, that's been nice because I have gone into [the peer's] materials and found new activities and new problems to kind of spruce up some of the stuff that I've been using for a few years now and you know, I want to add some new stuff in and I think [the peer] has been using some of my stuff too and [other peers] also I know have been using some of my stuff too
> -Catelyn

> And for [peer] I've asked [them] what [they do] in [class], so I'll ask [them] and incorporate what [they have] incorporated, so if [they are] doing more [active learning] stuff, then I am, kind of. [That peer] has done the course before I did so I'm kind of doing that too.
> -Bran

Sometimes this passing on of materials and innovations constrained the way an instructor taught at first and led to them substantially modifying or rejecting the innovations, often over a period of time rather than right away. In this case, knowledge or materials from a peer provided a basis to implement an innovation but further reflection on classroom experiences in later iterations of the innovation decision cycle led to a different result.

> No, that has definitely changed over time. So - um. I started clickers in [class] because I was taking over for [peer] when [they] moved to [other class] and [that peer] always used clickers, and [they] gave me some of [their] lectures and [they] typically used right or wrong questions and placed them throughout [their] lecture to kind of assess how everyone was doing up to that point. And so I generally started that way, I would use clicker questions every few slides just to gauge the previous few slides.
> -Davos (Davos previously described how he now used clickers in a much more discussion-oriented way.)

> Yes. I think – with - we do work together. So when we first started - I guess, [peer] obviously was here first, and then I was hired, and then [other peer] was hired. And I guess usually those all happen three years apart. But when I came, [peer] generously gave me all [their] materials for the class. And so some of the things I do started off as stuff that [they] did, and then I modified it, and then the same thing with [the other peer], when [they] came I gave [them] all my materials, and [they] modified some of that, but then in the process of those conversations, [peer] and I occasionally talk about, wow, they have a lot of trouble with [topic]
> -Daenerys

> The [class] started off with - I was actually - there were - the previous professor gave me all these, you know, here's how to [topic], and here's how to [topic] and [the peer] had all of these props and I didn't really like it, and for one thing it wasn't playing to my strong suit, but for one thing it just seemed really rote, and I just so - I think the first - second year I taught it, I took them on a field trip and during the field trip I had them do a project, like in real time, like ok, pick a question, and I helped them, and then we came back and they talked about it. -Stannis

Rejection

Regardless of their overall viewpoint toward innovations and active learning, instructors sometimes rejected innovations. We did not uncover evidence of instructors explicitly mentioning being influenced by a peer to reject an innovation, but we did find evidence of ideas from peers being rejected both implicitly and explicitly. There were three primary ways that instructors described rejecting ideas that they had learned about from their peers: a) rejection without implementation, b) rejection after implementation, and c) delaying or forgoing a decision. First, instructors could reject an idea by simply deciding not to implement it. This could happen with or without extensive deliberations, but instructors usually presented reasons to justify their decision:

> And then I talk to them about, well, "what are you doing, how is that going" and always with a thought of, do I want to do that, does it seem valuable, and I - yeah, flipping the classroom is something that people talk about in this department, and I've decided I don't want to do that.
> Interviewer: OK. And it's mostly time?
> D: It's mostly time, because it is really time consuming. Also I think I am - I don't exactly know what the utility is – I mean, for the time input. The cost-benefit.
> -Daenerys

> You know, [prof from other dept in PD] does some things that I think are really great, but don't necessarily apply to the topics I would have been covering that semester, right, or that I just - my game plan was pretty much already set and it wouldn't have been feasible really to add certain things without making much larger scale changes
> -Davos

Along the same lines, some instructors in the low interaction/low adoption group tended to take a default negative view toward teaching innovations and expressed a blanket soft rejection of most active learning approaches:

> But I don't know unless somebody proves me wrong that say, if I would tweak the way I teach a bit within my subject matter in the context of the university that I would get such big differences that it makes a difference.
> -Samwell

> So, there is a completely different dynamic, so for example on the really coarse end I could say, you people doing [DBER], I think that's great, that's fantastic. But your research is not going to affect how I do my teaching, no more than how I would expect you to incorporate [my research subject] into your teaching.
> -Bran

Secondly, instructors could try an innovation and decide it didn't work for them and not to use it again (rejection after implementation). These decisions were based heavily on personal experience; we did not find evidence of instructors seeking out peers or other resources for help reflecting on or troubleshooting their experience before these rejections (though that should not imply it never happens).

> I got the idea from [peer], where students on a card are supposed to write down one thing in class that was clear to them and one thing in class that wasn't clear to them. I found it useful, but it became somewhat hard to keep up on, especially - so, in [class] this year there weren't a whole lot of students, but when there are 30 or 50 students, I actually had a tough time reading through all of them, thinking about what feedback I was getting, and it just became a bit hard to stay on top of it in an effective way along with other things that I have on my plate.
> -Jaimie

> So I didn't do it next time I taught it. I dropped it. And I realized, the way [peer] did it, it may have worked for [them].
> -Stannis

Finally, there were some instances where instructors reported still being in the process of deciding. For now, they had rejected the innovation in that they were not actively using it, but they may decide to use it in the future with the right resources. An example is Joffrey, who was intrigued by the idea of using case studies:

> So actually there's some people at [another school] who have done some of that, and I've talked to some of the professors over there about using some of that approach to classes maybe where you don't have a lab but you can almost build one in to a classroom sort of setting with a case study. I haven't really tried going down that route because it seems pretty involved, but I've thought about it.
> -Joffrey

Joffrey went on to indicate that he would be more likely to try case studies if he knew of people he could talk to in the department who used them in his particular content area.

Discussion

These results provide some insight into how departmental teaching and social norms (Research Question 1) and peer interactions (Research Question 2) impact instructors' innovation decision processes and outcomes. Although there was general agreement about the presence of an "innovation-positive" teaching norm within the department (e.g. value of teaching, encouragement of active learning), this norm was experienced in different ways. These differences were associated with differential effects on affective states, reported innovation adoption, and attitudes about teaching innovations and active learning. These data suggest that the different affective states influenced by teaching and social norms may lead to different innovation decision outcomes. Furthermore, individual peer interactions impacted instructor knowledge and affective state in several ways categorized in this paper. Below, we elaborate on how our results relate to each of the research questions, with reference to the model (Figure 4-1) as an organizing framework. When possible, we offer alternative interpretations and suggestions for future work.

Research Question 1: In what ways do perceptions of departmental teaching and social norms affect the process of innovation decision in a department known to be innovation-positive?

Even though norms were experienced differently by different instructors, it is important to note that the prevailing departmental climate and norms likely contributed to the majority of instructors feeling positive about active learning. Additionally, instructors' attitudes themselves likely also created these prevailing norms, and as instructors interact with their peers, these norms are communicated. The iterative process of norm creation is indicated in our model by the mutual influence between peer interactions and norms.

Another set of commonly cited norms in the department were those focused on collaborative behavior in teaching, including sharing of teaching materials and the idea of an "intellectual community of teaching". These norms are also intimately connected with peer interactions, particularly as they typically involve some kind of direct interaction with a peer. According to our model, departmental social norms can impact the patterns of peer interactions, thus having an impact on the extent to which and the ways in which information is received from peers. The norm of collaboration and community is an example that illustrates that connection. Conversely, again, frequent experiences of collaboration, communication, and sharing of materials with peers can make an instructor feel that the departmental norms are friendly to this kind of interaction.

Departmental norms also impact the affective state of instructors, influencing the extent to which they are likely to exhibit seeking behavior and how they pay attention to the information they receive (Lund & Stains, 2015; Quardokus & Henderson, 2015; Sturtevant & Wheeler, 2019). Our interview data may support this, as they do show an association between the perception of and participation in an interactive, collaborative climate and the adoption of, and a positive attitude toward, teaching innovations. The connection between departmental norm perceptions and participation in different steps of the innovation decision process should be further explored in multiple departments.

Different perceptions of the prevailing norms were associated with differential adoption of teaching innovations

The teaching norms, and to some extent the social norms, within the department studied were perceived similarly. All participants viewed the departmental norms as generally favoring innovative teaching and active learning. Yet, while some instructors experienced those norms positively, there were others who held negative news about active learning and felt as if they were being judged for using more lecture-based approaches. This interpretation, particularly in combination with less frequent peer interaction, was associated with reported adoption of few or no active learning techniques. This indicates that the perception of judgement associated with teaching norms may have an innovation-negative impact on instructor affective state. Alternatively, instructors' decisions not to adopt teaching innovations may not be predicated on the perception of judgement but rather lead to it. In either case, the perception of judgement is not likely to be conducive to adoption of new innovations (Rogers, 2003; Schein, 1965). These results indicate that simply encouraging norms of instructional innovation adoption or active learning is not enough to develop positive attitudes about innovation among all faculty, nor to ensure adoption. Departmental norms are multi-faceted and their impacts are complex.

For example, the role played by the norm of autonomy in teaching is an interesting one to explore further. Similarly to the norm of active learning, autonomy was an uncontested norm that interviewees perceived as being an integral part of the departmental culture. Further, while some did not seem to agree with the positive value placed on active learning even as they acknowledged the prevailing norms, *all* who mentioned teaching autonomy as a norm described it in positive terms. Yet, it was explained in very different ways in relation to their innovation decisions. Some described autonomy as positive but not necessarily connected to their use or non-use of active learning, while others used it in support of their use of active learning and still others used it to explain why they weren't using active learning. This may indicate that the departmental norms were seen as hierarchical by some participants, with teaching autonomy taking precedence over encouragement of active learning and then being harnessed as a justification for either using or not using active learning techniques. Additionally, we can consider the interaction of the teaching autonomy norm with the norms of collaboration. It is interesting that some instructors interpreted the autonomy ideal in a way that meant they preferred not to interact, instead trying to figure out teaching problems by themselves or even seeking help preferentially from those outside the department rather than within. Meanwhile, others reconciled the autonomy ideal with a very collaborative viewpoint and frequent interaction with their peers, even to the point of making teaching decisions together with those peers, while still indicating that they felt they had teaching autonomy, and that it was important to them. These differing views on the meaning of teaching autonomy within the department may be due to differing experiences with the history of the culture within the department (with autonomy having been a departmental norm for a longer time than active learning, for example), individual instructor characteristics or priorities, microclimates, or some combination. These factors should be explored further in future studies that investigate specific aspects of departmental climate and norms.

Research Question 2: Beyond sharing and communicating teaching and social norms, in what ways do individual peer interactions affect the process of innovation decision?

We have described some of the ways instructors indicated being influenced by particular interactions with specific peers in situations where they sought help for a particular problem and shared ideas and experiences. These influences impacted both the "Knowledge" and "Affective State" portions of the model. Instructors received awareness of particular innovations as well as knowledge about how to implement them. They also received support (including potentially changes in both knowledge and affective state) when they shared frustrations or sought consultation on an idea they already had. Some of these changes in knowledge and affective state led to instructors making decisions to adopt innovations and/or seek out more information about them. Additionally, the sharing of class plans and materials among current instructors, and from previous to future instructors, appeared to lead to implementation among even relatively innovation-averse instructors. We found no evidence of peer interaction directly influencing an instructor to reject an innovation (although we cannot say that never happens), providing a hint that peer interactions in general may have a net positive impact.

Many peer interactions were described as a decision to seek out information from peers, which aligns with the Seeking step in our model and also reiterates the important role of departmental norms encouraging such behavior in facilitating information flow between instructors. It should also be noted that engaging in or witnessing frequent collaborative interactions plays a role in encouraging the perception of norms as collaborative and favorable to seeking behavior, since peer interactions are one of the conduits for disseminating teaching and social norms. In this way, departmental norms and peer interactions can be mutually reinforcing, especially in a department with frequent interaction.

Peer interactions have a net positive effect on adoption of teaching innovations

Our previous work in this department (McConnell et al., 2019) showed that number of teaching-related peer interactions was correlated with the level of assessment experience. In this paper, the correlation held up and was explored qualitatively. Instructors who perceived that the departmental norms favored interaction and collaboration in teaching reported having positive attitudes toward active learning and teaching innovation and trying more innovations in their classrooms. These were also the participants who tended to report frequent interactions about teaching, in interviews as well as the surveys (McConnell et al., 2019). The association between interaction and adoption relates well to similar findings in literature about teaching interaction at the college level (Andrews et al., 2016; Middleton et al., 2015; Quardokus Fisher et al., 2019; Van Waes et al., 2015).

By contrast, instructors who perceived a solitary teaching environment and reported little teaching interaction often were comparatively more resistant toward active learning and teaching innovation. They more frequently indicated that they were not interested in implementing active learning and reported using mostly lecture-based approaches. This was especially true for those instructors who reported both that they had few interactions and that the innovation-positive norms of the department led to a feeling of judgement or defensiveness about not doing active learning (Table 4-1). Instructors who experience departmental teaching norms negatively may also avoid interactions about teaching, particularly with those from they may perceive judgement of their techniques. The evidence suggests that interaction about teaching may be generally innovation-positive in outcome but that individual perceptions of climate (built in part by the interactions that do happen) and instructor attitudes still have a large impact on the roles interactions play and their results. Further exploration of these inter-relationships in additional departments is encouraged.

Implications

This research suggests several considerations for departments and change agents who wish to encourage adoption of teaching innovations such as active learning. First, while a positive, teaching-friendly and innovation-friendly environment is important, our results indicate that norms encouraging innovation adoption are not a guarantee of innovation-friendly attitudes among department members. The possibility should be considered that innovation-friendly norms will be perceived by a subset of instructors as judgmental and they may grow resentful. In addition, peer leaders and others within the department may be unaware of this resentment due to the existence of microclimates within the department. A strong climate of teaching autonomy may help to buffer defensiveness and frustration about active learning advocacy (Walter et al., 2016), but it may also be harnessed as an excuse for not adopting active learning techniques, as our data show.

Yet, even some participants who reported that frustration about active learning advocacy also reported interacting with other instructors and trying many new ideas in their teaching (particularly in the case of Jaimie). A second lesson to take away from this study is the complexity inherent in instructor decision-making. Multiple aspects and interpretations of departmental climate and norms emerged in our interviews and were associated with different attitudes and outcomes about innovation, depending on interaction with other norms, interaction with peers, and aspects of instructor personality. Another example is the perception of the teaching autonomy norm as either an innovation-positive or innovation-negative force, depending at least in part on whether the interviewee perceived norms facilitating a collaborative, interactive environment in regard to teaching. Change agents should be aware of this complexity, approaching and monitoring any changes in departmental climate and norms from multiple angles, and being aware of possible unforeseen impacts. For example, one might assume that providing professional development to a few well chosen "hubs" of information and expecting them to spread that information is a solid strategy. Yet, this strategy could both fail to work and result in the building of resentment if it is attempted in a department that has a strong ethic of autonomy in teaching but no established practice of interacting about teaching.

Departments and change agents should be aware that peer interaction appears to be a powerful influence for instructors to both try and continue using innovations. In general, multiple lines of evidence suggest that interaction may lead to adoption (McConnell et al., in prep; McConnell et al., 2019; Rogers, 2003; Tomkin et al., 2019). In this study, interviewees who reported adopting and using active learning innovations also frequently talked about the importance of a collaborative environment with norms encouraging the mutual sharing of ideas and support. Meanwhile, most interviewees who reported little interaction about teaching also reported adopting few innovations and did not have an overall favorable opinion of active learning. Frequent interaction may be fostered in the context of a supportive departmental climate that incorporates, as one interviewee noted, an "intellectual community around teaching", and this may lead to increased innovation adoption among at least some faculty. In particular, departments could find ways to support and encourage "seeking" behavior among peers when instructors have a question, problem, or frustration with their teaching. This behavior was prevalent in our interviews among those who perceived norms of collaborative teaching interactions, and it was associated with finding out about and trying new innovations.

Finally, one simple way that innovation adoption may be encouraged is through “passing the torch”, or sharing of materials between instructors who teach the same course either concurrently or successively. At least in the department we studied, this was common practice, even among those who did not perceive collaborative norms and without a consistently positive view of teaching innovations or active learning. Perhaps targeting one individual in a class rotation with professional development and/or encouraging this sort of interaction when rotating classes could help spread certain innovations to a broader set of faculty and potentially overcome resistance among them. Yet, care should also be taken to ensure faculty have the support and information they need to implement the innovations in a way that benefits student learning (Offerdahl et al., 2018; Stains & Vickrey, 2017).

Limitations

A strength of this interview study is that it was conducted among instructors within a single department who interacted with each other, and who were also subjects of a related study that provides further context to the results (McConnell et al., 2019). This allowed an in-depth exploration of the different perceptions and experiences that existed of the same departmental norms. Yet, this context is also the biggest limitation of the study, since all information was collected within a single department. Caution should be used when applying these results to departments in different disciplines and universities, with different teaching and social norms, and with a different mix of instructors (Lund & Stains, 2015). The conclusions would be strengthened by replicating or extending the results in other contexts. A second limitation is that all information used in this study came from instructors’ self-reported perceptions of their department’s climate and norms, their peers, themselves, and their teaching. Classroom teaching and interactions were not observed to confirm their self-reports. However, we did not notice any discrepancies between instructors' self-reported information and our informal knowledge of their teaching or interactions within the department. Although the interviews took place over a period of time, almost all instructors were only interviewed once. Thus, the results do not reflect the evolution of thinking over time that would be revealed by multiple interviews. Doing a similar study with faculty interviews at multiple time points, perhaps over the time period of a directed change initiative that aimed to alter departmental norms, would be illuminating. Finally, the study was completed by DBER-affiliated individuals within the department studied, which may have introduced bias. In Methodology, we described some ways we tried to overcome this potential bias.

Concluding remarks

The aim of this study was to understand the effects departmental teaching and social norms and peer interactions have on college STEM instructors' innovation decision processes. To that end, we used a model of instructor innovation decision (McConnell et al., in prep) to explore through interviews the perceptions, reported interactions, and innovation decision experiences of eleven instructors within the same department. We found that they agreed on certain departmental norms (positive toward teaching innovation and supportive of teaching autonomy) but that they experienced those aspects in different ways. Some perceived an interactive, collaborative environment which gave them the freedom to try new things and offered ongoing support to use active learning practices. Meanwhile, others were somewhat frustrated with the prevalence of active learning advocacy in the department. They tended to perceive the departmental teaching autonomy norm in a much more solitary and innovation-negative way.

Those instructors who perceived collaborative norms talked about experiencing ongoing support and a robust exchange of ideas. Seeking ideas and information about innovations from peers was common for most instructors in the department, particularly those who perceived a more collaborative, interactive environment. Adopting innovations directly from others who were teaching or had taught the same class was common even among those who perceived a solitary environment and expressed negative views about active learning generally. Combined with evidence from related studies (Dancy et al., 2016; McConnell et al., 2019; Tomkin et al., 2019), it appears that, at least in departments with innovation-positive norms, peer interaction may foster adoption of teaching innovations. In addition to providing certain tangible supports for teaching and reinforcing norms of good teaching, this department may have impacted teaching behavior within the department by creating an "intellectual community" that encouraged interactions about teaching. However, microclimates and individual instructor attitudes and perceptions seem to have played a large part in mitigating outcomes in terms of innovation adoption.

CHAPTER 5: BUILD IT AND THEY WILL COME? AN INVESTIGATION OF FORMATIVE ASSESSMENT AND FEEDBACK IN AN UNDERGRADUATE BIOLOGY SCALE-UP CLASSROOM

Abstract

Formative assessment and frequent feedback have been identified as important components of active learning in undergraduate STEM education, yet the degree to which they are implemented in classrooms is variable. Many possible barriers to instructor adoption of active learning have been previously described, including large class sizes. Although active learning can be implemented with any class size, instructors in large classes often face challenges implementing formative assessment and feedback practices effectively in a way that benefits the entire class. One classroom innovation that aims to address this challenge is SCALE-UP (Student-Centered Active Learning Environment with Upside-down Pedagogies), which is intended to increase student-student and student-instructor interaction, facilitating active learning. This study is a characterization of in-class assessment practices in an assessment-rich biology class which also explores the classroom aspect. We observed classes in two scenarios: one in which instruction took place in a large lecture hall and then transitioned to a SCALE-UP setting, and one in which instruction was already established within a SCALE-UP setting. We found that transition to the SCALE-UP classroom coincided with the instructor giving more assessment prompts and spending more time following up on prompts and moving through groups interacting with students. We also found substantial variability day to day in both semesters, and identified aspects of formative assessment and feedback that were consistently implemented infrequently. This study adds to the literature on in-class assessment in an

undergraduate STEM setting and provides evidence that SCALE-UP classrooms may facilitate certain assessment and feedback practices.

Introduction

Recently, much attention has been paid to the goal of improving instruction in undergraduate science, technology, engineering, and mathematics (STEM) courses generally and biology in particular (AAAS, 2015; Committee on STEM Education of the National Science & Technology Council, 2018; Stains et al., 2018). Calls to action and national reform initiatives recommend a widespread shift to a student-centered instructional approach of "active learning" (Bradforth et al., 2015; Committee on STEM Education of the National Science & Technology Council, 2018; Freeman et al., 2014; Rosenberg et al., 2018). Further, formative assessment and frequent feedback are emphasized as important components and drivers of active learning (Committee on STEM Education of the National Science & Technology Council, 2018; Offerdahl et al., 2018; Rosenberg et al., 2018). Formative assessment contributes to student learning by helping both students and instructors diagnose in-progress learning and adjust behaviors to meet learning objectives (Bell & Cowie, 2001; Nicol & Macfarlane-Dick, 2006; Offerdahl et al., 2018).

Despite the emphasis on increasing adoption of active learning and formative assessment, the extent to which instruction is rising to that challenge is variable and limited. Evidence indicates that didactic lecture practices are still very common in undergraduate classrooms, and formative assessment and feedback practices are still fairly limited (Eagan et al., 2014; Stains et al., 2018; Wu & Jessop, 2018). Additionally, in order to implement formative assessment techniques in a way that benefits student learning, instructors must know and incorporate beneficial adaptations of critical components. These critical components include learning objectives, prompts that are able to reveal student understanding, and actionable feedback (Offerdahl et al., 2018; Stains & Vickrey, 2017). Variation in use of critical components, and in outcomes of formative assessment, can be due to differences in instructor knowledge and skills, different kinds of formative assessments, and different classroom environments (Andrews et al., 2011; Henderson et al., 2011). Some of that variation may have substantial impacts on student learning.

Many factors may impact the extent to which instructors implement active learning and formative assessment in their classrooms and the ways in which they do so. These factors may include such things as departmental climate, instructor motivation and satisfaction, perceptions of student attitudes and capabilities, and time pressures as well as classroom environment (Ajzen, 1991; Andrews & Lemons, 2015; Lund & Stains, 2015; Sturtevant & Wheeler, 2019). Large classrooms with fixed seating ("lecture halls") in particular are often conceptualized as a barrier to active learning (Allen & Tanner, 2005; Landrum et al., 2017; Shadle et al., 2017). Although effective formative assessment and feedback can happen in classrooms of any size, large classes pose unique challenges for instructors to solicit meaningful evidence of student understanding and provide actionable feedback for students (Allen & Tanner, 2005; Wilton et al., 2019). This barrier is being addressed at many universities by incorporating classrooms with flexible seating designed for active learning, such as SCALE-UP (Student-Centered Active Learning Environment with Upside-down Pedagogies) classrooms (Beichner, 2008). SCALE-UP classrooms are a type of flexible seating classroom that aims to increase student-student and student-instructor interaction in larger classes, facilitating student groupwork and active learning (Beichner, 2008; Hacisalihoglu et al., 2018). A SCALE-UP setting may help make it easier for both instructors and students to engage in behaviors that promote learning (Felege & Ralph, 2019; Hacisalihoglu et al., 2018; Kranzfelder et al., 2019). Yet, Stains and colleagues (2018) found that about half of class periods that took place in a classroom with flexible seating were still didactic in nature, indicating that instructors do not always take advantage of the space.

Considering the variable extent to which active learning and formative assessment are being adopted in college classrooms (Eagan et al., 2014; Stains et al., 2018), the importance of formative assessment and feedback for student learning (AAAS, 2015; Offerdahl et al., 2018; Rosenberg et al., 2018), and the potential promise of SCALE-UP classrooms for facilitating active learning and formative assessment (Felege & Ralph, 2019; Hacisalihoglu et al., 2018), we sought to characterize formative assessment and feedback practices in an assessment-rich introductory biology setting. The classes we studied were taught by instructors who were informed and committed to active learning and formative assessment and received departmental and collaborative peer support to use them in introductory biology. This theoretically makes them well positioned to make use of beneficial adaptations of formative assessment and feedback, and their classrooms were considered assessment-rich. Three semesters of instruction in this study occurred in a SCALE-UP classroom while one occurred in a lecture hall, allowing us to investigate the results of change in classroom environment on the implementation of formative assessment and feedback within those biology classes. Observations were undertaken in order to address the following research questions:

Research Question 1: To what extent and how do formative assessment and feedback practices vary in the assessment-rich introductory biology classrooms?

Research Question 2: To what extent and how did formative assessment and feedback practices change when instructional setting changed from a fixed-seating lecture hall to a SCALE-UP classroom?

Research Question 3: To what extent and how did formative assessment and feedback practices change semester to semester when instruction was already established in a SCALE-UP classroom?

Background

Formative assessment is a complex but powerful tool for improving student learning

Formative assessment is an integral and impactful part of active learning which gives students an opportunity to work actively with the course material and provides opportunities for feedback from the instructor or instructional team. Together, this allows students to gauge where they are in relation to learning objectives and discern strategies for how to reach them (Hattie & Timperley, 2007; Nicol & Macfarlane-Dick, 2006). While summative assessments, such as exams, function primarily to evaluate how well a student has accomplished learning objectives and assign a grade, formative assessment is an integral part of the learning process (Bell & Cowie, 2001; Offerdahl et al., 2018). Formative assessment can include a variety of activities with the possibility to beneficially impact student learning, including clicker questions, in-class worksheets or groupwork, and "muddiest point" activities.

Formative assessments can be designed and implemented in a variety of ways. This is a benefit for instructors, as they can implement the types of formative assessments that work well for them and their students. It also allows for the use of a variety of assessments and feedback to maintain interest and collect and respond to different forms of student understanding according to the content and stage of instruction (Carless, 2019). However, instructors must also understand why formative assessment is important for student learning and incorporate the key ingredients for success into their assessment practices (Offerdahl et al., 2018). Variation in critical components may have important effects on student learning (Andrews et al., 2011; Dancy &

Henderson, 2010). Instructors may make modifications to techniques that reduce student interaction and participation, which is likely critical to their effectiveness (Dancy & Henderson, 2010). Without incorporating certain elements, formative assessment may be ineffective or even harmful.

Formative assessment can only impact the learning of all students if all students interact with and think about the material. Using prompts that elicit ideas from each student allows all conceptions to be brought to the attention of the instructor and not just those of the most outspoken or least shy individuals (Offerdahl & Montplaisir, 2014). The evidence collected by formative assessment prompts is also of varying detail and thus utility for feedback (Esterhazy & Damsa, 2019), ranging from a single word called out by a single student to worksheets, diagrams drawn on whiteboards by groups, and clicker response distributions. For these reasons, call-and-response style verbal prompts may not be as effective as a prompt where all students can give an answer (Nicol, 2010; Offerdahl & Montplaisir, 2014). Furthermore, prompts vary in the level of student thinking required to construct a response, which can be measured with Bloom's level (Crowe et al., 2008). Simple recall of facts (Knowledge) requires less student interaction with the material and provides less rich feedback opportunities than higher-order prompts which request students to create and evaluate complex solutions to problems (Crowe et al., 2008).

Once an instructor solicits evidence of student learning, what is done with that evidence matters. Many of the potential benefits of formative assessment are predicated on a robust dialogue between instructor and student, creating an iterative feedback loop (Nicol, 2010; Offerdahl et al., 2018). Both instructor and students obtain information in relation to learning goals. Effective formative assessment diagnoses how close students are to the learning objectives and provides the opportunity to give feedback that will show the students how to get closer to those objectives (Hattie & Timperley, 2007; Nicol & Macfarlane-Dick, 2006). Optimal feedback also facilitates student reflection and metacognition regarding the gap between current performance and objectives, and how that gap can be bridged (Evans, 2013; Hattie & Timperley, 2007; Offerdahl et al., 2018). Feedback which simply transmits evaluative information regarding the correctness of an answer may constrain students more than it helps them (Hattie & Timperley, 2007). Students should be given an opportunity to actively work to revise their thinking, regulate their own learning, and move closer to the learning goals (Boud & Molloy, 2013; Carless, 2019; Metcalfe, 2017). Ultimately, with appropriate feedback, guidance, and continued questioning, students will be expected to develop the metacognition to self-assess their understanding of the content and their own work (Carless, 2019; Tai et al., 2018). However, in order for this to happen, students have to be willing and able to understand, accept, and use the feedback they receive (Price et al., 2010; Wiltbank et al., 2019; Winstone et al., 2017; Zimbardi et al., 2017).

SCALE-UP classrooms may facilitate some forms of assessment

Although large class sizes by no means preclude using evidence-based assessment practices, they do pose some unique challenges. An increasingly popular classroom format, SCALE-UP, offers one possible solution to the problem of how to increase course structure and encourage active learning and student interaction in a large-enrollment course (Beichner, 2008; Brooker et al., 2013; Wilton et al., 2019). SCALE-UP classrooms are set up to encourage collaboration, seating students around circular tables in groups rather than in rows (Beichner, 2008). Although "SCALE-UP" originally referred to a method that encouraged problem-based learning and collaboration in addition to the space, the term is often used to simply describe a classroom, and implementation of teaching techniques can vary within the space. However, a

SCALE-UP is set up to facilitate active learning, student collaboration, and many kinds of formative assessment and feedback (Brooker et al., 2013; Hacisalihoglu et al., 2018). Students sit around tables of nine, allowing them to collaborate in small groups of 2-3 as well as larger groups of 9. They can also make their thinking visible easily by solving problems or making models on the whiteboards or displayed on the monitors. Instructors can move through the room more easily than a lecture hall and can interact with all groups. Evidence suggests that instructors in a SCALE-UP classroom use more guiding than lecturing behaviors (Kranzfelder et al., 2019) and that students in SCALE-UP classrooms learn better and prefer it to more traditional classrooms (Beichner, 2008; Felege & Ralph, 2019; Hacisalihoglu et al., 2018). A diagram of the SCALE-UP classroom in this study is provided in the Methodology section.

Methodology

Study context

Although recent calls to action have resulted in increased professional development initiatives and efforts toward encouraging more university STEM instructors to adopt active learning and formative assessment techniques (AAAS, 2015; Committee on STEM Education of the National Science & Technology Council, 2018), many classrooms still do not include these elements. Identifying and overcoming barriers that impact the use of active learning, including assessment practices, in university STEM classrooms is an active area of research (Andrews & Lemons, 2015; Dancy et al., 2016; Dancy & Henderson, 2010; Grunspan et al., 2018; Lund & Stains, 2015), as is the identification of supports or drivers for change (Bathgate et al., 2019; Shadle et al., 2017). Instructors need to have the knowledge necessary to implement formative assessment techniques, but also must prioritize them, dedicating the resources necessary to commit to teaching in that way (Andrews & Lemons, 2015; Dancy et al., 2016). Furthermore, they must have supportive peers and a departmental climate that allows or encourages such teaching (Grunspan et al., 2018; Lund & Stains, 2015; Tomkin et al., 2019; Wieman et al., 2013).

The courses observed for this study were part of the introductory biology majors' sequence at a doctoral-granting research-intensive land grant university in the upper Midwest. They were taught by a core group of four instructors who had the knowledge, commitment, and support to use active learning and formative assessment practices and in fact were working together to develop an assessment-rich environment. Classroom observation data from two of the instructors are used in this study, one for each scenario. All four of the core instructors had extensive training in pedagogy and formative assessment, were committed to teaching in a student-centered instructional style, and were familiar with active learning, backwards design, and formative assessment. The introductory biology sequence had been taught in an assessment-rich manner for years and although each instructor taught independently, they frequently collaborated, shared materials, and designed instruction together for course objectives agreed upon by all. Thus, instructors had ongoing support from peers in a community of practice of other knowledgeable instructors. They also enjoyed the benefit of a supportive department that valued teaching and teaching innovation. Instructors were encouraged to refine their practice and attend professional development opportunities, and funding was available to do so. This made for a favorable environment for implementing different types of formative assessment and refining them as needed.

The courses were large-enrollment (100+ students per section) and served a variety of majors, primarily biology, pre-health, pre-pharmacy, and agriculture. Most students were first- or second-year students, although juniors and seniors also were enrolled in the courses. Undergraduate learning assistants (Otero et al., 2010) were employed in each section to increase instructional interaction with groups. Introductory biology classes were traditionally taught in a large lecture hall (300+ seats) with rows of seats facing the instructor station and slide viewing in the front of the classroom only. One semester of instruction reported here took place in that environment (see Table 5-1). The other three semesters of instruction took place in a newly-introduced SCALE-UP classroom which seated 135 organized around 15 round tables that seated nine students each (Figure 5-1). Each table was equipped with connections to an individual monitor, and whiteboards were available continuously on all walls of the room. Six large screens as well as the individual monitors were situated around the perimeter of the room, with the instructor station near the middle (Figure 5-1).

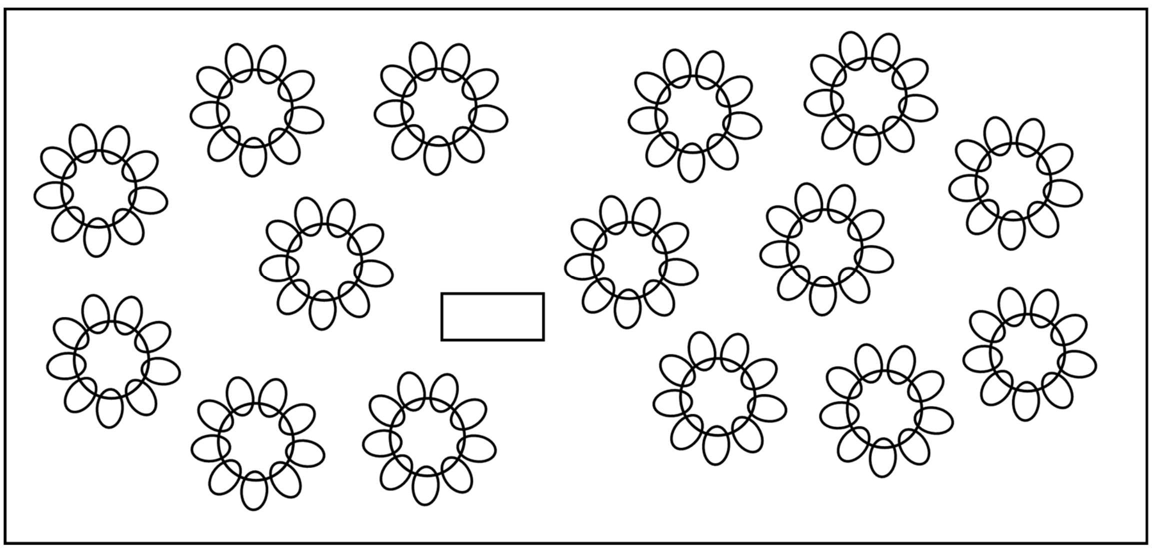

Figure 5-1. Layout of the SCALE-UP classroom instructors used in this study. Each table seats nine students, screens and whiteboards are positioned around the edges of the room, and the rectangle near the middle of the room represents the instructor station

This study is reported as two scenarios representing snapshots of the instruction in these introductory biology classes over time to demonstrate the impact of an active learning classroom on instruction. Each scenario consists of two semesters in which the instructor was consistent within scenarios. In scenario 1, the instructor moved from a 300+ student auditorium to the SCALE-UP room, while in scenario 2, instruction was in the SCALE-UP room in both semesters

(Table 5-1). We present these two scenarios with the understanding that formative assessment can and does take place in a variety of classroom settings. However, we also predict that university investment into specially designed active learning classrooms may have the potential to accelerate adoption or increase the use of certain forms of active learning techniques, including formative assessment and associated feedback. Table 5-1 presents the data streams and instructional context for each scenario.

Table 5-1. Structure of scenarios and data collection

	Scenario 1		**Scenario 2**	
	Semester 1	**Semester 2**	**Semester 1**	**Semester 2**
Instructional setting	Lecture hall	SCALE-UP	SCALE-UP	SCALE-UP
Course taught	BIOL 150	BIOL 150	BIOL 150	BIOL 151
Observations	6	14	13	12

Observations

During observational semesters, class sessions were 75 minutes long and were observed and video-recorded (with the camera focused on the instructor station) at least six times per semester. Observation days were chosen to be as evenly spaced as possible throughout the semester and to avoid exam days. Instructors gave consent for observations to happen at any point during the semester and did not know ahead of time which days they would be observed.

Transcripts were generated from the video-recorded observations. The transcripts included all recorded utterances of the instructor and students that were directed or audible to the entire class. These transcripts were used for coding formative assessment prompts and responses (see below), with reference to the video when needed to clear up any ambiguity in the transcript. More details are provided in the following sections regarding the information collected from each observation.

COPUS

A trained observer used the Classroom Observation Protocol for Undergraduate STEM (COPUS; Smith et al., 2013) to document student and instructor overt behaviors that occurred during each class observation. COPUS is a widely used protocol developed for observing undergraduate STEM courses that is split into two-minute time intervals. During each interval, the observer indicates if a particular behavior is observed. The COPUS includes 13 codes for student behaviors and 12 codes for instructor behaviors (Smith et al., 2013). Stains and colleagues (2018) conducted a cluster analysis to sort classroom periods into "profiles" and provide an online tool to assist investigators in determining profiles within data sets. We used the online tool (COPUS analyzer; copusprofiles.org) to determine the groups of profiles our observed class periods fell within.

Due to our interest in assessment and feedback, we further analyzed a subset of COPUS codes that may include some aspect of assessment. For the student behavior codes, we chose to analyze: SQ (student asking a question), GW (a combination of all of the student group work codes; Lund & Stains, 2015), and AnQ-S (student answering a question). For the instructor behavior codes, we used: FUp (following up on some kind of assessment or question), PQ (instructor posing a question), CQ (instructor administering a clicker question), AnQ-I (instructor answering a question), and MG (instructor moving through groups of students working). After the observation, the percentage of time blocks within a class period during which each of our codes of interest occurred was calculated. Percentages were compared between semesters for each scenario using Mann-Whitney U tests in RStudio (R Core Team, 2017; RStudio Team, 2016) and administering Benjamini-Hochberg corrections for multiple tests (Benjamini & Hochberg, 1995). COPUS was administered for each observation day; the remaining analyses (prompts, responses and feedback) were done on a subset of four observation days in each semester, chosen to be equally spaced throughout the semester, without regard to COPUS results.

Formative assessment cycles

We used the ESRU coding scheme (Furtak et al., 2017; Ruiz-Primo & Furtak, 2006) in a modified format as a framework for describing and characterizing assessment prompts as well as the ways instructors responded to evidence of student thinking. ESRU (Elicit, Student, Response, Use) refers to the stages of an in-class assessment process: an instructor elicits some sort of evidence of student thinking (E), to which one or more students respond (S), and then the instructor recognizes (R) and potentially uses (U) that student information in some way. Two or more coders reached consensus on ESRU codes applied to observations.

Prompts: From the transcripts and videos, we identified as an assessment prompt (or elicit event) any opportunity an instructor provided for evidence of student thinking to be collected. Prompts were further categorized as verbal questions (VQ), clicker or other voting questions (CQ), and worksheets or written prompts (WP) using the modified ESRU coding scheme (Furtak et al., 2017; Ruiz-Primo & Furtak, 2006). Prompts were identified and analyzed even if they resulted in no student response. Two coders independently assigned a Bloom's level to all prompts that probed the cognitive domain. Questions like "Everybody with me?" or "any questions on that?" were considered outside the cognitive domain and therefore excluded. Three coders had an initial Fleiss' kappa of 0.882. All instances of disagreement were negotiated for consensus. We present prevalence of prompts, type, and cognitive level categorized as lower-order (Knowledge, Comprehension, and Application) and higher-order (Analysis, Synthesis, and Evaluation).

Instructional responses and feedback: Like Furtak and colleagues (2017), we combined the R and U stages into a single RU category which includes any related instructor behavior that followed the student question or response. These behaviors include: displaying, drawing attention to, verbally repeating, or paraphrasing student work (R); praising or providing encouragement (PR); displaying a distribution of student responses, such as to a clicker question (DD); verbally describing a distribution of student responses or themes within the student responses (V); asking students to explore or elaborate on ideas, e.g. “Why do you think that?” (EXP); providing an evaluation of the correctness of the student response (EV); clarifying or providing further information (C); comparing and contrasting student ideas (CC); shaping student behavior such as study skills (SH); and connecting the current evidence of student thinking to a future high stakes assessment (CA). It should be noted that the EXP code also signifies a new prompt, since the student(s) are being asked to provide further evidence of thinking. Instances of the EXP code, then, are also simultaneously coded E.

Although the ESRU cycle traditionally begins with an elicit event, we considered that student questions also provide an instructor with insight into student thinking and an opportunity to recognize it and give feedback. Therefore, all student responses to a prompt, as well as student questions, were categorized under the “S” stage of the ESRU, and anything that happened after and related to an “S” stage was considered “RU” and characterized for instructional response and feedback. Since this study focuses on instructor behavior, we did not further analyze student thinking or responses.

Table 5-2. Modified ESRU coding scheme to characterize instructional prompts and responses to student input. Codes in the RU stage are further categorized as to whether they represent feedback and whether they are a focus of this study

Stage of ESRU process	Code	Description	Represents feedback?	Relevant in current study?
Elicit/ Prompt	CQ	Clicker or voting question		
	WP	Worksheet or other written prompt (may be displayed on screen)		
	VQ	Verbal question		
Student	S	Student response to a prompt		
	SQ	Unprompted student question		
	PSQ	Prompted student question: occurs after a "checking-in" prompt by the instructor (e.g. "Any questions?")		
Response/ Use	R	Verbally repeating, paraphrasing, displaying, or drawing attention to student input		Yes
	PR	Praising or providing encouragement	Yes	Yes
	DD	Displaying a distribution of student responses	Yes	
	V	Verbally describing a distribution of student responses or themes within student responses	Yes	
	EXP	Prompting students to explore or elaborate on ideas (also coded as a new prompt)		Yes
	EV	Providing an evaluation of the correctness of the student response	Yes	Yes
	C	Clarifying or providing further information	Yes	Yes
	CC	Comparing and contrasting student ideas		
	SH	Shaping student behavior such as study skills	Yes	
	CA	Connecting the current evidence of student thinking to a future high stakes assessment		

A subset of the instructor RU codes was categorized as feedback, which we define as: "information communicated to the learner following evidence of student understanding (i.e. student response, student question) that is intended to reinforce or modify their thinking or behavior for the purpose of improving learning". The codes designated as constituting feedback are PR, DD, V, EV, C, and SH (Table 5-2). Additionally, the RU codes that are relevant in a particular classroom can vary. In our study, we will focus on EXP (due to its utility in soliciting additional, and potentially deeper, student thinking), and the feedback codes PR, EV, and C (due to our interest in feedback). We will also include the simple recognition code R, to provide further context and because of its frequency. The other feedback codes (DD, V, and SH) occurred at similar and low frequencies in all semesters and were thus excluded from analysis. We compared our codes of interest by the frequency with which they occurred in conjunction with evidence of student thinking, using Mann-Whitney U tests in RStudio (R Core Team, 2017; RStudio Team, 2016) with Benjamini-Hochberg corrections (Benjamini & Hochberg, 1995).

Results

COPUS profiles

Class periods observed in this study fell into all seven clusters when categorized with the COPUS analyzer (Stains et al., 2018; www.copusprofiles.org). The six observations in the lecture hall were evenly split between didactic (clusters 1 and 2; 2 class days), interactive lecture (clusters 3 and 4; 2 class days), and student-centered (clusters 5-7; 2 class days). Meanwhile, the classes taught in the SCALE-UP room were skewed more heavily toward student-centered clusters, with 22 observations being classified as student-centered and 10 as interactive lecture. Didactic instruction was still present in the SCALE-UP setting, with 7 class periods being classified as such.

Scenario 1: moving instruction to a SCALE-UP setting

Scenario 1 includes one semester in which instruction occurred in a lecture hall (Semester 1) and one taught for the first time in the SCALE-UP classroom. The two semesters (both

General Biology I) were consistent in terms of instructor and student population, although Semester 1 had a larger class size due to the differences in environment. In Scenario 1, our goal was to see how instruction evolved when the environment changed to a SCALE-UP setting. Six class periods were observed in Semester 1 and fourteen in Semester 2. All class periods observed were analyzed with COPUS, and four per semester were chosen at approximately equally spaced intervals for the other analyses.

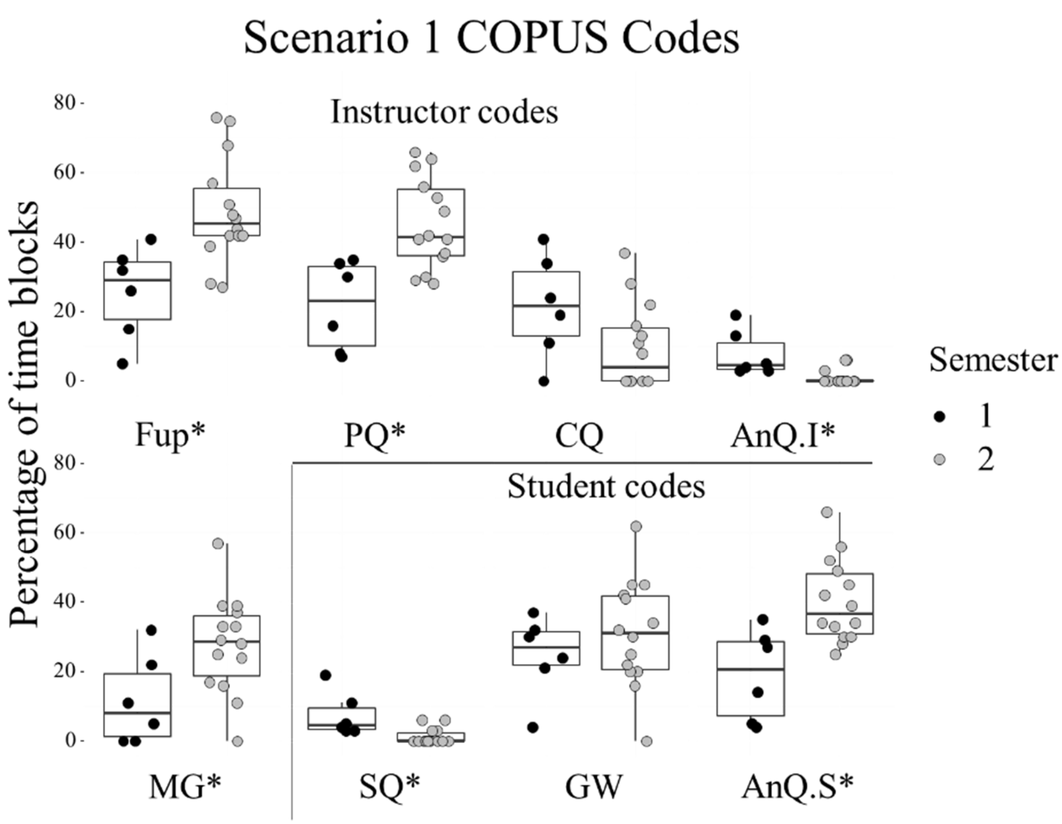

Figure 5-2. Percentage of time blocks in which COPUS codes of interest were applied in Semesters 1 and 2 of Scenario 1. *Significantly different between semesters at alpha = 0.05 using Mann-Whitney U test with Benjamini-Hochberg correction.

COPUS

COPUS analyses for Scenario 1 tended to show substantial variability in the proportions of codes applied from class period to class period within semesters (Figure 5-2). Several instructor behaviors potentially related to formative assessment increased from Semester 1 to

Semester 2 as a percentage of time periods (see Table 5-3). Questions posed by the instructor (PQ) were present in significantly more time blocks in Semester 2 (28-66%, median 42%) than in Semester 1 (7-35%, median 23%). Moving through groups (MG) increased from 0-32% of time blocks in Semester 1 (median 8%) to 0-57% of time blocks (median 29%) in Semester 2. Instructor follow-up behaviors (FUp) also increased between the two semesters. They were present in 5-41% of time blocks (median 29%) in Semester 1 and 27-75% of time blocks (median 46%) in Semester 2. Interestingly, time blocks in which the instructor answered questions decreased from Semester 1 (3-19%; median 5%) to Semester 2 (0-6%; median 0%). There was no significant change in the number of time blocks in which clicker questions were used (CQ).

Table 5-3. Median percentages of time blocks in which COPUS codes were observed in Semesters 1 and 2 of Scenario 1, and results of Mann-Whitney U tests comparing time block percentages between semesters.

	Median: Semester 1	**Median: Semester 2**	**W**	**p-value**	
Instructor codes					
FUp	29	46	7	0.0044	*
PQ	23	42	8.5	0.0065	*
CQ	22	4	62	0.0965	
AnQ-I	5	0	75	0.0033	*
MG	8	29	15.5	0.0316	*
Student codes					
SQ	5	0	74	0.0053	*
GW	27	31	33	0.4826	
AnQ-S	21	37	10	0.0093	*

*Statistically significant after Benjamini-Hochberg correction with a false discovery rate of 0.05

The students worked in groups for comparable amounts of time in both semesters, although there was a wider range of percentages in Semester 2. The GW code was present in 4-

37% of time blocks in Semester 1 (median 27%) and 0-62% of time blocks in Semester 2 (median 31%). Opportunities to respond to questions asked by the instructor (AnQ-S) increased from Semester 1 (4-35% of time blocks; median 21%) to Semester 2 (25-66% of time blocks; median 37%). Student questions (SQ), in tandem with the instructor answering questions, significantly dropped, being present in 3-19% of time blocks in Semester 1 (median 5%) and 0-6% of time blocks in Semester 2 (median 0%). The changes observed from semester to semester in Scenario 1 are summarized in Table 5-3 with indications of statistical significance that take into account multiple tests.

Assessment prompts

The total number of prompts increased dramatically between the two semesters in Scenario 1, with 4-41 prompts per class period in Semester 1 (median 23) and 50-96 prompts per class period in Semester 2 (median 74). Despite the small sample size, this difference was statistically significant (Mann-Whitney U test; $W=0$, $p=0.0286$). Prompt types remained more consistent and were predominantly verbal in both semesters (77% VQ in Semester 1 and 81% in Semester 2). Clicker questions (CQ) and worksheets or written prompts (WP) made up a smaller percentage of prompts. In Semester 1, 12% of prompts were clicker questions and 9% were written prompts or worksheets, while in Semester 2, 5% of prompts were clickers and 14% were written prompts or worksheets.

In both semesters of Scenario 1 prompts at lower Bloom's levels predominated, particularly Knowledge and Comprehension (Figure 5-3). Occasional prompts were given at the application and analysis levels. Synthesis prompts were seen only in Semester 2, and no Evaluation prompts were observed. Both lower order and higher order prompts increased in Semester 2 compared to Semester 1, and higher order prompts increased slightly as a percentage of total prompts (Figure 5-3). The median percentage of higher order prompts (Analysis, Synthesis, Evaluation) per class period was 0% in Semester 1 and 8% in Semester 2. In summary, student thinking was solicited at a range of cognitive levels in both semesters, skewed toward lower-level prompts. In Semester 2, a greater total number of prompts were given and different Bloom's levels were present more consistently. However, none of these increases reached statistical significance.

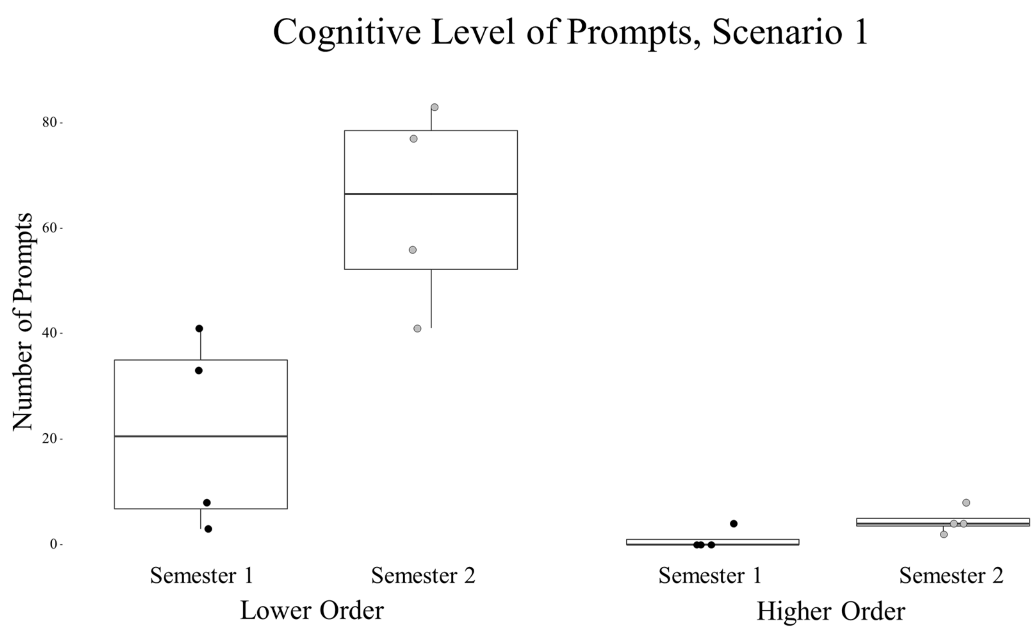

Figure 5-3. Cognitive level of prompts by Bloom's level (lower order vs. higher order) of prompts given in Semesters 1 and 2 of Scenario 1.

Instructional responses and feedback

The most common instructional responses to student thinking among our codes of interest in Scenario 1 included: repeating or paraphrasing a student response (R), evaluating the correctness of a response (EV), and providing clarifying information (C). Again, small sample size meant that no significant differences could be found, but some codes did appear to change frequencies from one semester to the next (Figure 5-4). PR, EV, and C codes all showed a decrease in the number of prompts that resulted in that code. Median percentage of prompts and student questions that were responded to with a PR decreased from 14% in Semester 1 to 6% in Semester 2. The EV code was present in response to a median of 71.5% of prompts and student questions in Semester 1 and only 36% in Semester 2, and the C code was present in response to a median of 68% of prompts and student questions in Semester 1 and 30% in Semester 2. The R code shows a possible smaller increase, from a median of 52% in Semester 1 to 58% in Semester 2. The EXP code showed consistent, lower frequencies, existing in response to a median of 4% of prompts and student questions in Semester 1 and 5% in Semester 2.

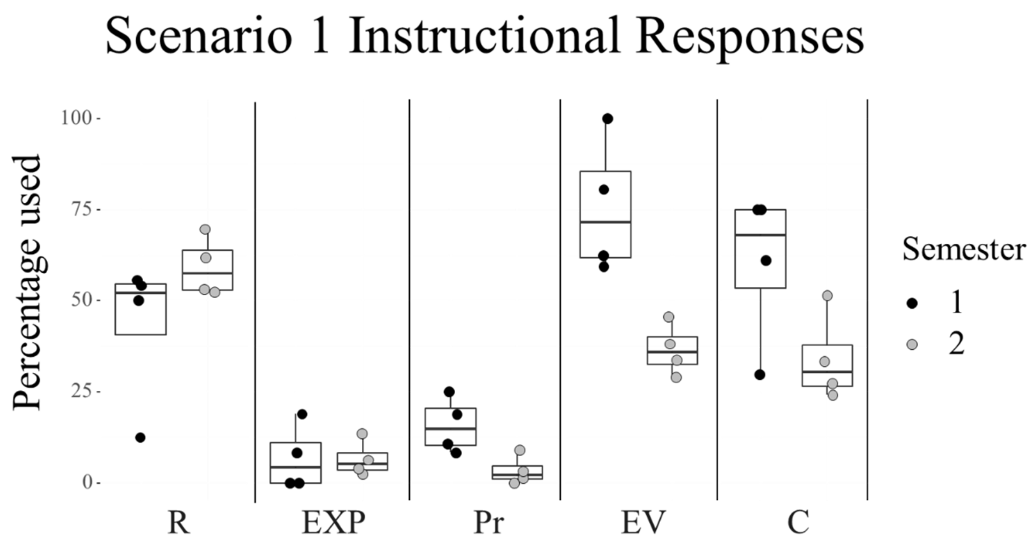

Figure 5-4. Percentage of times response codes were applied in each class period in Semester 1 vs. Semester 2 of Scenario 1. Percentages are calculated out of all instances of student stage (S), both responses to prompts and questions

Scenario 2: established instruction in a SCALE-UP classroom

While scenario 1 tracked a biology class through a switch from a lecture hall to a SCALE-UP setting, scenario 2 involved the second and third semesters that biology instruction happened in the SCALE-UP classroom. Semester 1 in this scenario refers to General Biology I and Semester 2 to General Biology II. Although these two semesters differed in the specific content that was covered, they were consistent in regard to environment and instructor and had comparable class sizes and student populations. We endeavored to see to what extent instructor practices remained stable from semester to semester when instruction was already established within a SCALE-UP context. Thirteen class periods were observed in Semester 1 and twelve in Semester 2. As in scenario 1, each class period was analyzed with COPUS, and a subset of four per semester were chosen at approximately equally spaced intervals for the other analyses.

COPUS

Individual class periods differed, sometimes dramatically, in the application of COPUS codes for both instructor and students in each semester (Figure 5-5). In Semester 1, PQ was present in 3-32% of time blocks (median 13%), while in Semester 2 it was present in 5-35% of time blocks (median 26%). This increase does not represent a significant difference (see Table 5-4). The instructor spent some amount of time moving through groups consistently during

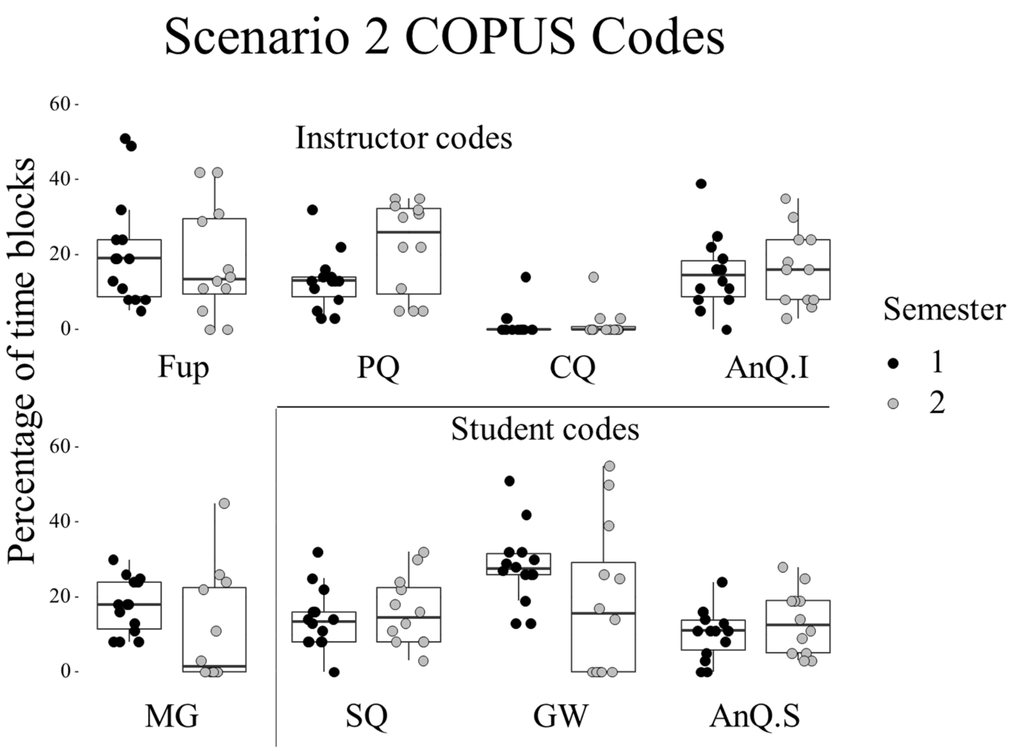

Figure 5-5. Boxplots of instructor and student COPUS codes for Scenario 2. Each data point represents the percentage of time blocks that a certain code was observed within a single class period

Semester 1 (MG 8-30% of time blocks; median 18%), and in Semester 2 this was less consistent and more variable (0-45% of time blocks; median 2%). Clicker or voting style questions (CQ) were used very infrequently. Instructor following-up behaviors (FUp) were present in 5-51% of time blocks during Semester 1 (median 19%) and 0-42% of time blocks in Semester 2 (median 14%). The instructor frequently solicited questions from students and spent similar amounts of time in both semesters answering these questions. AnQ-I was present in 0-39% of time blocks in Semester 1 (median 16%) and 3-35% of time blocks in Semester 2 (median 16%).

Table 5-4. Median percentages of time blocks in which COPUS codes were observed in Semesters 1 and 2 of Scenario 2, and results of Mann-Whitney U tests comparing time block percentages between semesters. No significant differences were found

	Median: Semester 1	**Median: Semester 2**	**W**	**p-value**
Instructor codes				
FUp	19	14	95	0.5881
PQ	13	26	49.5	0.0788
CQ	0	0	81	0.8613
AnQ-I	16	16	79	0.8157
MG	18	2	119	0.0735
Student codes				
SQ	14	15	75	0.6584
GW	28	16	117.5	0.0879
AnQ-S	11	13	66.5	0.379

Students in Scenario 2 spent some time in most class periods doing some form of group work (GW). However, there were five class periods, all in Semester 2, in which no group work was recorded. In Semester 1, GW was applied to 13-51% of time blocks (median 28%), and in Semester 2 it was recorded in 0-55% of time blocks (median 16%). Student behavior was very similar between semesters in regard to asking and answering questions. Students answered questions (AnQ-S) during 0-24% of time blocks in Semester 1 (median 11%) and 3-28% of time blocks in Semester 2 (median 13%). Students were also given the opportunity to ask questions (SQ) and did so in 0-32% of time blocks in Semester 1 (median 14%) and 3-32% of time blocks in Semester 2 (median 15%). No significant differences were observed from one semester to the other in instructor or student COPUS codes (Table 5-4).

Assessment prompts

The number of prompts per day in Scenario 2 was 12-40 in Semester 1 (median 18) and 16-28 in Semester 2 (median 24). Most prompts were verbal (72% in Semester 1 and 78% in Semester 2). In Semester 1, 28% of prompts took the form of written prompts or worksheets, and in Semester 2, 15% did. The instructor in Scenario 2 did not use clicker questions during the semesters studied.

The cognitive level of prompts tended to be lower order (Knowledge, Comprehension, and Application). In Semester 1, some Synthesis prompts were observed, while in Semester 2, some Analysis prompts were observed. No Evaluation prompts were observed in either semester. Higher order prompts (Analysis, Synthesis, and Evaluation) made up a median of 6% of total (including unbloomable; see below) prompts in Semester 1 and 3% in Semester 2. There were no significant differences in higher order vs. lower order prompts between the semesters (Figure 5-6).

The instructor for Scenario 2 asked frequent "unbloomable" questions in both semesters that were not in the cognitive domain, such as "Any questions?" and "Does that make sense?". These questions often resulted in a string of student questions to which the instructor then responded. Such unbloomable questions occurred 6-14 times per class period during Semester 1 (median 10) and 7-15 times per class period during Semester 2 (median 13.5). These prompts are not included in the characterization of cognitive level, but the resulting student questions are

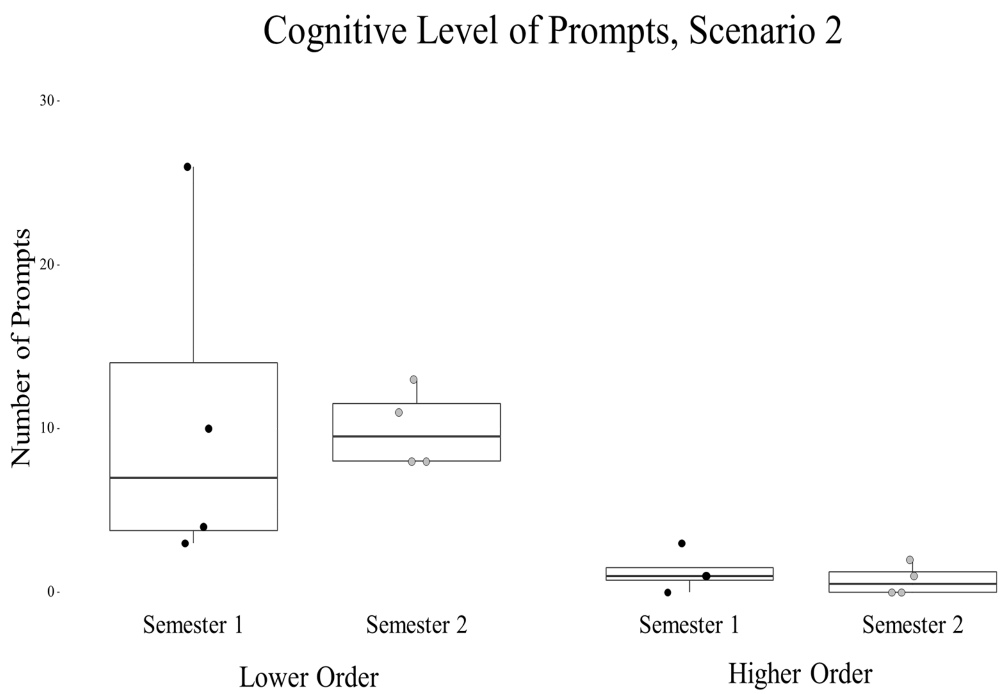

Figure 5-6. Cognitive level of prompts (lower order and higher order) in each semester of Scenario 2.

included in the instructional response analysis below since these questions provided evidence of student understanding and thus an opportunity for feedback.

Instructional responses and feedback

In Scenario 2, like Scenario 1, the most common instructional responses to student thinking among our codes of interest were evaluating the correctness of a response (EV), providing clarifying information (C), and repeating or paraphrasing a student response (R). The frequencies of response codes varied substantially between class periods. Some patterns were observed that suggested differences between semesters in proportions of student responses or questions responded to in certain ways (Figure 5-7). The median percentage of prompts or student questions that were responded to with a C code within each class period was 92% in Semester 1 and only 58.5% in Semester 2. The median percentage of EV codes increased from 26.5% in Semester 1 to 56% in Semester 2. EXP codes likewise showed an increase (a median of

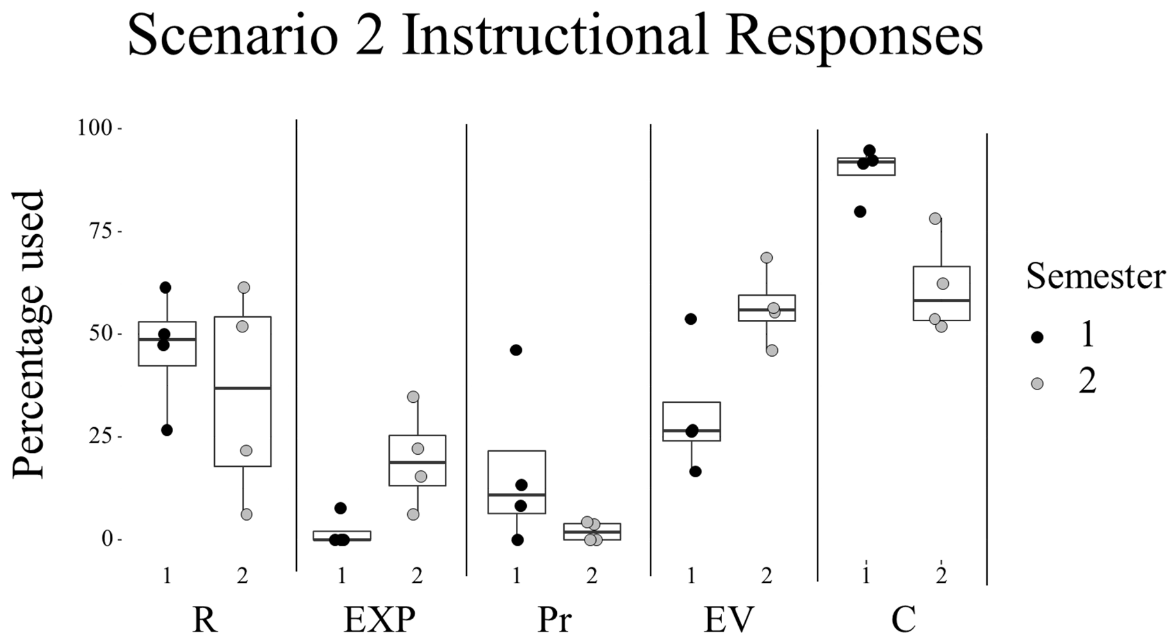

Figure 5-7. Percentage of times response codes were applied in each class period in Semester 1 vs. Semester 2 of Scenario 2. Percentages are calculated out of all instances of student stage (S), both responses and prompts and questions

0% in Semester 1 and 19% in Semester 2). R codes and PR codes varied between class periods but showed less obvious differences between semesters. Sample size was small, and no differences between semesters were statistically significant.

Discussion

All introductory biology semesters studied here were taught by instructors who had received professional development relating to formative assessment, feedback, and active learning and were part of a supportive departmental environment as well as a smaller collaborative group that had been working to create an assessment-rich environment for students in introductory biology. The classroom environments in both scenarios were intended to be assessment-rich, making this a "best case" scenario for the characterization of assessment and feedback in a biology classroom. We have characterized the use of formative assessment and feedback both during and after adjustment to a SCALE-UP classroom, identifying some changes in assessment practices that may have been facilitated by the SCALE-UP setting, as well as some aspects of assessment that were rarely present regardless of classroom environment. Practices varied substantially day to day but were broadly consistent between semesters after transition to the SCALE-UP room. In addition to identifying possible changes in assessment practice in the switch to a SCALE-UP classroom, the results of this study point out that a commitment to active learning can result in a variety of assessment and feedback practices, even for the same instructor in the same semester. It also points to some implications for encouraging effective use of assessment and feedback practices.

SCALE-UP may facilitate change in the amounts and types of certain assessment practices

Scenario 1 compares a pre-SCALE-UP implementation of introductory biology to the first implementation in SCALE-UP, and we found that the move to SCALE-UP coincided with several dramatic changes in practice related to formative assessment. Number of prompts (overwhelmingly verbal) increased significantly, as did student time spent answering questions and instructor time spent following up on formative assessments. Although student group work time did not increase, the instructor spent more time moving through groups interacting with students, likely facilitated by the layout of the SCALE-UP classroom (Beichner, 2008). This is important because moving through groups allows the instructor to see a greater variety of student responses and get a sense of the depth and breadth of student understanding (Offerdahl & Montplaisir, 2014). The number of higher order prompts (though still infrequent) increased but not significantly, potentially indicating a higher level of instructor-student discourse in the SCALE-UP.

Conversely, the time students spent asking questions, and the time the instructor spent answering them, decreased in the SCALE-UP room. This could be in part because the instructor was spending more time moving through the classroom, allowing students to ask questions and receive answers individually (we did not characterize instructor-student interactions in small groups). While an individual student and their group receive more detailed and personalized feedback in such a situation, the student questions and feedback do not benefit the entire class. Additionally, there were fewer students in the SCALE-UP than in the lecture hall, and this may have impacted the number of student questions that were asked.

In terms of responses to student thinking, non-significant decreases were found in praising, clarifying, and evaluating responses while repeating/paraphrasing increased slightly. The instructor was using more prompts but not necessarily spending much time following up on each one, frequently just acknowledging and moving on. In addition to the move to the SCALE-UP classroom, this instructor was undergoing professional development and adjusting to a new class (Semester 1 was their first time teaching this particular class), so we cannot show that any changes are due to the SCALE-UP alone; however, it seems the SCALE-UP setting may have facilitated their use of prompts, especially verbal prompts, and interaction with students while they worked in groups, providing ample opportunity for beneficial assessment practices.

By contrast, in Scenario 2, when both semesters of instruction happened in the SCALE-UP room, instruction was largely stable between semesters, although there was substantial variability day to day. It seems likely that the SCALE-UP classroom facilitated certain changes (demonstrated in Scenario 1), which were adapted to quite quickly, with any initial broad-scale changes in place by the second semester (as shown in Scenario 2). The slight differences we did observe between semesters in Scenario 2 were not statistically significant. They could have been due to the instructor continuing to adjust to the space, but they could also have been due to differences in instructor motivation due to time of year, different content (BIOL 150 vs. 151), different student populations, or simply sampling error.

Certain beneficial aspects of assessment and feedback remained infrequent

Instructors in all semesters were implementing many formative assessment and feedback practices thought to be beneficial, and certain aspects of formative assessment increased and changed concurrently with the switch to the SCALE-UP classroom. Yet, some aspects of formative assessment and feedback remained uniformly infrequent. Two potentially beneficial aspects of formative assessment and feedback that were present infrequently were higher order prompts and asking students to expand on their thinking (our EXP code). Both of these adaptations of formative assessment probe student thinking at a deeper level, helping them recognize and move toward reaching learning objectives (Evans, 2013; Hattie & Timperley, 2007). Although students were given ample opportunity in all semesters to provide evidence of their thinking, prompts primarily requested lower order student thinking skills, especially Knowledge and Comprehension. Additionally, students were much more likely to receive evaluative or clarifying feedback than to be given a further chance to revise their thinking. Both higher order prompts and continuing to probe student understanding on a given prompt tend to take up more class time and demand more student effort than the alternatives; thus, it is difficult to estimate the proportion of prompts that "should" be higher order, or the amount of student thinking that "should" be further probed. Certainly we do not expect to see those things exclusively, but our data show that they were present in very small proportions. This indicates that even when the format of an assessment-rich environment is undoubtedly present, it doesn't necessarily mean that the substance and nature of the assessment and feedback practices reflect beneficial adaptations of critical components important for optimal student learning. Indeed, our study also acts as a reminder that the COPUS measures instructor and student behaviors, not the quality of active learning practices. Using the ESRU alongside the COPUS as well as analyzing prompts by Bloom's level allowed us to characterize the assessment prompts and feedback in greater detail than that allowed for by the COPUS alone.

Assessment-rich classrooms show high variation in practices

In every semester studied, instructors gave students opportunities to demonstrate their thinking through prompts (e.g. PQ, CQ, elicits), group work (GW, MG), and providing opportunity to ask questions (SQ), and spent time following up on prompts and giving feedback (FUp, AnQ-I, response codes). Feedback included evaluating the correctness of student answers and clarifying or providing further information. Overall, instructors were successfully implementing an interactive environment with many important aspects of formative assessment (soliciting evidence of student thinking, allowing students to interact with each other and the instructional team, and giving timely and relevant feedback). Yet, the measurements we took (e.g. COPUS, ESRU) often varied from day to day. These data demonstrate the importance of considering multiple time points in a semester when investigating instructor practices; the more observations collected, the more complete the picture of assessment and feedback (Reichenbach, 2017; Stains et al., 2018). The data also underscore the important observation that assessment-rich active learning environments do not all look the same. A number of different practices and class formats can incorporate formative assessment and relevant feedback, potentially impacting student learning.

Implications

This work highlights several things to pay attention to as research continues into instructor assessment practices and change as well as classroom environments. Further, it implies a few action steps for those involved in institutional change efforts. First, we know that SCALE-UP settings are meant to facilitate student groupwork and formative assessment (Beichner, 2008). This study provides evidence of an instructor's assessment practices changing concurrently with beginning to teach in that setting. The instructor in Scenario 1 indicated in an interview after the observational semesters that though they believed it was possible to use active learning activities in a large lecture hall, the SCALE-UP setting made using them much easier and more comfortable for the students. This study contributes to an evidence base indicating that aspects of classroom environment may impact instructor practices and student learning (Felege & Ralph, 2019; Hacisalihoglu et al., 2018; Kranzfelder et al., 2019).

It is also important to consider *how* the instructor's practices changed. In this case, lower order verbal "call and response" style prompts showed the most dramatic increase, and student groupwork behavior did not increase but the instructor moved through those groups and interacted with students more. Although more examples are needed as this study followed only one instructor through the change in classroom, this work highlights the importance of considering the ways in which SCALE-UP classrooms may facilitate evidence-based practices, and the types of practices or aspects for which instructors may need further support as they adapt to a SCALE-UP classroom. For example, perhaps the instructor in Scenario 1 could have benefitted from some strategies to encourage full-class student questions in the SCALE-UP setting.

Secondly, the variety of instructional practice is highlighted. One day often looks very different from another, even in the same semester, the same classroom, and with the same instructor. This is true for the amount of class time spent doing different activities as well as the substance of those activities (e.g. types of feedback). When characterizing instructor classroom practices, researchers should take into account that variability and be careful to collect data from several days of instruction (Reichenbach, 2017; Stains et al., 2018). Professional development for instructors should likewise emphasize this variability, noting that instructors don't teach the same every day, and there are many ways to implement student-centered assessment practices that can look vastly different.

Finally, this research highlights that, though student-centered practices can come in many different flavors and look different day to day, there are some aspects of evidence-based assessment practices (e.g. higher order questions, asking students to expand on their thinking) that seem consistently difficult for instructors to incorporate. There is perhaps a need for more professional development and support for instructors that focuses on the substance of assessment and feedback in addition to practical aspects of assessment such as types and formats.

Limitations

This study was limited in scope, encompassing one university, one series of courses, and two instructors in two semesters each. Other instructors in different contexts, teaching different classes, may not show the same patterns. Additionally, the instructors we studied were already interested and practiced in using formative assessment and feedback at the beginning of the study. We do not know how instructors who are less experienced in these techniques may adapt to SCALE-UP classrooms. Further, although we took care to observe classes throughout the semester, we were only able to collect detailed formative assessment and feedback data on four equally spaced class periods per semester. Those class periods were highly variable, emphasizing the difficulty of fully characterizing an instructor's formative assessment and feedback practices.

Conclusion

This study provides a detailed look at the instruction in assessment-rich large-enrollment introductory biology courses in terms of formative assessment and feedback. As a “best case scenario”, courses were taught by instructors who were knowledgeable, committed and supported in active learning techniques and formative assessment. When this instruction transitioned from a lecture hall to a SCALE-UP classroom, several assessment- and feedback-related changes were observed, including a greater number of prompts, more time following up on prompts, and more time moving through and interacting with student groups. Despite these changes, we detected some aspects of formative assessment that were rarely implemented, such as higher order prompts and asking students to expand on their thinking. When instruction was already established in a SCALE-UP classroom, assessment practices varied substantially day to day but did not show measurable changes from one semester to the next. This study adds to the literature on in-class assessment in an undergraduate STEM setting and provides evidence that SCALE-UP classrooms may facilitate certain assessment and feedback practices.

CHAPTER 6: CONCLUSION

General discussion

Collectively, the papers presented in this dissertation provide insight into instructor practices and behaviors at several different levels. They address the patterns of interaction among instructors within a department in regard to assessment experience (Chapter 3) and how those interactions, in concert with departmental teaching and social norms, impact instructor decisions about teaching innovations (Chapter 4), all in the context of an overarching theoretical framework (Chapter 2). Finally, Chapter 5 goes further to address concrete instructor assessment practices in relation to classroom environment. This chapter will present a brief summary of each chapter separately and then a reflection on a few key themes of the work as a whole, as well as implications and limitations of the work.

Chapter 2

In Chapter 2, previous literature and models of instructor innovation decision were synthesized to propose a novel model of the impacts of teaching and social norms and peer interactions on instructors' innovation decision processes. The model indicates that norms impact instructor affective state, and peer interactions can impact affective state or knowledge. Knowledge and affective state together then determine whether an instructor will implement (with or without changing) an innovation, reject it, or seek more information.

The theoretical model in Chapter 2 brought forth several hypotheses and implications that were available to explore within the other chapters in this volume. For example, the model implies that interaction should have a positive impact on innovation adoption and that peer interaction patterns will impact and be impacted by departmental norms. Aspects of the model were explored in Chapters 3 and 4 in a department which was expected to have a positive climate for teaching, with norms encouraging teaching innovation, instructors adopting innovations, and frequent teaching interaction (allowing for the relationships between these aspects to be probed).

Chapter 3

Since the model in Chapter 2 is the innovation decision process of one instructor, we can visualize multiple instructors connected through the "Peer Interactions" arrows within the same departmental social context, forming a network of interactions. Within this network, each individual instructor is also impacted by departmental teaching and social norms and potentially undergoing their own innovation decision process or processes. The network is the subject of exploration in Chapter 3. Based on an innovation diffusion framework, instructors with differing levels of innovation use must interact with each other in order for innovations to be passed through a network. These conditions for diffusion were analyzed, focusing on self-reported assessment experiences as an example of a student-centered teaching innovation. Results showed that such interactions did happen, providing the opportunity for peers to spread ideas for evidence-based teaching. Further, instructors with the highest levels of self-reported assessment innovation use were interacted with the most frequently by their peers. Both instructors with high assessment experience and low assessment experience reported interacting more frequently with instructors with high experience. This provides a means for instructors to have access to beneficial information and ongoing support. It also raises questions about whether high experience individuals are sought out because of their teaching expertise or whether frequent interaction with peers leads to expertise. Both are hypothesized to be true, but the model indicates that interaction may lead to adoption (the latter scenario), and in Chapter 4 this possibility is further explored.

Chapter 4

In Chapter 4, aspects of the model were explored using interviews of a subset of the same instructors (in the same department) who provided data for Chapter 3. The focus was on: 1) the impact of perceived departmental norms on instructor affective state, 2) the impacts of peer interactions on instructor knowledge and affective state, and 3) the downstream impacts of both (which decisions instructors made). In addition, the interplay between perceptions of norms and peer interactions was explored.

Perceptions of departmental norms varied. Some instructors experienced a very collaborative and interactive environment while others viewed it as more solitary. Although all agreed that norms in the department favored instructors using active learning, some interpreted this positively while others interpreted it negatively and felt somewhat judged for using more lecture-based approaches. Perceptions of these innovation-positive norms were also mitigated by perceptions of a strong ethic of instructor autonomy. Instructors' viewpoints of the departmental norms and the amount of peer interaction they reported were associated with their attitudes toward active learning and the extent to which they reported adoption of teaching innovations, consistent with the hypothesis that peer interaction has a positive impact on innovation adoption. All participants reported receiving some form(s) of knowledge and/or support from peers. Impactful peer interactions characterized included seeking and consultation behavior, sharing and commiserating behavior, and sharing or passing on of materials when teaching the same class.

Chapter 5

In Chapter 5, the theoretical model from Chapter 2 is relevant implicitly in that instructors in the study were reflecting on and iteratively implementing assessment innovations, but it is not the focus. The objective in Chapter 5 was to observe classrooms to see how instructors actually implement formative assessment and feedback practices in a “best case” scenario. The scenario was “best case” in that the climate was innovation-positive, peer interaction was frequent, the conditions for innovation diffusion existed, and instructors were in a collaborative instructional group committed to active learning and formative assessment. Assessment and feedback practices were observed during the change to an active learning classroom (SCALE-UP) and in an established SCALE-UP setting to discern how classroom environment impacted instructor assessment practices.

The SCALE-UP classroom (combined with other influences listed above and the instructor’s own development) may have contributed to several changes in assessment and feedback practices in the introductory biology classes observed. The instructor who changed classrooms asked more questions of their students in the SCALE-UP setting, had more interaction with groups, and gave different types of feedback. Practices within the established SCALE-UP classroom were more stable semester to semester, and substantial variation existed in both situations day to day.

Interaction favors adoption

The social context within which instructors make decisions can have substantial impact on an instructor’s decision-making (Andrews et al., 2016; Lund & Stains, 2015; Pataraia et al., 2015; Quardokus & Henderson, 2015; Rogers, 2003). Several lines of evidence point to the conclusion that peer interaction likely has a net positive effect on instructor innovation adoption. First, the theoretical model developed in consultation with literature on peer interaction and innovation adoption predicts a higher rate of implementation when seeking behavior occurs (Chapter 2) and increasing opportunity for information exchange with increased interaction.

Secondly, Chapter 3 establishes conditions for innovation diffusion and an association between self-reported assessment experience (a proxy for level of assessment innovation adoption) and teaching in-degree centrality, the number of peers who reported interacting with a particular instructor about teaching. Similar associations have been found in other departmental contexts (Judson & Lawson, 2007; Middleton et al., 2015; Van Waes et al., 2015). Finally, this association is further born out in the interview data (Chapter 4), which indicated that participants who spoke a lot about peer interaction and perceived a norm of collaboration also tended to have a positive attitude about active learning and mention implementing more innovations. Conversely, participants who reported fewer peer interactions and a more solitary environment reported implementing few innovations and sometimes had negative views about active learning. Further, the perceptions of interaction and innovation participants expressed in interviews corresponded with what was found on the surveys in Chapter 3.

Chapter 4 found that interviewed instructors received information from peers that impacted their knowledge and affective state through seeking/consultation behavior and sharing behavior as well as through the passing on of class materials. Information obtained included information regarding how and why to implement an innovation, opinions and advice, and initial awareness of innovations. Some of these align well with behaviors and outcomes previously described (Dancy et al., 2016; Pataraia et al., 2015; Rogers, 2003) and can be understood using the model (Chapter 2). This potential for peer interaction to provide beneficial information, promoting innovation adoption and diffusion, could be harnessed by administrators and change agents by encouraging beneficial interactions (see “Implications for instructional change” below).

Perceptions of departmental norms have important implications

Innovation adoption rates have been demonstrated to vary with perceptions of departmental climate and norms (Bathgate et al., 2019; Landrum et al., 2017; Lund & Stains, 2015), and this study indicates that those perceptions can vary even within the same department (Chapter 4). The degree to which participants in this study indicated they experienced active learning norms negatively was associated with the extent to which they reported trying and adopting innovations, as was the extent to which they perceived the collaborative vs. solitary social norms around teaching interaction. This fits well with what is known about innovation adoption and persistence increasing with access to a supportive community (Tomkin et al., 2019; Wieman et al., 2013). More information from different departments is needed for comparison of climates, but within this department, results support the idea that peer interaction is favorable for innovation adoption, and that the amount of peer interaction can be experienced as an aspect of departmental norms. The existence of "microclimates" (Roxå & Mårtensson, 2015) may have also been a factor here, since instructors who implemented many active learning innovations tended to talk most about their interactions with others doing the same. This was also true of instructors who used more lecture-based methods (when they reported interacting at all). These results are also an indication that feeling "judged" because of departmental norms encouraging active learning or teaching innovation may make an instructor react negatively and be less likely to implement innovations, an outcome that may be mitigated by feelings of autonomy in teaching (Chapter 4).

The perceptions of teaching and social norms in this study, though they varied by individual instructor, were shaped by the members, administration, and history of the department studied. In this case, norms in the department were widely agreed by interviewees to value teaching and be favorable toward teaching innovation. These norms may have helped to create a climate conducive to teaching innovation adoption. Additionally, such a climate may have been facilitated by norms that encouraged and nurtured a collaborative environment in which at least some instructors regularly sought help and advice from each other, shared ideas and materials, and collaborated with each other about teaching. In less collaborative environments, the dynamics of innovation adoption and decision may be different, and in departments in which active learning is not encouraged or not the norm, frequent interaction about teaching may not be present, or may lead to different results.

Active learning classrooms can make formative assessment easier

Besides peer interactions, another factor that can be experienced as an aspect of departmental culture as well as having its own potential impacts on instructor behavior is the availability of certain types of classroom spaces. In particular, fixed seating lecture classrooms have a different set of barriers and affordances than flexible seating active learning classrooms (e.g., SCALE-UP). Chapter 5 was an attempt at characterizing in detail the formative assessment and feedback that occurred in introductory biology during the switch from a lecture hall to a SCALE-UP room as well as over two semesters of established instruction in a SCALE-UP room. Although there was substantial variety in practices in both situations, the SCALE-UP room may have facilitated certain changes in formative assessment practices. Prompts, especially verbal prompts, were more frequent in SCALE-UP, as was instructor time spent moving through groups and following up on student work. These are both important aspects of formative assessment and allow the instructor to collect more evidence of student understanding (Offerdahl et al., 2018; Offerdahl & Montplaisir, 2014). Meanwhile, after the transition to the SCALE-UP setting, practices were more consistent. Yet, certain assessment and feedback practices which probe student thinking at a deeper level were rarely present regardless of classroom environment. These important missing elements underscore the importance of continuing efforts to enhance instructor assessment practices, even in "best case" situations (Evans, 2013; Hattie & Timperley, 2007). The results in Chapter 5 indicate that active learning classrooms may be helpful for instructors who are already committed to active learning techniques to increase their formative assessment and feedback practices in a large class. New classrooms should be combined with professional development efforts to help instructors make the most of the space. The impact of classroom type on instructors who are not already using active learning techniques is still unclear.

Impacts are complicated by complexity and variability

Even though the general trends discussed above were noted, the expected variability of human subjects and complexity of different levels of effects was also abundantly clear throughout this research. Instructor innovation decisions occur in a complex system involving individual-level attributes as well as impacts of students, peers, norms of the department, and outside influences (Sturtevant & Wheeler, 2019). Further, each of these aspects also influence each other. Therefore, it is expected that outcomes would be highly variable and difficult to boil down to single influences.

In Chapter 3, this was noted particularly in the variability of the HLI; although the general trend was for participants to interact more often with high assessment experience individuals, the ratios of the number of high assessment experience individuals to low assessment experience individuals they interacted with was highly variable from person to person. Likewise, Chapter 4 showed that even similar views of teaching norms can be perceived in multiple ways and have multiple impacts. It also reiterated that multiple aspects of departmental norms and peer interactions can have impacts in terms of an instructor's innovation decisions. Surveys are being developed to investigate many of these multiple aspects and their impacts on a different scale than addressed in this dissertation (Landrum et al., 2017; Sturtevant & Wheeler, 2019; Walter et al., 2016). Those studies and others should consider that in addition to individual impacts, combinations of perceptions and interactions may have a substantial impact on instructors, their affective states, and decisions. Finally, even in a "best case" scenario where instructors are committed to using active learning and formative assessment and are using them in a collaborative way in a supportive environment, substantial variation was observed in classroom practices even within the same semester (Chapter 5). The entire "ecosystem" of instructor adoption (Emery et al., 2019), from departmental culture to peer interactions to individual decision-making, eventual implementation, and student reaction, should be considered to understand how to promote instructional change (Lund & Stains, 2015; Sturtevant & Wheeler, 2019).

Implications for future research

A model of the impacts of departmental teaching and social norms and peer impacts on instructional innovation adoption was created in Chapter 2 and further explored in Chapter 4. This model provides a way of understanding and thinking about instructor innovation decision which takes into account social context. It can be used in future work to study how instructors make decisions about whether and how to use innovations in their teaching and how departmental norms and peer interactions perturb that process. The model should continue to be validated, explored, and modified as necessary in a variety of contexts (different departments and types of schools, different disciplines, and during the process of change initiatives) to assess and increase its applicability.

The model will also assist in extending the study of some of the aspects of instructor decision-making explored in this dissertation. It would be productive to tease apart the relative impacts of different social factors on individual instructor innovation adoption and innovation diffusion, so change agents know which steps are likely to be most important. Using a theoretical framework of individual instructor innovation adoption with a focus on departmental-level drivers and barriers, including peer impacts, to survey multiple full departments would be one way to do this. Current climate surveys (e.g. Landrum et al., 2017; Sturtevant & Wheeler, 2019) could be adapted for that purpose. It would also be interesting (though difficult) to follow instructors through the process of innovation adoption, or an entire department through the process of diffusion to discern more detail about the steps and the factors that impact decisions and the spread of ideas.

Adding the element of classroom observation would enable the characterization of how instructors interpret their implementation of an innovation over time. Potentially, factors that increase the fidelity of implementation of innovation implementation can be discerned in this way. More work is needed on how instructors use formative assessment and feedback in different classroom settings as well as how students respond to it. Chapter 5 indicates merely a starting point for using multiple measures in a classroom to observe below the surface level in terms of assessment and feedback behaviors. Developing an evidence base for how students at different levels respond to the different forms of feedback for example, would allow more helpful advice to be given to instructors who are designing assessment activities and offering feedback. Further, although Chapter 5 indicates a potential impact of switching to a SCALE-UP room, this was with instructors who were already familiar with active learning. It would be interesting to see if and how instructors who use more lecture techniques and are novices in active learning change their assessment techniques when they begin teaching in an active learning classroom.

Implications for instructional change

This work grows out of a desire to encourage the incorporation of evidence-based teaching strategies in university classrooms. The intended outcome is not changed departmental norms, increased peer interaction, or even instructor attitude or perceptions of doing active learning, but actual classroom change. The chapters collected here present knowledge that can help guide efforts toward promoting classroom change and provide hope that those efforts can succeed.

The model and findings here could lead to changes in policy or actions that could maximize the positive impacts of departmental climate and norms and peer interactions on innovation decision and minimize negative ones. Administrators, professional development designers, and other change agents can consider leveraging peer interactions to increase the impact of their initiatives. However, they should keep in mind that this strategy may work differently (or not work at all!) depending on departmental context. Chapter 4 has made clear that "teaching-focused" or active learning-positive norms are not perceived the same by everyone, and subgroups of faculty may experience such norms negatively, leading them to feel resistant or skeptical toward innovations a change agent may want them to adopt. These feelings could be counter-productive not only to individual faculty but to the relationships within the department, leading to negative impacts on departmental climate and the spread of ideas (Roxå et al., 2011; Schein, 1965; Shadle et al., 2017). Change agents should consider this and find ways to mitigate negative perceptions, such as careful introduction of ideas and emphasizing teaching autonomy (Walter et al., 2016).

Those who are in a position to impact departmental norms (including leadership as well as individual faculty members) can consider working toward the creation of an environment that reflects a collaborative "intellectual community of teaching" (Chapter 4) and incorporates the conditions for innovation diffusion (Chapter 3). Such an environment would ideally create space and norms for interaction about teaching and encourage seeking behavior, consultation with peers, collaboration, and seeing one another as a resource for teaching ideas. Additionally, normalizing and encouraging the sharing of teaching materials between instructors who concurrently or successively teach the same course may be one way to encourage adoption of innovations by even the most reluctant and skeptical instructors (Chapter 4). If instructors who employ many evidence-based practices are rotated through those classes, such materials may be more enriched with innovations as well.

In terms of instructor classroom assessment practices, SCALE-UP and similar active learning environments may facilitate the use of certain practices, particularly in-class verbal questions and interaction with groups. Those considering the addition of such an active learning classroom to their facility should also consider that instructors will likely need support in implementing these practices effectively. Professional development and peer support groups can help provide specifics of formative assessment and feedback in terms of practicalities and principles, potentially improving fidelity of implementation in a classroom setting (Mulnix, 2016; Offerdahl et al., 2018; Stains & Vickrey, 2017). Yet, it should also be noted that the participants in our study showing an impact of SCALE-UP happened with instructors who were already committed and well-positioned to make the most of the classroom's affordances. In addition to classroom environment, concerns about departmental norms and microclimates, peer support, and other contextual factors should be considered in the process of change initiatives.

Limitations

One of the most obvious limitations of Chapters 3-5 is that all data was collected and analysis occurred within a single department. This choice allowed a multi-layered, in-depth exploration of instructor innovation adoption and practices in the context of their climate and peer network. However, it also means that different departmental climates and norms could not be compared. Results are expected to differ based on disciplinary norms, types and history of the institution and department, and other factors, and our data is necessarily limited to a single context.

An additional limitation of Chapters 3 and 4 is that all survey and interview data was self-reported. This was mitigated somewhat in Chapter 3 by using in-degree rather than out-degree centrality, meaning a particular instructor's interactions needed to be reported by a peer rather than themselves. Additionally, discrepancies between instructors' self-report of their practices and interactions were not detected based on informal knowledge of the department. Yet, this limitation means there is no guarantee that an instructor actually does in the classroom what they report doing in an interview or on the survey, and neither innovation adoption nor diffusion was tracked observationally.

This limitation was overcome in Chapter 5, where instructors' formative assessment and feedback practices were observed directly in their classrooms. However, in this case, no data about student learning were collected to discern the impact of various assessment and feedback practices on student performance.

Concluding thoughts

In this dissertation, a model was presented of the impact of departmental teaching and social norms and peer interaction on instructor innovation decision-making (Chapter 2), which was then used to explore instructors' decisions (Chapters 3 and 4), interactions (Chapters 3 and 4), and practices (Chapter 5) within a single departmental context. Results indicate that peer interaction (at least in a department with teaching innovation-positive norms) likely has a net positive effect on innovation adoption, and that the conditions for diffusion were in place in the department studied, particularly the opportunity for instructors experienced in classroom assessment techniques to interact with and provide beneficial information to those less experienced. Additionally, active learning classrooms within such a supportive environment may favor implementation of certain aspects of formative assessment and feedback when used by committed instructors, particularly increasing verbal prompts. Yet, substantial variability is also demonstrated among instructors, classroom practices, and perceptions of norms. Aspects of this work can inform future efforts to increase adoption of active learning practices in university STEM classrooms by leveraging the power of peers, being aware of the complexity of potential impacts of social context and norms, and understanding some of the ways in which instructors implement formative assessment and feedback in the classroom.

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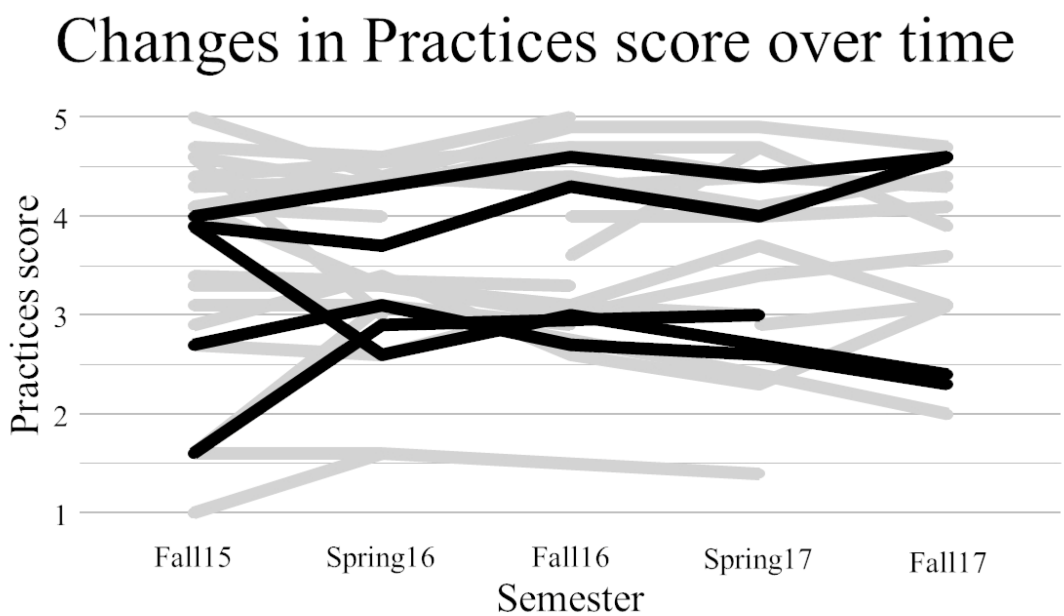
APPENDIX A: SUPPLEMENTAL FIGURE 1



A-1. Practices scores of participants over time. The black lines represent the five instructors (two highs, one mid, and two lows) discussed within the text who demonstrated relatively clear, sustained change in Practices score over time, while the gray lines in the background represent the other participants.

APPENDIX B: INTERVIEW PROTOCOL

Regarding teaching style and its change over time (with follow-ups addressing how teaching decisions were made):

- Can you tell me a little bit about your teaching style?
    - Possible follow-ups: What classes do you teach? Which class are you referring to? How is it structured?
    - If applicable: Your surveys indicate that ____. Can you tell me more about that?
    - If indicate they use active learning: Have you always taught in that way? If not, what led you to change?
- Aside from exams, how do you know if your students are learning what you expect them to learn?
- When you observe something about your students' learning, do you respond to them about this, and if so, how?
- How, if at all, has your teaching been changing in the last year or two?
    - Possible follow-ups: Why did you decide to make those changes? Were there any people or resources that influenced your instructional choices? What has been going well? What hasn't? What is your plan for addressing challenges?
- How, if at all, do you feel your teaching is changing now or will change in the near future?
    - Possible follow-ups: Why are you considering that? What appeals to you about it? What makes you hesitant about trying it? Do you anticipate challenges, and how will you deal with them? How will you know if you are implementing this effectively? Is there anything that limits you from trying or using it? Have you talked to anyone about this idea and how has that conversation affected your thoughts? What resources would you need to effectively implement this?
- Are there any changes in your teaching that you have considered and decided not to make?
    - Possible follow-ups: Why did you decide not to implement this? Did you talk to anyone about this idea and how did that conversation affect your decision? Is there something in particular that limits or prevents your use of this technique?
- (When needed) Have you considered using any active learning or student-centered teaching approaches?
    - Why or why not?

Regarding interactions within the department:

- Tell me about the interactions you have with others in the department about teaching.
    - Possible follow-ups: What do you usually talk with (this person) about? How have the interactions you've reported influenced your thinking about teaching and why?
- Do you give advice? Get advice? Share experiences or frustrations? Something else?
- What else has influenced your teaching recently?

Regarding departmental climate perceptions (added):

- What have you noticed about whether there is resistance or a feeling of resentment regarding the push for active learning in the department?

APPENDIX C: CODING SCHEME

Table C-1. Layer One: Innovation decision process

Primary Code	Subcode	Definition and notes	Include	Exclude	Example
Seeking		Individual talks about making a decision to seek some form of knowledge or advice. Can be seeking ideas to solve a problem or seeking more information about an innovation they've heard about. Can be seeking from any source, not just peers.	"bouncing ideas"	Simply attending a seminar or workshop, unless they indicated specifically seeking out that opportunity for particular knowledge/ideas	"I knew that I wanted to still have a writing component , but I didn't want the weekly writing, so you know, I asked [peer] what she does in some of her classes"
Implementation		Talked about implementing/trying an innovation	Intent to implement or considering implementing (e.g. next time they teach) but hasn't actually done so yet; Re-implementation; Confirmation/continuation		"So, another thing I have changed more and more is, again, depending on the size of the class, is to make it more interactive. I spent far less time on formal lecturing and more where I have them do exercises and present it to the class for instance, things like that."
	Refinement	Talks about decision to change something about an innovation before using it (or using it again) (Re-invention)	"adapting" it to their class	Using innovation again, with no mention of change or any specific changes (code Implementation)	"So I have tried to kind of incorporate some of those things and revise, so I'm probably going to revise the writing somehow, I just don't know how yet."
Rejection		Talks about decision to stop using, or to not try, an innovation	Even if they tried it again at a later date, code the initial rejection	Re-invention of an innovation, even if dramatic (code Refinement)	"I'm really down on clickers right now."

Note: "Innovation" is defined liberally, since the focus is on the process and not what the individual innovation is. An innovation can be anything from clickers to a specific activity to "less lecture" or "active learning"; it can also be general statements about the process of adopting/not adopting.
The steps do not have to present in order, nor do they all have to be present regarding a single innovation in order to be coded.
More than one step can sometimes happen in a single excerpt.

Table C-2. Layer Two: Peer impacts and interactions with potential impacts

Primary code	Subcode	Definition and notes	Include	Exclude	Example
Knowledge		A peer provided some form of knowledge.	Knowledge about content, students	Knowledge about culture, personal experiences	
	Awareness	Giving or receiving initial knowledge/awareness of an innovation	General statements – i.e. this is where I do or would get ideas	Excerpts describing only other types of knowledge (although they can be present together)	"So we had a lot of people in the department that were really knowledgeable… so just being around and you know, hearing about the things that they were doing."
	How-to	Giving or receiving how-to level knowledge of an innovation	Technical help; Troubleshooting		"I also go to [peer] a lot for help. With Blackboard."
	Principles	Giving or receiving principle-level knowledge of an innovation (how/why it works or the principles behind it)			"…and we had just talked about the value of asking questions, and so that was sort of thinking about how to do reflections"
	PCK	Giving or receiving knowledge about teaching particular content and/or a particular group/level of students	Information about how students usually respond		"I do talk about evolution for instance… And some of the quirks that we've had to deal with with students who don't understand it or don't believe it"
	Materials	Sharing teaching materials	Gave them resources about an innovation or about teaching in general, shared actual class activities, readings, etc.		"I started clickers in [class] because I was taking over for [peer] when [they] moved to [other class] and [they] always used clickers, and [they] gave me some of [their] lectures"

Table C-2. Layer Two: Peer impacts and interactions with potential impacts (continued)

Primary code	Subcode	Definition and notes	Include	Exclude	Example
Affective state		A peer provided some other type of interaction that may have impacted affective state in some way			
	Support	Commiseration or emotional support			"I mean, the typical complaints about whether or not the students are paying attention to this, that, or the other, I probably have just casually talked to people like [peer] and maybe [other peer] in the department"
	Influence	Interviewee received some sort of guidance or advice or a peer influenced them in some way	Mentorship (official/unofficial)	Awareness of an innovation or ideas; Anything that would fit under knowledge	"I remember a colleague of mine in [previous school] saying, well you know we're not training scientists but we're training people that have proven that they can find information….and I agree, it's true."
	Sharing	Sharing of personal experiences			"I've heard other people say, you know 'well that was a disaster I did this...'"

Note: More than one code may apply to a single excerpt. Code both giving and receiving.

Table C-3. Layer Three: Perceptions of climate and instructor/climate interactions

Primary code	Subcode	Definition and notes	Include	Exclude	Example
Community		Interaction among colleagues is promoted, or there is an intellectual community of teaching	Collaboration		"And I would say we have a really great environment for talking about teaching and sharing and like cross-pollination."
Independence		The climate is "live and let live" and/or promotes independence, silo-ing, and/or lack of interaction about teaching	Being a loner; Few interactions about teaching		"So you definitely in this department have no feeling of, that there's any like push back from other faculty or, or, you know the department as far as what I can do"
Values		Interviewee discusses perceived values of the department or group, and/or their impacts on affective state	Administrative supports and barriers; Perceived content-coverage pressures; Conflicts of values		
	Positive	The climate is positive or supportive toward teaching, active learning techniques, and/or innovation			"I mean, the department is incredibly supportive."
	Pushy	The innovation-positive climate is perceived as pushy or judgy; climate pressures instructors to do active learning techniques	Talking about how pushy it is (even if they conclude it's NOT *too* pushy)		"There does seem to be a sentiment from the gung-ho active learning group that any sort of - if you spend more than 10 minutes on in-class instruction then you're not doing it right."
Climate*Peers		The impact on the climate of an individual instructor, or their peers, or attempted impact		Perceived influences of the department head in a leadership/administrative role; code this under Values.	"But I think all of us that have been in the [intro courses] hopefully have kind of started to enforce that culture."

Note: These codes apply when interviewees express their perceptions of the departmental climate, or subsets of it. Both official, administrative actions and informal support/discouragement count. Interactions with only one specific peer do not fall under climate – it must be a general sense or a perception of a group or the entire department.