PROFESSIONAL DEVELOPMENT FOR EVIDENCE-BASED TEACHING: AN INVESTIGATION OF UNIVERSITY STEM FACULTY'S INSTRUCTIONAL REFORM EFFORTS

by

BLAKE WHITT

(Under the Direction of Julie A. Luft)

ABSTRACT

Active learning (AL) instruction is a powerful tool for improving student learning outcomes and retention in university STEM, but teaching in this way is difficult. To promote wide-spread adoption of AL instruction, professional development programs (PDP) are created to support university faculty. However, these programs frequently achieve limited success in promoting instructional change. This dissertation is composed of two manuscripts which explore previously under-investigated elements of the instructional reform process in university STEM. The first manuscript examines the relationship between STEM faculty's use of AL instruction and the physical orientation of their classroom post-participation in one of various PDPs. Using observational data of instructors' and students' classroom behavior, the degree of AL instruction is interpreted in the context of classroom space and professional development received. This manuscript indicates a strong relationship between classroom space and degree of AL instruction over-and-above the influence of PD. Implications of this manuscript include that while PDPs are essential for instructional change, they must provide specific support for the instructional constraints classrooms may place on AL instruction. The second manuscript is a mixed-methods

extension of the first. Using interview and observational data, this study examines how STEM instructors' experience with and use of AL instruction changes over time. This manuscript promotes efforts to support instructional change by describing how barriers to AL instruction arise long after participation in PD and how these barriers affect instructors' practice. Implications of this manuscript include the need for continuing, individually-responsive forms of instructional support to enhance the longevity of instructional change efforts in university STEM.

INDEX WORDS: Active learning, STEM, professional development, faculty learning

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CHAPTER 1

INTRODUCTION AND DISSERTATION OVERVIEW

Introduction

Calls for reform in science education have been made for decades, a recent example seeks one million additional university graduates in science, technology, engineering, and mathematics (STEM) fields over ten years (PCAST, 2012). Given the importance of increasing the number of STEM students in the workforce, exploring the role of professional development programs (PDP) on faculty is timely for addressing the urgent needs of combating anthropogenic climate change, responding to widespread health crises, and developing citizens who are better prepared to make scientifically informed decisions in a democratic society.

One approach to increase the number of STEM students involves reforming the instruction of undergraduate STEM students (Olson & Riordan, 2012). To improve instruction, numerous programs have been developed to support STEM faculty's replacement of lecture-centric forms of instruction with student-centered practices such as active learning (AL). This form of instruction has demonstrated improvement in student outcomes and retention in university STEM disciplines (Freeman et al., 2014). Additionally, AL instruction has been shown to disproportionately benefit students from educationally and economically disadvantaged backgrounds, reducing the achievement gap in university STEM education (Haak et al., 2011).

PDPs are one way that faculty can be supported to change their instruction towards AL practices. They can provide forms of instructional support to participating faculty which can include, but is not limited to, sharing course materials and/or assisting in their creation,

disseminating information on the benefits of student-centered instruction on learning outcomes, assessment and formative feedback on teaching practices, and bringing together faculty from differing departments and institutions with a shared interest in instructional innovation.

However, instructional innovations are challenging for faculty to implement in undergraduate courses. New STEM faculty often lack pedagogical knowledge, as becoming an instructor at the university level typically requires that one has earned a master's or doctoral degree which, in STEM, rarely incorporates formal training on how to be an effective educator (Golde & Dore, 2001; Tanner & Allen, 2006; Addy & Blanchard, 2010). Consequently, STEM teachers' instruction most often emulates how they were taught as students (Sakshaug & Wohlhuter, 2010; Ball, 1990). This results in their favoring of lecture over evidence-based instruction (Hurtado et al., 2012). The initial lack of pedagogical training, inclination to reproduce the teaching methods they experienced as students, and a host of other personal and contextual barriers (Andrews & Lemons, 2015; Henderson & Dancy, 2007; Gess-Newsome et al., 2003) are likely to perpetuate the norm of lecture-based instruction unless instructional support and PD opportunities are provided for STEM faculty.

Purpose of Studies

AL instruction has been shown to improve both student performance and persistence in university science, technology, engineering, and mathematics (STEM) programs (Freeman et al., 2014; Braxton, Milem, & Sullivan, 2000; Graham et al., 2013; Haak et al., 2011; Freeman, Haak, & Wenderoth, 2011). Classes following this instructional approach involve a reduction in lecture in order to allow students time to solve problems and reflect on their level of comprehension through interaction with the presented materials (Andrews & Lemons, 2015; Prince, 2004).

These AL experience may include regular practice with problem-solving, data analysis, and other higher-order cognitive skills related to the practices of course subject matter (Haak et al., 2011). Students in these classes develop skills most STEM instructors consider valuable, such as critical thinking and problem solving (Kim et al., 2013; Prince, 2004), and are more likely to persist in STEM majors than their peers in classes using traditional, didactic instruction (Freeman et al., 2014; Prince, 2004; Rodenbusch, 2016).

Despite mounting evidence of the benefits of AL, many STEM instructors do not use this instructional orientation and continue to use extensive lecturing (Miller & Metz, 2014; Hurtado et al., 2012). These traditional instructional practices are not aligned with major reform movements such as *Vision and Change* (American Association for the Advancement of Science [AAAS], 2011), which call for a shift from didactic to student-centered instruction in science education.

Simple dissemination of education research has proven to be insufficient for bringing about instructional change. Faculty members report varied difficulties preventing adoption and implementation of new educational practices, including insufficient training, understanding of new teaching practices, and university/departmental support (Dancy & Henderson, 2010). The considerable time required to convert a course from lecture to student-centered instruction is frequently described as the primary barrier to adoption (Postareff, Lindblom-Ylänne, & Nevgi, 2008). At research-focused institutions, the comparatively small contribution of teaching performance towards career advancement may disincentivize faculty from committing limited time and resources to the gradual and difficult process of instructional change.

To support university faculty's adoption and use of active instruction, the teaching and learning communities at institutions of higher education have developed and implemented PDPs.

These PDPs can support faculty who wish to change their instructional approach by providing expert insight into evidence-based practices, supplying instructors with teaching materials, and serving as a hub for teaching-based professional networking. However, instructors' favorable view of student-centered instructional practices may decrease after PD training once they are implementing these practices in their own classrooms (Postareff, Lindblom-Ylänne, & Nevgi, 2008), suggesting a need for prolonged individual support.

While promising forms from instructional PD exist, additional studies are needed to better understand the relationships between elements of instructional support included in the PDP and the demographics or context of participating instructors. For example, a successful two-year program training post-doctoral professionals in the use of student-centered teaching strategies (e.g. Derting et al., 2016) may not produce the same desirable outcomes with veteran STEM faculty at research-intensive universities. A detailed understanding of how successful PDPs support their participants and how to adapt these programs, or key elements of these programs, to successfully support faculty working in differing contexts is crucial for future reform efforts of existing programs. Additionally, how university STEM instructors continue to implement instructional innovations over prolonged periods of time following participation in PD is still poorly understood and longitudinal studies are needed (Shaha, Glasset, & Ellsworth, 2015).

The importance of student-centered teaching for the improvement of science education is too great to ignore. Successfully adopting this instructional approach, however, is difficult. While support for university STEM faculty is needed, many existing approaches to promoting instructional change appear to require refinement. Improving PDP support for STEM faculty's learning and enactment of evidence-based teaching practices is central to answering the call for widespread reform in university STEM education. If we wish to improve the quality of student

outcomes in STEM, we must first better understand the challenges faculty face when learning to implement new teaching practices and the most efficacious roles of PDPs in supporting change.

The purpose of this dissertation is to investigate the experiences of university STEM faculty learning to implement AL instructional practices following participation in various forms of instructional PDP. The investigation is further extended into the following year to examine the persistence of instructional change and the experiences of faculty's continuing use of active, student-centered instruction.

Dissertation Questions

This dissertation is composed of two manuscripts which extend what is known of teaching reform efforts in university STEM and faculty professional learning. These manuscripts ultimately contribute to our knowledge in the field of undergraduate STEM education by exploring the relationship between STEM faculty instruction and physical teaching space -a hitherto unexamined facet of instructional change at the university level- and providing a longitudinal assessment of faculty's use of AL instruction following participation in a PDP. These studies offer insights into how to better support faculty learning to adopt evidence-based practices such as AL instruction, which will ultimately improve student learning outcomes and retention in university STEM programs.

These two manuscripts are associated with a larger project and include data which were originally collected as part of a concurrent study. The parent study to the manuscripts in this dissertation examined the congruence of STEM faculty's conceptions of how students learn and their instructional practices following participation in a PDP intended to promote the use of AL instruction. This mixed-methods study collected faculty interview responses on the relationship

between teaching practices and student learning with classroom observations of those faculty to examine the congruence of espoused views of teaching and learning with observed instructional practice.

During these explorations, it was evident that another factor may have been influencing faculty change. Trends in our observational data and faculty interview comments regarding the difficulty of teaching in auditorium-style classrooms, combined with limited existing research on the relationship between classroom space and instructional change, served as an impetus for the investigation into physical space and instruction. Following the completion of this emergent study, a longitudinal study of the participating faculty members was designed and became the second manuscript.

The first research question in this dissertation addresses the relationship between physical space and instructional innovation. PDPs require considerable time and resources for the education and support of faculty's adoption of AL instructional practices. A frequently overlooked element of faculty's efforts to implement these practices is the physical orientation of their teaching space. While largely unexamined, the orientation of teaching space may impede or facilitate an instructor's early efforts at implementing AL instruction.

The design of this study provided an opportunity to explore another underexamined aspect of PD and instructional change: How do instructors' use of learned AL instruction change over time? To assess the longevity of instructional change, a mixed-methods study was created to compare classroom observations to faculty interview data related to their ongoing teaching experiences.

The second research question concerns the longevity of instructional PDP outcomes and the challenges STEM faculty face in their continuing implementation of AL instruction. Most

instructional PDPs are brief and do not provide ongoing support beyond an instructor's initial participation in the program. Manuscript 2 suggests a lack of longitudinal support for instructional change efforts and a scarcity of studies examining the outcomes of these efforts over time may point to a critical omission by PDPs working towards promoting accurate and long-term implementation of AL instructional practices.

Overview of Manuscripts

The first manuscript in Chapter 2 is titled, "The Influence of Physical Classroom Space on Efforts to Reform Instruction in Undergraduate STEM" and compares the teaching practices of 22 STEM faculty who have recently participated in a PDP for AL instruction. Instructor and student classroom behaviors were quantified using the Classroom Observation Protocol of Undergraduate STEM (COPUS) and compared between differing physical classroom configurations. An additional analysis is included examining the relationship between the most successful implementers of active teaching and the specific PDPs they took part in. Implications for PD designers and university administrators are proposed to support faculty's implementation of AL instructional practices following PD and suggestions are made for the most prudent application of resource-intensive classrooms supporting the use of active instruction.

The second manuscript in Chapter 3 is titled, "Supporting Undergraduate STEM Educators' Instruction: A Longitudinal Investigation of Faculty Instruction Post-Professional Development" and extends the work in Chapter 2 into a longitudinal study of a subset of six faculty from the previous investigation. This study employs a mixed-methods research design and continues to make classroom observation with the COPUS and contextualizes observed changes in classroom behavior over time with pre- and post-semester interviews of participating

STEM faculty. These data provide a description of how faculty instructional practice changes over a prolonged period, post-participation in an instructional PDP. Implications for PD designers and university administrators are proposed to support faculty's implementation of active instructional practices in light of emerging situational barriers faced by faculty and need for continuing support.

The dissertation concludes by describing the contributions of this work to the broader academic literature and outlines plans for future research based upon these manuscripts.

References

Addy, T., Blanchard, M. (2010). The problem with reform from the bottom up: instructional practices and teacher beliefs of graduate teaching assistants following a reform-minded university teacher certificate programme. *International Journal of Science Education 32,* 1045-1071.

American Association for the Advancement of Science (2011). *Vision and Change: A Call to Action, Final Report.* Washington, DC: AAAS.

Andrews, T., & Lemons, P. (2015). It's Personal: Biology Instructors Prioritize Personal Evidence over Empirical Evidence in Teaching Decisions. *CBE-Life Science Education.* 14, ar7.

Ball, D. (1990). The mathematical understandings that prospective teachers bring to teacher education. *The Elementary School Journal, 90*(4), 449-466.

Braxton, J., Milem, J., Sullivan, A. (2000). The influence of active learning on the college student departure process. (2000). 71, 569-590.

Dancy, M., & Henderson, C. (2010). Pedagogical practices and instructional change of physics faculty. *American Journal Physics 78,* 1056-1063.

Derting, T., Ebert-May, D., Henkel, T., Maher, J., Arnold, B., & Passmore, H. (2016). Assessing faculty professional development in STEM higher education: Sustainability of outcomes. *Science Advances, 2*(3).

Freeman, S., Eddy, S., McDonough, M., Smith, M., Okoroafor, N., Jordt, H., & Wenderoth, M. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410-8415.

Freeman, S., Haak, D., & Wenderoth, M. (2011). Increased Course Structure Improves Performance in Introductory Biology. *CBE-Life Science Education.* 10, 175-186.

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

Golde, C., & Dore, T. (2001). *At Cross Purposes: What the Experiences of Today's Doctoral Students Reveal about Doctoral Education*. Philadelphia, PA: Pew Charitable Trusts.

Graham, M., Frederick, J., Byars-Winston, A., Hunter, A., & Handelsman, J. (2013). Increasing persistence of college students in STEM. *Science*. 341, 1455-1456.

Haak, D., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology. *Science*, 332, 1213 1216.

Henderson, C., Dancy, M. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Phys Rev Spec Top-Ph,* 3.

Hurtado, H., Eagan, M., Pryor, J., Whang, H., & Tran, S. (2012). Undergraduate teaching faculty: The 2010-11 HERI faculty survey. *Los Angeles: Higher Education Research Institute*.

Kim, K., Sharma, P., Land, S., & Furlong, K. (2013). Effects of Active Learning on Enhancing Student Critical Thinking in an Undergraduate General Science Course. *Innov. High. Educ.* 38, 223-235.

Miller, C., & Metz, M. (2014). A comparison of professional-level faculty and student perceptions of active learning: its current use, effectiveness, and barriers. *Adv. Physiol. Educ*. 38, 246-252.

Olson, S., & Riordan, D. (2012). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Report to the President.* Washington, DC: Executive Office of the President.

Postareff, L., Lindblom-Ylänne, S., & Nevgi, A. (2008). A follow-up study of the effect of pedagogical training on teaching in higher education. *Higher Education.* 56, 29-43.

President's Council of Advisors on Science and Technology (PCAST) (2012). *Report to the President: Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics*.

Prince, M. Does Active Learning Work? A Review of the Research. *Journal of Engineering Education*. 93, 223-231.

Rodenbusch, S., Hernandez, P., Simmons, S., & Dolan, E. (2016). Early Engagement in Course Based Research Increases Graduation Rates and Completion of Science, Engineering, and Mathematics Degrees. *CBE-Life Science Education*. 15, ar20.

Sakshaug, L., Wohlhuter, K. (2010). Journey toward teaching mathematics through problem solving. *School Science and Mathematics, 110*(8), 397-409.

Shaha, S., Glasset, K., & Ellsworth, H. (2015). Long-term impact of on-demand professional development on student performance: A longitudinal multi-state study. *J. Int. Educ. Res.* 11, 29-34.

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

CHAPTER 2

THE INFLUENCE OF PHYSICAL CLASSROOM SPACE ON EFFORTS TO REFORM INSTRUCTION IN UNDERGRADUATE STEM

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Abstract

To encourage the use of active learning (AL) practices, administrators in higher education support professional development programming (PDP) and the construction of specialized learning spaces. PDPs have been shown to have an impact on STEM faculty instruction of undergraduates, but how these specialized learning spaces influence STEM faculty in their use of AL practices remains unexplored by education researchers. To examine the relationship between physical space and implementation of AL techniques, we observed the behavior of university STEM instructors and students in multiple classroom spaces. The instructors in the study were in the process of learning to use AL techniques. Our analysis found that both instructors and students displayed behaviors characteristic of AL instruction more often in specialized learning spaces than in traditional classrooms, and that these differences were better predicted by classroom space than the type of PDP received. While additional research is needed in this area, this initial study suggests that administrators and PDP developers should consider physical classroom space when promoting AL instruction.

Introduction

Active learning (AL) instruction has been shown to improve both student performance and persistence in university science, technology, engineering, and mathematics (STEM) programs (Freeman et al., 2014; Braxton, Milem, & Sullivan, 2000; Graham et al., 2013; Haak et al., 2011; Freeman, Haak, & Wenderoth, 2011). Classes following this instructional approach involve a reduction in lecture to allow students time to solve problems and reflect on their level of comprehension through their interaction with classroom assignments (Andrews & Lemons, 2015; Prince, 2004). These assignments require students to apply their understanding of course concepts to solve problems as a means of learning. When this instructional approach is used accurately, students develop skills most STEM instructors consider valuable, such as critical thinking and problem solving (Kim et al., 2013; Prince, 2004) related to core course concepts. Additionally, these students are more likely to persist in STEM majors than do their peers in classes using traditional instructional methods (Freeman et al., 2014; Prince, 2004; Rodenbusch, 2016).

Despite evidence of the benefits of AL, many STEM faculty continue to report the use of lecture-based instruction over AL (Miller & Metz, 2014; Hurtado et al., 2012). Simple dissemination of education research has proven to be insufficient for bringing about instructional change. Many faculty members report varied difficulties preventing adoption and implementation of new educational practices, including insufficient training, understanding of new teaching practices, and university/departmental support (Dancy and Henderson, 2010) and the considerable time required to convert a course from lecture to AL instruction is frequently described as a primary barrier to adoption (Postareff, Lindblom-Ylänne, & Nevgi, 2008).

To support university faculty's adoption and use of active instruction, the teaching and learning communities at institutions of higher education (IHE) have developed and implemented professional development programs (PDP). These programs can support faculty who wish to reorient their instruction towards AL by disseminating literature on teaching innovations, providing expert insight into evidence-based practices, supplying instructors with teaching materials, and serving as a hub for teaching-based professional networking.

While several forms of support provided to faculty by organizations in IHEs have been shown to be successful in informing instructors of AL instructional practices (e.g. articles, conferences, workshops), they frequently fall short of the support faculty need to adopt these practices (Henderson & Dancy, 2008). Many instructional PDPs appear to be effective at increasing faculty knowledge and motivation to attempt AL techniques (Henderson, Dancy, & Niewiadomska-Bugaj, 2012), but instructors frequently return to primarily lecture-based instruction. Additional innovation of these programs appears to be necessary to support faculty's accurate and sustained use of AL instruction.

One frequently overlooked way to support faculty's use of active instruction is to attend to the physical classroom space in which they are assigned to teach students. Because AL frequently involves student-to-student and student-to-instructor interactions (Andrews et al., 2011), a classroom intentionally designed for lecture (i.e. an auditorium) may create barriers for effective use of active instruction. In auditorium-style classrooms, students in forward facing, fixed-seats will find it difficult to converse and collaborate with peers behind-and-above them. Similarly, instructors will find it difficult to reach students seated in the middle of long, narrow aisles. If PDPs do not provide specific training and support for using active instruction in

classroom spaces that are less-than-ideal for collaborative work, they may be neglecting an important element for supporting STEM faculty's instructional change efforts.

The central research question in this study is: Is the physical orientation of the classroom associated with the degree of student-centered instruction among university STEM faculty post-participation in a PDP? This study sought to quantitatively examine the relationships between the teaching of university STEM faculty who had recently participated in a PDP to promote the use of AL instruction to: a) the form of PD they took part in and b) the physical configuration of their classroom.

Related Literature

STEM Professional Development in Higher Education

New STEM faculty usually lack pedagogical knowledge. Becoming an instructor at the university level typically requires earning a master's or doctoral degree which, in STEM, rarely incorporates formal training in how to be an effective educator (Golde & Dore, 2001; Tanner & Allen, 2006; Addy & Blanchard, 2010). As a result, many STEM faculty become largely self-taught educators who closely model their instructional practices on their classroom experiences as a student (Mazur, 2009; Oleson & Hora, 2014), perpetuating the historical dominance of lecture-based teaching in university STEM. This initial lack of pedagogical knowledge may persist depending on the PD received throughout an instructor's career.

The norm of preparing future STEM faculty through exclusive focus on science disciplinary knowledge, with the belief that pedagogical knowledge will be developed later through practice, disadvantages both instructors and their students. STEM content and STEM pedagogy are closely related and the development of STEM pedagogical knowledge is most

appropriately thought of as an interdisciplinary endeavor (Henderson, Beach, & Finkelstein, 2011). This interdisciplinary understanding of teaching has been previously described as "pedagogical content knowledge" (Shulman, 1992), which is the idea that both pedagogical knowledge and disciplinary knowledge are necessary to teach effectively.

To encourage and support the development of STEM instructors' pedagogical knowledge, many IHEs have devoted considerable resources to PDPs designed to support faculty's learning and adoption of AL instructional practices (Ebert-May et al., 2015; Pfund et al., 2009). These programs often originate from centers in IHE that are focused on improving the teaching of faculty (e.g. a university's Center for Teaching and Learning).

The PD faculty receive is varied and can include the development of teaching portfolios (Seldin, Miller, & Seldin, 2010; Clarke & Boud, 2016), mentoring (Baiduc, Linsenmeier, & Ruggeri, 2016), workshops (Simon et al., 2011), collaboration (Slowinshi, Walz, & Alfano, 2016), and peer-review of colleagues' teaching (Pembridge, Allam, & Davids (2015). Regrettably, despite the diversity and broad availability PDPs, many instructors continue to teach primarily through lecture or abandon the instructional innovation altogether. This may be due in part to the tendency of IHE to place a premium on the research productivity of their faculty. Because many institutions offer little or no additional remuneration or significant professional advancement for faculty's instructional development (Walczyk, Ramsey, & Zha, 2007), a lack of incentives may inhibit change efforts.

Empirical evidence to support the efficacy of PDPs for reforming STEM faculty's instructional practice is relatively scarce (Garet et al., 2001; Gibbs & Coffey, 2004; Henderson, Beach, & Finkelstein, 2011; Henderson, Dancy, & Niewiadomska-Bugaj, 2012). In a review of 108 studies on the impact of instructional development in higher education, only 14% of studies

using a quantitative or mixed-methods design made use of a control or comparison group (Stes et al., 2010). If we wish to identify the elements of PDPs most effective at supporting instructional change, rigorous assessments of the outcomes of PDPs on faculty teaching are needed.

Further complicating our understanding of PDPs' impact on instructional change is the academic literature's frequent reliance on self-reported data to measure change in instructors' teaching. In a study of faculty teaching practices following participation in instructional PDP, video recordings of biology instructors were analyzed and compared against their self-reported use of AL instruction (Ebert-May et al., 2011). They found that while 89% of instructors who completed the PDP self-reported incorporating AL instruction into their course, video recordings revealed that 75% of instructors were using lecture-centric teaching. Additionally, Andrews and colleagues (2011) found that biology faculty's self-reported use of AL did not correlate with their students' learning gains, suggesting that faculty may overestimate the alignment of their own practice with the features of AL as they are presented in PDPs.

A recent report from the U.S. National Academies of Sciences, Engineering, and Medicine called for more rigorous data collection methods to assess the use of evidence-based teaching practices (National Academies of Science and Medicine, 2018). The incongruity of faculty's perception of their teaching and their actual practice underscores the importance of collecting observational measures of instruction when assessing the outcomes of PDPs. Additional studies are needed to better understand the relationships between elements of instructional support included in PDPs and the observed teaching outcomes.

Teaching Space and Instruction in STEM

Existing studies have examined PDPs' influence on instruction by participating faculty (Ebert-May et al., 2015; Hutchins & Friedrichsen, 2012) and the structure of the PDPs themselves (Gast, Schildkamp, & van der Veen, 2017). While PDPs are important in supporting faculty learning, the physical configuration of a learning environment may also influence instructional choices made by faculty, especially those who are new to AL instruction.

Students' engagement through AL can be facilitated through instructional approaches including cooperative learning, peer instruction, and flipped instruction (Johnson, Johnson, & Smith, 1991; Crouch & Mazur, 2001; Strayer, 2012), all of which involve interpersonal interactions within the classroom. The quality of these interactions is in turn influenced by the restrictions placed on students and instructors by the physical configuration of the classroom. To enhance AL outcomes and facilitate the use of student-centered instruction, classroom design efforts like SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) have developed spaces intended to better facilitate student group work and interpersonal communication (Beichner et al., 2007).

The design of SCALE-UP classrooms seeks to facilitate the kinds of interactions and work typical of AL instruction (e.g. faculty-student and student-student communication, collaborative problem-solving). These rooms are composed of large, round tables where students face inwards towards their peers. Each table may also be equipped with connections for laptops and/or desktop computers with options to broadcast their work to the class via projectors or wall-mounted screens. By redesigning learning spaces to decentralize the instructor as the primary focus of attention and providing students with workspace to more easily communicate with and access one another, researchers have observed promising improvements in student learning

outcomes and attitudes towards learning (Beichner et al., 2007; Brooks, 2011; Whiteside & Fitzgerald, 2009).

While several studies have connected SCALE-UP rooms to positive student outcomes (Gaffney et al., 2008; Brooks, 2011; Cotner et al., 2013), others have found no association between SCALE-UP rooms and student performance (Stoltzfus & Libarkin, 2016) and suggest that improved student outcomes are a function of the AL instruction these spaces facilitate and not the infrastructure of the room itself. However, it is important to note that the influence of these spaces on faculty instructional practices remains underexamined by the academic literature.

University STEM instructors report that it is difficult to use AL practices in traditional, auditorium-style classrooms (Shadle, Marker, & Earl, 2017). And though student-centered teaching can be implemented effectively regardless of the physical orientation of the room, teaching within an AL-compatible classroom does not necessarily result in more student-centered teaching (Lund et al., 2015). For these reasons, specifically-designed teaching spaces like SCALE-UP rooms appear to be ideal for faculty who have recently participated in instructional PDP and are learning to implement AL in their own courses. Attending to the classroom space may be an overlooked consideration that PDPs can use to support faculty's instructional change more effectively.

IHEs are another stakeholder in the process of instructional change and are involved in funding the creation of instructional spaces to support the use of AL instruction. The cost of developing these classroom spaces can be considerable, with renovations of larger rooms costing upwards of 269,000 USD per room (Whiteside et al., 2009) and can become substantially more expensive depending on the inclusion of embedded technological resources. As IHEs continue to invest significant resources into construction and renovation of teaching spaces, it is increasingly

important to understand the influence of physical space on teaching practice to better inform design choices and institutional spending.

The arrangement of space and layout of classroom resources render some behaviors more probable than others and we often fail to notice how space facilitates or constrains what we intend to accomplish (Strange & Banning, 2002). If we accept that the behaviors of an instructor are related to the learning of students, then we must analyze the relationship between teaching space and teaching practice among instructors interested in innovating their teaching.

Methods

This observational study quantified classroom activities in STEM courses following instructors' participation in a PDP designed to promote the use of AL instruction. By isolating observed student and instructor behaviors indicative of either active or lecture-based pedagogies, the degree of AL implementation could be calculated as a proportion of overall class time and compared across levels of the independent variables: form of PDP received and physical classroom space.

Context, Participants, and Programs

This study was conducted at a large research-oriented university in the southeastern United States and assessed the influence of physical classroom configuration on instructor and student behaviors. Study participants were recruited from a list of instructors who had applied to take part in PDPs designed to promote more active, student-centered teaching practices. Forty instructors were contacted via email or other personal communication and 22 agreed to participate in the study (Table 2.1).

Table 2.1. Faculty Participant Demographics

Classroom	Discipline	Position	Gender
Auditorium	2 Biology 3 Ecology 2 Physics 1 Engineering	3 Lecturer 2 Assistant Professor 3 Professor	6 Male 2 Female
Small Class	3 Mathematics	1 Lecturer 1 Post-doc Researcher 1 Professor	2 Male 1 Female
SCALE-UP	4 Biology 1 Physics 1 Mathematics 3 Chemistry 2 Computer Science	1 Lecturer 1 Academic Professional 1 Assistant Research Scientist 1 Limited-term Assistant Professor 1 Assistant Professor 4 Associate Professor 2 Professor	7 Male 4 Female

The four PD programs faculty took part in were: 1) Experienced-Novice Instructor Pairing, which were informal mentorships in which faculty members inexperienced in the use of active instruction would learn from, and be supported by, more senior faculty from their own discipline area. Due to the informal nature of these pairings, the type and degree of support provided was not normalized and differed between participants. This program lasted throughout the observed semester in the fall 2016 – 2017 academic year. 2) Peer Learning Assistants Program, which involved hiring undergraduate students who had previously completed a course to assist with instruction of said course. Peer learning assistants were utilized during instruction occurring in the fall 2016 and/or spring 2017 semesters. 3) Department-Based Small Class Initiative, which was funded by the university Provost's office, involved a drastic reduction in

class size taught by faculty within a single department. This department made additional hires specifically to facilitate this initiative and held monthly instructor-led discussion groups to discuss ongoing teaching efforts. This initiative continued through the fall 2016 and spring 2017 semesters. 4) The Student-Centered Active Learning Environment for Undergraduate Programs (SCALE-UP) Learning Community, which was organized by the host university's Center for Teaching and learning, involved monthly meetings during the 2015-2016 academic year and a four-day workshop during the summer of 2016. During the summer workshop, faculty designed instructional materials to be used in their classrooms during instruction in the fall 2016 or spring 2017 semesters. This present study did not investigate the individual PDPs, but rather used these programs to recruit STEM faculty who were learning about, and intended to implement, active instruction practices in the following academic year.

Faculty who agreed to participate were briefed on the nature the study and the extent of their participation requested by the researchers. It was further explained that all data collected would remain confidential and that no information would be disseminated that would individually identify them. All interactions with participants were conducted with informed consent and in accordance with the requirements specified by the university's institutional review board (IRB) for human subjects research.

Observational Data Collection

All behavioral data in the present study were collected using the Classroom Observation Protocol of Undergraduate STEM (COPUS) (Smith et al., 2013). This instrument allows observers to record the actions of instructors and students as defined by 25 pre-specified behaviors (12 for instructors and 13 for students) occurring within two-minute intervals. The authors of the COPUS have demonstrated the tool can be successfully used by a variety of

observers (i.e., science education specialists, K-12 teachers, researchers) while achieving high interrater reliability (Smith et al., 2013).

All data were collected over a period of 10 months during the 2016-2017 academic year. Before data collection, all researchers were trained to use the COPUS by watching video recordings of university science classes that exhibited a wide range of classroom practices. Afterwards, coding discrepancies were identified and discussed by researchers to build conformity of coding criteria. Once a high level of interrater reliability was achieved (Cronbach's Alpha = 0.976), researchers began observations of participating instructors as they taught various undergraduate STEM courses.

Researchers conducted observations of each participants' classroom three times, evenly spaced, within a single semester during the 2016-2017 academic year. Researchers were assigned to instructors based on a rotation system to prevent all observations of an instructor being made by a single researcher. The exact observation dates were not known to the instructors to capture instructional practices representative of the overall course rather than a single day or content unit. However, notice was given to each instructor of a two-week window during which their next observation would occur. This was done to solicit information regarding days that should be excluded from observation (e.g. administration of exams, instructor absence, etc.).

When using the COPUS, researchers marked a behavior as having occurred if it was observed during the current two-minute interval. If a behavior occurred multiple times within the same two-minute interval, no additional "weight" was assigned to that observation. If a behavior began within one two-minute interval and concluded within the next interval, the behavior was reported as having occurred within both intervals. Researchers also included qualitative notes of

classroom behaviors that defied easy categorization by the COPUS. These notes would be discussed by the research group at weekly meetings to further align coding interpretations.

Instructors were observed teaching in one of three types of classrooms: auditoriums, low-occupancy classrooms, and SCALE-UP (Student-Centered Active Leaning Environments for Undergraduate Programs) classrooms. Auditoriums (n = 16) are lecture halls that typically seat over 100 students and have forward-facing seats arranged in rows with tiered elevation. Small, low-occupancy classrooms (n = 6) take place in small classrooms with fixed, forward-facing seats with 20 or fewer students enrolled in the course. SCALE-UP classrooms (n = 22) consist of round tables with multiple computers for groups of students to work collaboratively during the lesson (Beichner et al., 2007) and can seat 72 or fewer students.

Analysis

Once all observational data were collected, the researchers analyzed the frequency at which all instructor and student COPUS codes were observed during each classroom observation. The frequency of each behavioral code determined by obtaining the average number of two-minute intervals in which the target behavior occurred per total two-minute intervals observed. The resulting percentage served as an approximation of class time during which certain behaviors were exhibited. Notably, percentages of instructor or student behaviors do not add up to 100%, as multiple behaviors may be recorded within each two-minute interval.

Table 2.2. Combined COPUS Codes for Instructor and Student Behaviors

Combined Codes	Individual Codes
Instructor Lecturing	Lecturing Demonstrations/Videos
Instructor Questioning	Posing Question Clicker Question Answering Question Follow-Up
Instructor Interacting	Moving and Guiding One-on-One
Student Listening	Listening
Student Speaking	Posing Question Answering Question Whole Class Response Student Presentation
Student Groups	Worksheet Group Clicker Group Other Group

Note. All individual codes are operationalized in Smith et al. (2013).

Researchers noted that several COPUS codes described very similar behaviors within students and instructors. To better characterize behaviors that were consistent with traditional lecture-based instruction or AL instruction, several of the COPUS codes were combined according to behavioral themes of interest to the researchers, particularly with regard to active

and passive instructor and student behaviors during class (see Table 2.2). Overall, six combined codes were created, three for instructors and three for students, and served as our dependent variables. All combined COPUS codes were operationalized among researchers prior to data collection and analysis. If any constituent code of these combined codes was observed during a two-minute interval, the combined code was marked as having occurred during that interval.

Combined instructor codes included: Instructor lecturing, Instructor questioning, and Instructor interacting. “Lecturing” included the COPUS codes for lecturing and classroom demonstrations/videos. “Questioning” included the COPUS codes for posing question, clicker question, answering question, and following-up on a previously asked question. All “questioning” behaviors are defined as those performed with the attention of the entire class. “Interacting” included the COPUS codes for moving-and-guiding and one-on-one interaction with an individual or small group of students without the attention of the rest of the class.

Combined student codes included: Student listening, Student speaking, and Student groups. “Listening” was used as the original COPUS code and was not combined with others. “Speaking” included the COPUS codes for students posing questions, students answering questions, whole class response to questions, and student presentations. All “speaking” behaviors are defined as those performed with the attention of the entire class and instructor. “Groups” included all COPUS codes pertaining to students working in small groups to complete a worksheet, respond to a clicker question, or other task posed by the instructor.

The frequency of each combined behavioral code was then averaged between each participant’s two most active sessions during an observed semester. For all analyses, each subject’s two most “active” classroom observations were identified by the least amount of time students spent passively listening during class. This was done to capture each instructor’s best

efforts at using active, student-centered instruction as they learned to implement these new techniques. While this approach allowed for better characterization of the behaviors of interest, it resulted in a lower overall number of observations and contributed to the need for non-parametric analyses to characterize the data.

To test for differences in trends of instructor and student behaviors between classroom formats, a non-parametric Kruskal-Wallis test was performed using the percentage of time target behaviors were displayed during class time (described above) as the dependent variables and the three classroom formats (auditorium, SCALE-UP, and small classroom) as the levels of the independent variable. When the overall test indicated the presence of significant differences, a post-hoc Dunn's pairwise comparison was performed between the three classroom formats. For the pairwise comparisons that showed statistical significance, Chi-square values were obtained to calculate eta^2 (η^2 = Chi-square/(N-1). Additionally, a Mann-Whitney U test was performed to compare the classroom behaviors observed between SCALE-UP and non-SCALE-UP rooms. A final Mann-Whitney U test compared behaviors observed within SCALE-UP rooms between instructors who had taken part in the SCALE-UP-specific PDP and those received PD non-specific to SCALE-UP.

Results

These analyses revealed that classes taught in SCALE-UP classrooms involved significantly more student group work ($H = 9.927$, $\eta^2 = 0.286$, $P = 0.013$) and instructor interaction with individual or small groups of students ($H = 13.529$, $\eta^2 = 0.366$, $P = 0.001$) than did classes taught in auditorium-style classrooms, which involved more student listening ($H = 12.51$, $\eta^2 = 0.338$, $P = 0.01$) and student speaking in front of the class ($H = 8.752$, $\eta^2 = 0.237$, $P =$

0.023) than in SCALE-UP classrooms. Instruction in small classrooms also involved more student speaking in front of the class than in SCALE-UP classrooms ($H = 5.543$, $\eta^2 = 0.205$, $P = 0.021$) (Figure 2.1).

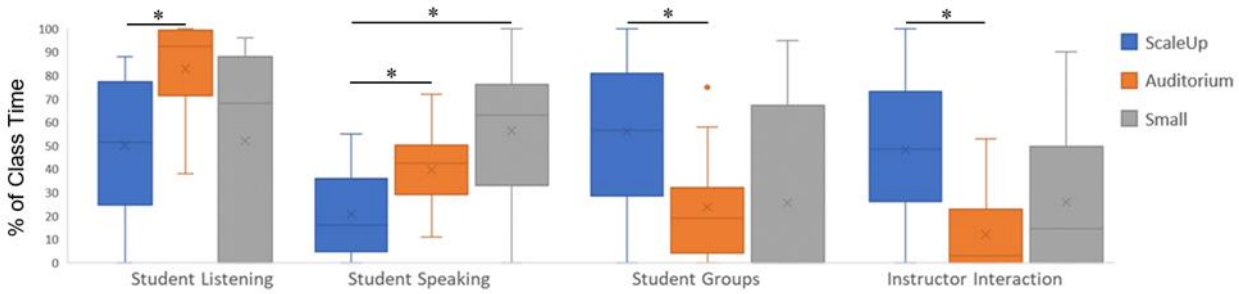

Figure 2.1. Significant differences in instructor and student behaviors between three physical classroom orientations.

Two additional analyses were performed that tested for behavioral differences between a) classes taught in SCALE-UP classrooms and those that were not, and b) differences, *among instructors teaching in a SCALE-UP classroom,* between classes taught by instructors who had taken part in a SCALE-UP-specific PDP and those who took part in a PDP not specific to SCALE-UP. For each analysis, a non-parametric Mann-Whitney test was conducted and p-values obtained. For each statistically significant difference, the z-score was obtained to calculate eta^2 ($z^2/(N-1)$).

The second analysis compared observations of instructor and student behaviors between classes taught in SCALE-UP classrooms ($n = 22$) and non-SCALE-UP ($n = 22$) classrooms (Figure 2.2). A non-parametric Mann-Whitney U Test revealed significantly more student group work ($U = 104$, $\eta^2 = 0.245$, $P = 0.001$) and individualized instructor interaction with students ($U = 91$, $\eta^2 = 0.298$, $P < 0.001$) in SCALE-UP classrooms. Non-SCALE-UP classrooms involved more student listening ($U = 105.5$, $\eta^2 = 0.239$, $P = 0.001$) to instructors' lecturing ($U = 149.5$, η^2

= 0.109, P = 0.03), and more student speaking (U = 100, η^2 = 0.259, P = 0.001) in front of the class than was observed in classes taught in SCALE-UP classrooms.

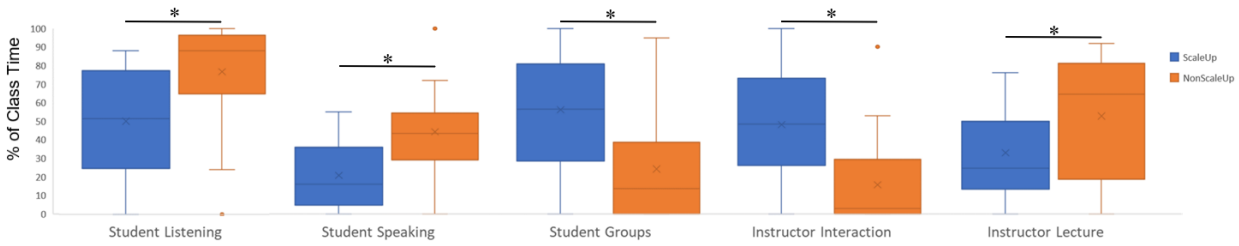

Figure 2.2. Significant differences in instructor and student behaviors between SCALE-UP and non-SCALE-UP classrooms.

Our final analysis examined whether physical classroom configuration predicted active classroom behaviors better than the PDP in which an instructor participates. We examined 11 instructors teaching in SCALE-UP classrooms, six of whom attended a PDP specific to using the SCALE-UP classroom prior to the start of semester. The remaining five instructors took part in various non-SCALE-UP specific PDPs. A Mann-Whitney U Test revealed no difference in instructor or student behavior during SCALE-UP classes taught by instructors who had received SCALE-UP specific PD and those who had not.

Discussion

These data suggest that the more active behaviors observed in the SCALE-UP classrooms are better predicted by the classroom itself than by the type of PDP the instructors attended at the university. Specifically, instructors who taught in SCALE-UP classrooms tended to conduct

classes that frequently contained features of AL instruction. In these classrooms, the instructors spent less time lecturing and more time interacting with individual or small groups of students as they worked to solve problems related to the course content. These tendencies held regardless of the type of PDP that instructors received.

An important component of this analysis is the prior experience of instructors with AL techniques. All the instructors in this study were new to both the use of AL techniques and teaching in SCALE-UP classrooms. Our study suggests that a SCALE-UP classroom may promote AL instruction among instructors who are new to this approach and that SCALE-UP classrooms may be a powerful tool for assisting STEM instructors while implementing AL instruction.

The present study indicates that instructors in auditorium-style classrooms, on average, spent more time lecturing to students who spent more time passively listening than in courses taught by instructors in other classroom configurations. This supports university STEM faculty's perceptions that the physical configuration of a classroom can create added difficulty for using AL practices (Shadle, Marker, & Earl, 2017). However, outliers within our data also support previous work indicating that 1) student-centered teaching can be implemented effectively regardless of the orientation of the room and 2) teaching within an classroom designed to be compatible with AL instruction does not necessarily result in more student-centered teaching (Lund et al., 2015). Our data suggests that while teaching in a SCALE-UP classroom supports STEM faculty's initial efforts to use AL instruction, it is in-and-of-itself insufficient for promoting instructional change.

SCALE-UP or other non-traditional classrooms may not be available for all instructors learning to implement AL instruction. PDPs should tailor their instruction and support of faculty

to the classroom(s) in which the instructors will teach their courses, allowing expert instructional developers the opportunity to provide individualized guidance to address barriers to AL use that may arise from the physical constraints of the room. Ultimately, a SCALE-UP classroom may provide instructors who are new to AL instruction an ideal environment to build their instructional skills. Further research examining the transferability of these teaching strategies to traditional teaching spaces is needed.

These findings underscore the importance of the physical space in which STEM instructors teach and the role of PDPs aimed at promoting the adoption of AL instruction. While SCALE-UP spaces have been shown to improve students' performance as measured by their course grades (Gaffney et al., 2008; Brooks, 2011; Cotner et al., 2013), our study suggests that the SCALE-UP environment can also influence whether an instructor is likely to use AL strategies when teaching.

Potential explanations for this could include both practical and perceptual influences of the teaching space on instructors' practice. Teaching within a SCALE-UP room allows a level of mobility not typical of traditional classrooms and facilitates students' access to peers and instructors' access to students. If training in AL instruction is presented to instructors in a way that emphasizes student group work on course content, the degree of mobility their classroom allows may either support or hinder their implementation of AL techniques. Alternatively, spatially decentralizing the instructor from students' focus may assist in reconceptualizing the role of the instructor from a provider of knowledge to a facilitator of students' knowledge construction. Traditional classrooms normally position students facing directly towards the instructor at the front of the room while SCALE-UP rooms place the instructor station in the center of a room of students facing inwards towards their peers. In all cases, additional

qualitative studies are needed to examine the experiences of faculty during their efforts to use Al instruction across a variety of classroom spaces.

This analysis of the influence of classroom space on instructional change of STEM instructors is the first of its kind and invites further exploration of additional factors that may aid or hinder the efficacy of PDPs intended to promote adoption of AL instruction. Additional factors related to space and PDPs that should be explored include: 1) the relationship of PDP and instructional space while learning to use AL techniques, 2) instructors' orientation to student learning and teaching in an AL approach, and 3) the instructional space's influence on the quality of AL implementation. Such studies would provide additional insight into how to cultivate change STEM instruction at IHE.

This study suggests that SCALE-UP classrooms may provide considerable benefit to instructors learning to use student-centered teaching practices. However, SCALE-UP rooms can be costly to create, limiting instructor and student access. If SCALE-UP rooms can be leveraged as a training ground for active instruction, we must also investigate the forms of support necessary to help faculty transfer their new teaching practices to traditional classrooms.

Future Directions

This observational study characterizes observed instructor and student classroom behaviors following the instructor's participation in a PDP intended to promote the use of active instructional practices. The data presented here highlight several important questions requiring additional investigation. First, does the STEM subject matter influence the ease of adopting active instructional practices? Because individual and context-specific barriers may differ by discipline or department, a one-size-fits-all approach to supporting instruction change may be

ineffective (Lund & Stains, 2015). In the interest of developing more individualized forms of instructional support for faculty, the DBER (discipline-based education research) communities could benefit from a mixed-methods study examining which STEM disciplines experience the greatest difficulty implementing active instruction and why. For example, are biological subjects which frequently cover abstracted concepts like evolution or phosphorus cycling more difficult to teach actively than subjects typically covering more concrete topics as in computer programming?

Second, while the present study examined instructor and student behaviors typical of student-centered classrooms as indicators for the amount of AL instruction used, it does not offer an analysis of the quality of that instruction. If faculty use AL instruction which inadvertently includes changes not intended by PD providers, the resulting instruction may misalign with central features of the teaching strategy (Henderson & Dancy, 2008; Turpen, Dancy, & Henderson, 2010) and result in diminished benefit to students. To better understand the relationship between PDP support, classroom space and instructional practice, additional studies examining the fidelity of faculty's AL instruction following participation in PD and whether differences may be observed between classroom configurations.

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References

Addy, T., Blanchard, M. (2010). The problem with reform from the bottom up: instructional practices and teacher beliefs of graduate teaching assistants following a reform-minded university teacher certificate programme. *International Journal of Science Education 32,* 1045-1071.

Andrews, T., & Lemons, P. (2015). It's Personal: Biology Instructors Prioritize Personal Evidence over Empirical Evidence in Teaching Decisions. *CBE-Life Science Education*. 14, ar7.

Andrews, T., Leonard, M., Colgrove, C., & Kalinowski, S. (2011). Active learning not associated with student learning in a random sample of college biology courses. *CBE-Life Sciences Education*. 10: 394-405.

Baiduc, R., Linsenmeier, R., & Ruggeri, N. (2016). "Mentored Discussions of Teaching: An Introductory Teaching Development Program for Future STEM Faculty." *Innovative Higher Education, 41*(3): 237-254.

Beichner, R., Saul, J., Abbott, D., Morse, J., Deardorff, D., Allain, R., Bonham, S., Dancy, M., & Risley, J. (2007). The Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) Project. *Research-based reform of University Physics*. 1, 2-39.

Braxton, J., Milem, J., Sullivan, A. (2000). The influence of active learning on the college student departure process. (2000). 71, 569-590.

Brooks, D. (2011). Space matters: The impact of formal learning environments on student learning. *Br. J. Educ. Technol*. 42, 719-726.

Clarke, J., & Boud, D. (2016). "Refocusing Portfolio Assessment: Curating for Feedback and Portrayal." *Innovations in Education and Teaching International*. doi:10.1080/14703297.2016.1250664.

Cotner, S., Loper, J., Walker, J., & Brooks, D. (2013). "It's Not You, It's the Room" –Are the High-Tech, Active Learning Classrooms Worth It? *J. Coll. Sci. Teaching.* 42, 82-88.

Crouch, C. & Mazur, E. (2001). Peer instruction: ten years of experience and results. *Am J Phys.* 69: 970 - 977.

Dancy, M., & Henderson, C. (2010). Pedagogical practices and instructional change of physics faculty. *American Journal of Physics,* 78, 1056-1063.

Ebert-May, D., Derting, R., Hodder, J., Momsen, J., Long, T., & Jardeleza, S. (2011). What we say is not what we do: effective evaluation of faculty professional development programs. *BioScience, 61*: 550-558.

Ebert-May, D., Derting, T., Henkel, T., Maher, J., Momsen, J., Arnold, B., & Passmore, H. (2015). Breaking the cycle: Future faculty begin teaching with learner-centered strategies after professional development. 14, 1-12.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410-8415.

Freeman, S., Haak, D., & Wenderoth, M. (2011). Increased Course Structure Improves Performance in Introductory Biology. *CBE-Life Science Education.* 10, 175-186.

Gaffney, J., Richards, E., Kustusch, M., Ding, L., & Beichner, R. (2008). Scaling up education reform. *J Coll Sci Teach.* 37: 48-53.

Garet, M., Porter, A., Desimone, L., Birman, B., & Yoon, K. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, 38: 915-945.

Gast, I., Schildkamp, K., van der Veen, J. (2017). Team-Based Professional Developement Interventions in Higher Education: A Systematic Review. *Rev. Educ. Res*. 87, 736-767.

Gibbs, G., & Coffey, M. (2004). The impact of training of university teachers on their teaching skills, their approach to teaching and the approach to learning of their students. *Active Learning in Higher Education* 5: 81-101.

Golde, C., & Dore, T. (2001). *At Cross Purposes: What the Experiences of Today's Doctoral Students Reveal about Doctoral Education*. Philadelphia, PA: Pew Charitable Trusts.

Graham, M., Frederick, J., Byars-Winston, A., Hunter, A., & Handelsman, J. (2013). Increasing persistence of college students in STEM. *Science*. 341, 1455-1456.

Haak, D., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased structure and active learning reduce the achievement gap in Introductory Biology. *Science*. 332, 1213-1216.

Henderson, C., & Dancy, M. (2008). Physics faculty and educational researchers: Divergent expectations as barriers to the diffusion of innovations. *American Journal of Physics*. *76*, 79.

Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating Change in Undergraduate STEM Instructional Practices: An Analytic Review of the Literature. *Journal of Research in Science Teaching, 48*(8): 952-984.

Henderson, C., Dancy, M., Niewiadomska-Bugaj, M. (2012). Use of research-based instructional strategies in introductory physics: Where do faculty leave the innovation-decision process? *Physics Educational Research*, *8*, 1-15.

Hurtado, H., Eagan, M., Pryor, J., Whang, H., & Tran, S. (2012). Undergraduate teaching faculty: The 2010-11 HERI faculty survey. *Los Angeles: Higher Education Research Institute*.

Hutchins, K., & Friedrichsen, P. (2012). Science Faculty Belief Systems in a Professional Development Program: Inquiry in College Laboratories. *J. Sci. Teach. Educ.* 23, 867-887.

Johnson, D., Johnson, R., & Smith, K. (1991). Cooperative Learning: Increasing College Faculty Instructional Productivity (ASHE-ERIC Higher Education Report No. 4) Washington, DC: George Washington University.

Kim, K., Sharma, P., Land, S., & Furlong, K. (2013). Effects of Active Learning on Enhancing Student Critical Thinking in an Undergraduate General Science Course. *Innov. High. Educ.* 38, 223-235.

Lund, T., Pilarz, M., Velasco, J., Chakraverty, D., Rosploch, K., Undersander, M,. & Stains, M. (2015). The Best of Both Worlds: Building on the COPUS and RTOP Observation Protocols to Easily and Reliably Measure Various Levels of Reformed Instructional Practice. *CBE Life Science Education*, 14(2): ar18.

Lund, T., & Stains, M. (2015). The importance of context: an exploration of factors influencing the adoption of student-centered teaching among chemistry, biology, and physics faculty. *International Journal of STEM Education, 2*(13), doi:10.1186/s40594-015-0026-8

Mazur, E. (2009) Farewell, lecture? *Science*, 323, 50-51.

Miller, C., & Metz, M. (2014). A comparison of professional-level faculty and student perceptions of active learning: its current use, effectiveness, and barriers. *Adv. Physiol. Educ*. 38, 246-252.

National Academies of Sciences and Medicine (2018). “Indicators for monitoring undergraduate STEM Education.” The National Academies Press: Washington, DC.

Oleson, A., & Hora, M. (2014). Teaching the way they were taught? Revisiting the sources of teaching knowledge and the role of prior experience in shaping faculty teaching practices. *Higher Education*, DOI 10.1007/s10734-013-9678-9

Pembridge, J., Allam, Y., & Davids, L. (2015). “Influence of Professional Demographics on Faculty Feedback in Asynchronous, Video-Annotated Peer Review (VAPR).” *Frontiers in Education Conference (FIE)*, 1-8.

Pfund, C., Miller, S., Brenner, K., Bruns, P., Chang, A., Ebert-May, D., Fagen, A., Gentile, J., Gossens, S., Ishrat, K., Labov, J., Pribbenow, C., Susman, M., Tong, L., Wright, R., Yuan, R., Wood, W., & Handelsman, J. (2009). Summer Institute to Improve University Science Teaching. 324, 470 471.

Postareff, L., Lindblom-Ylänne, S., & Nevgi, A. (2008). A follow-up study of the effect of pedagogical training on teaching in higher education. *Higher Education*. 56, 29-43.

Prince, M. (2004). Does Active Learning Work? A Review of the Research. *Journal of Engineering Education*. 93, 223-231.

Rodenbusch, S., Hernandez, P., Simmons, S., & Dolan, E. (2016). Early Engagement in Course Based Research Increases Graduation Rates and Completion of Science, Engineering, and Mathematics Degrees. *CBE-Life Science Education*. 15, ar20.

Seldin, P., Miller, E., & Seldin, C. (2010). *The Teaching Portfolio: A Practical Guide to Improved Performance and Promotion/Tenure Decisions*. New York: Jossey Bass.

Shadle, S., Marker, A., & Earl, B. (2017). Faculty drivers and barriers: laying the groundwork for undergraduate STEM education reform in academic departments. *International Journal of STEM Education*. 4:8.

Shulman, L. (1992). "Merging Content Knowledge and Pedagogy: An Interview with Lee Shulman." *Journal of Staff Development, 13*(1): 14-16.

Simon, B., Bales, E., Griswold, W., & Cooper, S. (2011). "Case Study: Faculty Professional Development Workshops for Innovation Diffusion." *Proceedings of the 42nd ACM Technical Symposium on Computer Science Education*, 673-78.

Slowinshi, M., Walz, K., & Alfano, K. (2016). "Renewable Energy Technician Education: The Impact of International Faculty Collaboration." *Proceedings of the ASEE Annual Conference and Exposition*, 39.

Smith, M., Jones, F., Gilbert, S., Wieman, C. (2013). The Classroom Observation Protocol for Undergraduate STEM (COPUS): A New Instrument to Characterize University STEM Classroom Practices. *CBE-Life Science Education*. 12, 618-627.

Stes, A., Min-Leliveld, M., Gijbels, D., Van Petegem, P. (2010). The impact of instructional development in higher education: The state-of-the-art of the research. *Educ. Res. Rev.*, 5, 25-49.

Stoltzfus, J. & Libarkin, J. (2016). Does the Room Matter? Active Learning in Traditional and Enhanced Lecture Spaces. *CBE-Life Science Education*. 15(4): ar68

Strange, C., & Banning, J. (2002). *Educating by Design: Creating Campus Learning Environments That Work*. San Francisco: Jossey-Bass, 15.

Strayer, J. (2012). How learning in an inverted classroom influences cooperation, innovation and task orientation. *Learn Environ Res*. 15: 171-193.

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

Walczyk, J., Ramsey, L., & Zha, P. (2007). Obstacles to instructional innovation according to college science and mathematics faculty. *Journal of Research in Science Teaching. 44*(1): 85-106.

Whiteside, A., & Fitzgerald, S. (2009). Designing learning spaces for active learning. *Implications, 7,* 1-6.

Whiteside, A., Jorn, L., Duin, A., Fitzgerald, S. (2009). Using the PAIR-up Model to Evaluate Active Learning Spaces. (available at https://er.educause.edu/articles/2009/3/using-the pairup-model-to evaluate-active-learning-spaces).

CHAPTER 3

SUPPORTING UNDERGRADUATE STEM EDUCATORS' INSTRUCTION: A LONGITUDINAL INVESTIGATION OF FACULTY INSTRUCTION POST-PROFESSIONAL DEVELOPMENT

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Abstract

Active learning (AL) instructional practices are a powerful tool for improving student learning outcomes and retention in university STEM, but learning to teach in this way is difficult. To support the adoption of AL instruction, professional development programs (PDP) are created to assist university faculty. However, most PDP support lasts less than one semester. Furthermore, there is little longitudinal research examining the longevity of instructional outcomes from PDPs. This is restrictive to our understanding of how to promote persisting use of AL instruction in university STEM. The present study is a mixed-methods extension of a previous exploration of STEM faculty's use of AL instruction post-participation in a PDP. Classroom observations and instructor interviews were used to characterize faculty's instructional practices and experiences over two consecutive academic years. The analyses revealed that: instructors who increased or maintained a high degree of AL instruction over time were those receiving ongoing support; administrative barriers completely reverted high AL-use instruction back to lecture; and some instructors came to view their use of AL instruction as dependent on one or more teaching resources. This suggests that PDPs can sustain instructional change through continuing support that responds to emerging situational barriers to AL instruction.

Introduction

Despite calls for wide-spread adoption of student-centered teaching practices throughout American universities (AAAS, 2011), most STEM instructors continue to use traditional, lecture-based teaching (Miller & Metz, 2014; Hurtado et al., 2012). In answer, a variety of professional development programs (PDP) have been created to support long-term adoption of active learning (AL) instruction among university STEM faculty. However, workshops, seminars, and other forms of PD aimed at reforming undergraduate instruction are unlikely to bring about persisting changes in faculty teaching behavior if they are not accompanied with continuing, critical feedback on the instructor's efforts to implement the strategies (Levinson-Rose & Menges, 1981).

STEM faculty sometimes inadvertently follow their own interpretation of AL instruction, which can lead to misalignment with necessary details of the strategy described by PD facilitators (Henderson & Dancy, 2008; Turpen, Dancy, & Henderson, 2010). If these modifications to AL strategies are significant, they can reduce the innovation's effectiveness at improving student comprehension, performance, and engagement with course material. The resulting discrepancy between the student benefits observed by the instructor and what was described during dissemination efforts may lead to faculty dissatisfaction and discontinuation of adopting research-based instructional strategies.

These sometimes-problematic interpretations made by faculty using AL techniques are partially formed through the lens of the instructor's experiences, including their own past instruction and the instruction they observed as a student in STEM courses (Oleson & Hora, 2014). For example, Ebert-May et al (2011) found an inverse relationship between class size and observational scores measuring the frequency of AL used during class. This finding was

consistent with the work of Murray and MacDonald (1997), who suggested that once the number of students reaches 40 or greater, instructors tend to perceive a class as a lecture. If STEM faculty recall the instruction they received in high-enrollment courses as being primarily or exclusively lecture, they may be more likely to emulate that instruction within similar classroom contexts.

To assess the efficacy of PDPs' support of STEM faculty, questionnaires are commonly used to collect faculty's self-reported use of the teaching innovation post-participation in PD. However, faculty often overestimate the degree to which they use AL instruction in their classrooms (Ebert-May et al., 2011) and their self-reported use of AL instruction does not necessarily correlate with their students' learning gains (Andrews et al., 2011). This suggests a discrepancy between faculty conceptions of AL instruction and its intended use, as well as a need to assess PD outcomes through classroom observation. Combining direct classroom observations with faculty's self-described teaching experiences appears to be needed to better assess the instructional outcomes of PDPs, identify the challenges STEM faculty face while implementing AL instruction over time, and provide evidence-based suggestions to PD designers.

The difficulties STEM faculty encounter while innovating their instruction indicate a need for more effective forms of support. Faculty PD appears to be best supported through intervention programs lasting multiple semesters or years (Emerson & Mosteller, 2000; Ebert-May et al., 2015). However, the long-term impact of PDPs for instructional change, including the specific forms of support that may enhance the longevity of change, are not yet well understood (Stes et al., 2010; Steinert et al., 2016; Manduca et al., 2017). PDP designers and university administrators, who allocate considerable time and resources to these programs, would benefit

from the products of observation-based longitudinal assessments of the relationship between PDPs and participating faculty's instructional change efforts over time.

The central research question of this study is: How does STEM faculty's use of AL instruction change over time and to what do faculty attribute changes in their instruction? This study sought to combine STEM faculty's self-described experiences teaching over two years with observational data from their instruction to examine 1) the longevity of instructional change, 2) the difficulties encountered in continuing their teaching innovation over time, and 3) how we might more effectively support STEM faculty's continued use of AL instruction.

Related Literature

Barriers to Instructional Change

Science education researchers have developed an extensive body of literature detailing the barriers to faculty use of AL. Barriers to attempting instructional innovation can consist of time, training, and lack of incentives for the effort required for instructional innovation (Brownell & Tanner 2012; Henderson, 2011). While PDPs can anticipate and provide support for the immediate barriers faculty will face while learning to use AL instruction, they cannot anticipate the barriers that may emerge months or years post-participation in PDPs. Because most instructional PDPs at the university level are relatively brief, our understanding of the longevity of instructional change and the factors that hinder it are limited.

Instructional practices may be the result of both individual and situational factors and faculty require support to identify and overcome associated barriers which can take the form of any externally imposed change to the context or requirements of the teaching practices to which they are accustomed. Many STEM instructors will employ lecture-centric pedagogy while

espousing beliefs on teaching and learning that are more consistent with evidence-based instruction (Henderson & Dancy, 2007). Further complicating the instructional change process is the influence of an instructor's context on their practice. For example, instructors wishing to use AL instruction in their classrooms may find their use of the teaching strategy limited by the physical constraints of the room relative to peers teaching in rooms that have been specialized to support Al instruction (Whitt et al., in review).

If a PDP has not provided specific support to that instructor to overcome a situational barrier, it may hinder or prevent instructional change. In the K-12 literature, efforts to support the adoption of reform-based instruction do not lead to sustained use when they do not provide individualized, expert feedback on their implementation (Stewart, 2014). In higher education, however, the common practice of self-reported AL instruction use following PDP participation has resulted in unreliable assessments of the outcomes of PDP on instructional change in STEM (Ebert-May et al., 2011), regardless of the forms and duration of support provided. To better understand the efficacy of PDPs at promoting long-term instructional change, more longitudinal research on STEM faculty instruction is needed.

Adult Learning Theory and Professional Development

In this study, the guiding theory on faculty learning is based on Knowles' (1980) adult learning theory, or "andragogy." This theory of learning asserts that the needs and motivations of adult learners differ from those of young students and that effective support for adults' learning should specifically attend to these inclinations. The four major assumptions of this theory are that as people mature, they (1) change from dependent to highly self-directed mindsets, (2) accumulate a considerable reservoir of experiences that can be leveraged as a resource of

learning, (3) are ready and willing to learn largely to the extent that the information is relevant to their professional and/or personal tasks and (4) can be immediately applicable to those tasks.

Most central to this study is how these assumptions of adult learners can be leveraged to inform the creation of PDPs that meet the needs and inclinations of faculty instructors learning to teach in new ways. The self-directed nature of faculty as learners supports claims that effective instructional change strategies are generally unsuccessful when following a "top-down" approach and should instead attend to the goals and beliefs of the individuals involved (Henderson, Beach, & Finkelstein, 2011). Moreover, these top-down approaches fail in part because they ignore the knowledge and experiences of faculty (Henderson & Dancy, 2008). Following the suggestions of Oleson and Hora (2014), PD developers should recognize and build upon faculty's prior experiences related to teaching and learning to support change.

The latter two assumptions of Adult Learning Theory emphasize the preference for task-relevant, immediately applicable learning. However, creating a PDP that provides this sort of instruction and support is difficult. The challenges and tasks of teaching in higher education can be highly variable, both between instructors and over time. If changes to teaching context, course and classroom assignment, and access to teaching resources alter the immediate applicability -or perception of applicability- of learned AL instructional techniques, then longitudinal forms of PD would be most appropriate for supporting faculty's instructional change. If we wish the goal of educational PDPs to be long-lasting changes to future teaching (Ericsson, 2008), then PDPs must be responsive to the changing experiences of STEM instructors.

In K-12 education, high quality PD for teaching is relevant to an instructor's own practice, involves collaboration, emphasizes content and is of adequate duration (Luft et al., 2020). Thus, effective PDPs should attend to the tasks of teaching, assessment, and reflection as

they relate to the problems in the learner's own instructional setting (Darling-Hammond & McLaughlin, 1995) in such a way that respects the autonomy of the individual (Henderson, Beach, & Finkelstein, 2011) and builds upon their existing knowledge and experience (Oleson & Hora, 2014). Finally, because the problems and nature of one's instructional setting is subject to change over time, effective PD must forgo the traditional one-or-two day workshop approach in favor of providing ongoing opportunities for faculty support over prolonged time to affect and sustain instructional change (Cohen & Hill, 2000; Garet et al., 2001).

In this study, adult learning theory guides the interpretation of data. That is, the collected and analyzed observational and interview data will be used to further understand how principles of adult learning may be leveraged to meet the needs of faculty's instructional change efforts over time. This will be explored in the discussion section of this paper.

Methods

A mixed-methods study was used to investigate how STEM faculty support and enact their use of active instructional techniques over time post-participation in PD. Our goal was to inductively examine faculty members' experiences using AL instruction, so qualitative research methods were necessary (Creswell & Creswell, 2017). However, previous studies have established that sole reliance on instructors' self-reported use of AL instruction can yield inaccurate representations of actual classroom practices (e.g. Ebert-May et al., 2011). Consistent with a mixed-methods design, we collect quantitative measures of classroom observations as well as insights from semi-structured interviews with faculty regarding their recent teaching experiences.

Context

This study was conducted at a large research-oriented university in the southeastern United States. Participants were recruited from a list of instructors who took part in a similar study that had recently concluded (Whitt et al., in review). The faculty members were contacted via email and invited to continue in this longitudinal extension of the original study. Of the 22 prior participating faculty, six elected to continue participation.

Participants ranged in STEM discipline, including computer science, mathematics, physics, anatomy and physiology, and biochemistry. Each instructor had taken part in a previous study in which their instructional practices were observed following their participation in one of four PDPs designed to promote the use of active instruction: 1) Experienced-Novice Instructor Pairing, which were informal mentorships in which faculty members inexperienced in the use of active instruction would learn from, and be supported by, more senior faculty from their own discipline area. Due to the informal nature of these pairings, the type and degree of support provided was not normalized and differed between participants. This program lasted throughout the observed semester in the fall 2016 – 2017 academic year. 2) Peer Learning Assistants Program, which involved hiring undergraduate students who had previously completed a course to assist with instruction of said course. Peer learning assistants were utilized during instruction occurring in the fall 2016 and/or spring 2017 semesters. 3) Department-Based Small Class Initiative, which was funded by the university Provost's office, involved a drastic reduction in class size taught by faculty within a single department. This department made additional hires specifically to facilitate this initiative and held monthly instructor-led discussion groups to discuss ongoing teaching efforts. This initiative continued through the fall 2016 and spring 2017 semesters. 4) The Student-Centered Active Learning Environment for Undergraduate Programs

(SCALE-UP) Learning Community, which was organized by the host university's Center for Teaching and learning, involved monthly meetings during the 2015-2016 academic year and a four-day workshop during the summer of 2016. During the summer workshop, faculty designed instructional materials to be used in their classrooms during instruction in the fall 2016 or spring 2017 semesters.

The instructors who agreed to participate were briefed on the nature of the study and the extent of their participation requested by the researchers. It was further explained that all data collected would remain confidential and that no information would be disseminated that would individually identify them. All interactions with participants were conducted with informed consent and in accordance with the requirements specified by the institutional review board (IRB) for human subjects research at the authors' university.

Participants

A brief description of the six faculty participants and their experiences in the prior study follow. Exact titles of faculty's positions at the university have been changed to "instructor" and the names of the courses taught were removed to prevent identification of participants.

Logan has a dual appointment as researcher and instructor of biochemistry and a majority of his work is currently dedicated towards research. In both years of observation, he taught in one of several newly built SCALE-UP classroom on campus designed to improve student-student and student-instructor interactions –two behaviors common in classrooms using AL instruction.

In the first year of this study, he took part in the mentor-mentee PD initiative. He was paired with a faculty mentor who is a faculty member in biochemistry and an accomplished

researcher in science education. Support from the PD included shared teaching materials, weekly discussions, and feedback on active instruction use throughout the observed semester.

Brent is an instructor in computer science. For all observations, he taught the same introductory level undergraduate course. Before his first year of observations, he took part in the SCALE-UP PDP. In the initial study, Brent taught in a SCALE-UP classroom and demonstrated the highest use of active instructional practices among the 22 STEM faculty participants, demonstrating 0% time lecturing and 84% of student time spent working in groups on course material.

Brent's context was unique in our study. For his second observed year of teaching, he agreed to be observed teaching the same course in a SCALE-UP classroom, as he did in his first year, while simultaneously teaching another section of that course in a traditional, auditorium-style classroom.

Alan is an instructor in the mathematics department. Prior to the start of his first observed year of instruction, he took part is his department's small class initiative to help facilitate the use of active instruction in mathematics courses. In both years of observation, he taught in a small (< 20 students) classroom with fixed seating. Support from this initiative also came in the form of monthly department meetings to discuss instruction and, in his case, the assistance of undergraduate learning assistants.

Similar to Brent, Alan demonstrated an affinity for AL instruction. In the first year of observation, over three quarters (76.5%) of student class time was spent engaging with the course material in groups while only 5.5% was dedicated to lecture.

Neil is an instructor in the life sciences teaching primarily high-enrollment (~250 student) introductory courses in large auditorium-style classrooms. He did not take part in a PDP prior to

the initial study but is well-informed regarding science education research literature and is highly reflective on his teaching practices. He expressed interest in joining the initial study after discussing his intent to try implementing AL instructional practices in his classes.

> "I've taught myself to teach as a pure lecturer and there's a huge disconnect between that and what I know the research says about…the way that students learn best."

Though Neil described his past instruction as purely lecture-based, his teaching during the first year dedicated roughly 1/5th of overall class time to active instruction, with 79% of time spent on lecture and 21.5% spent on student group work. And although he was content with how students responded to his use of case studies, he described personal barriers to more extensive implementation and his plans for increasing active instruction in the coming year.

> "It's very hard for me to let student learn on their own. One of the problems with the cases was that I felt like there was a certain point of content that I needed to get to before I introduce this case rather than letting them learn *through* the case."
>
> "That's my plan before spring. I am gonna…make room for more cases and then I wanna keep shifting more of the lecture type content out of the classroom so that I also have more room for …summarizing things at the end of every class period and time for engagement activities at the beginning."

Demetri is an instructor in the physics department. He primarily teaches high-enrollment (~170 student) introductory courses in large auditorium-style classrooms. He took part in the Peer Learning Assistant (PLA) Program and utilized the undergraduate PLAs during both years

of observed teaching. He had seven PLAs who he described as instrumental to his use of active instruction.

> "I was using PLAs for the first time and they were absolutely fantastic…I felt the students enjoyed having them in the class…it made doing active learning in a large lecture format much more realistic."

His first year of instruction consisted of roughly 1/3rd of class time dedicated to students engaging with course material in groups (29.5%) and 44.5% of class time spent on lecture. The remainder of class time unaccounted for by these two behaviors was primarily posing questions to the class as a whole with individual students answering in call-response fashion.

Rachel shares several similarities with Logan. She is a dual-appointed researcher and instructor in biochemistry with a majority of her time allocated toward research. In the first year of this study, she took part in the mentor-mentee PD initiative. In fact, she worked with the same faculty mentor as Logan and received the same forms of PD support. Rachel also taught in a SCALE-UP classroom during both years of observation.

She uses case studies to introduce material to students through their small group work before going over the topic as a class and describes her role as a teacher in this environment as,

> "…more of a facilitator of their learning instead of just feeding them information. I think this is sometimes why people don't like active learning is because it makes the students take more responsibility for their own learning. So for the case studies, a lot of the material is introduced by them working on their own or with their group…and then we go over it."

The classroom observations of her first year reflect this mindset, as well over half (65%) of class time is spent on students engaging with concepts through group work and 23.5% of class time as lecture.

Data Collection

Data used in this study were collected across two years and consist of both quantitative and qualitative sources. Data collected in the 2016-2017 academic year included the observational data from Whitt et al. (in review) and interview data collected immediately following the semester in which the observations were made. Data collected in the 2017-2018 academic year included observational data of the second year of instruction and an interview immediately following the semester in which instructors were observed. The research team consisted of six members who were involved in the collection and analysis of both observational and interview data to improve the internal validity and reliability of findings (Merriam, 2009).

Observational Data Collection

All behavioral data in the present study were collected using the Classroom Observation Protocol of Undergraduate STEM (COPUS) (Smith et al. 2013). This instrument allows observers to record the actions of instructors and students as defined by 25 pre-defined behaviors (12 for instructors and 13 for students) occurring within two-minute intervals. The authors of the COPUS have demonstrated the tool can be successfully used by a variety of observers (i.e., science education specialists, K-12 teachers, researchers) while achieving high interrater reliability (Smith et al., 2013).

Observational data were collected over a period of 10 months during the 2017-2018 academic year. Before data collection, all researchers were trained to use the COPUS by

watching video recordings of university science classes that exhibited a wide range of classroom practices. Afterwards, coding discrepancies were identified and discussed by researchers to build conformity of coding criteria. Once a high level of interrater reliability was achieved (Cronbach's Alpha = 0.976), researchers began observations of participating instructors.

Researchers conducted observations of each participants' classroom three times, evenly spaced, within a single semester during the 2017-2018 academic year. Researchers were assigned to instructors based on a rotation system to prevent all observations of an instructor being made by a single researcher. The exact observation dates were not known to the instructors to capture instructional practices representative of the overall course rather than a single day or content unit. However, notice was given to each instructor of a two-week window during which their next observation would occur. This was done to solicit information regarding days that should be excluded from observation (e.g. administration of exams, instructor absence, etc.). Of note: all instructors taught within similar physical classroom configurations between the two semesters of observation included in this study, with the exception Brent (described above).

When using the COPUS, researchers marked a behavior as having occurred if it was observed during the current two-minute interval. If a behavior occurred multiple times within the same two-minute interval, no additional "weight" was assigned to that observation. If a behavior began within one two-minute interval and concluded within the next interval, the behavior was reported as having occurred within both intervals. Researchers also included qualitative notes of classroom behaviors that defied easy categorization by the COPUS. These notes would be discussed by the research group at weekly meetings to further align coding interpretations.

Interview Data Collection

All participants were interviewed once per year, primarily by one of three researchers. Attempts were made to keep the interviewer-interviewee pairs consistent between years but scheduling conflicts did not allow for this in all cases. Each interview was conducted immediately following the semester in which the participant's instruction was observed: the first during the 2016-2017 academic year, and the second during 2017-2018. Interviews were semi-structured, allowing interviewers to adjust questioning based on participants answers while allowing for a degree of consistency between each interview (Bogdan & Biklen, 2006; Kirk & Miller, 1986). Interviews lasted an average of 45 minutes.

Questions were prepared by the research team to prompt participants' elaboration on topics related to research questions, which included their recent teaching, difficulties they experienced implementing AL instruction, views on undergraduate learning, and perceptions of students' experiences. For each question, the interview protocol included probing questions which could be used to invite further elaboration from faculty on related topics. The second interview included additional questions to follow up on topics and responses participants described in the first interview. Audio recordings were made of each interview and transcribed prior to analysis.

Data Analysis

Observational Data Analysis

Once all observational data were collected, the researchers analyzed the frequency at which all instructor and student COPUS codes were observed during each classroom observation. The frequency of each behavioral code determined by obtaining the average number of two-minute intervals in which the target behavior occurred per total two-minute intervals

observed. The resulting percentage served as an approximation of class time during which certain behaviors were exhibited. Notably, percentages of instructor or student behaviors do not add up to 100%, as multiple behaviors may be recorded within each two-minute interval.

Table 3.1. Combined COPUS Codes for Instructor and Student Behaviors

Combined Codes	Individual Codes
Instructor Lecturing	Lecturing Demonstrations/Videos
Instructor Questioning	Posing Question Clicker Question Answering Question Follow-Up
Instructor Interacting	Moving and Guiding One-on-One
Student Listening	Listening
Student Speaking	Posing Question Answering Question Whole Class Response Student Presentation
Student Groups	Worksheet Group Clicker Group Other Group

Note. All individual codes are operationalized in Smith et al. (2013).

Researched noted that several COPUS codes described very similar behaviors within students and instructors. To better characterize behaviors that were consistent with traditional lecture-based instruction or AL instruction, several of the COPUS codes were combined according to behavioral themes of interest to the researchers, particularly with regard to active and passive instructor and student behaviors during class (see Table 3.1). Overall, six combined codes were created, three for instructors and three for students, and served as our dependent variables. All combined COPUS codes were operationalized among researchers prior to data collection and analysis. If any constituent code of these combined codes was observed during a two-minute interval, the combined code was marked as having occurred during that interval.

Combined instructor codes included: Instructor lecturing, Instructor questioning, and Instructor interacting. “Lecturing” included the COPUS codes for lecturing and classroom demonstrations/videos. “Questioning” included the COPUS codes for posing question, clicker question, answering question, and following-up on a previously asked question. All “questioning” behaviors are defined as those performed with the attention of the entire class. “Interacting” included the COPUS codes for moving-and-guiding and one-on-one interaction with an individual or small group of students without the attention of the rest of the class.

Student codes included: Student listening, Student speaking, and Student groups. “Listening” was used as the original COPUS code and was not combined with others. “Speaking” included the COPUS codes for students posing questions, students answering questions, whole class response to questions, and student presentations. All “speaking” behaviors are defined as those performed with the attention of the entire class and instructor. “Groups” included all COPUS codes pertaining to students working in small groups to complete a worksheet, respond to a clicker question, or other task posed by the instructor.

The frequency of each combined behavioral code was then averaged between each participant's two most active sessions during an observed semester. For all analyses, each subject's two most "active" classroom observations were identified by the least amount of time students spent passively listening during class. This was done to capture each instructor's best efforts at using active, student-centered instruction as they learned to implement these new techniques. Once these percentages were calculated, classroom observation data could be compared against the first year of observations collected in Whitt et al. (in review).

Interview Data Analysis

Transcribed interview data were first analyzed using *a priori* codes to identify participant responses that were related to the research questions (Miles, Huberman, & Saldana, 2014). These deductive codes were used to identify when participants were describing their experiences with AL instruction, instructional supports, future teaching goals, and comparisons to previous teaching experiences. Then, the sections of interview identified through *a priori* codes were further analyzed using *in vivo* codes, which are inductive codes created using the participant quotations to support the analysis (Miles, Huberman, & Saldana, 2014). These codes allow researchers to determine with greater detail what the participants were describing in the *a priori* coded sections. In the analysis, we focused on faculty's described experiences and perceptions in relation to their implementation of AL instructional practices and how they changed between the first and second year of observed instruction. *In vivo* codes were not compared between subjects, but only within subjects across semesters.

Initially, each interview was cooperatively coded by two or more researchers to create *a priori* and *in vivo* codes. Then, the interviews were reviewed by the remainder of the research team to search for disconfirming evidence and alternative interpretations of selected codes and to

search the transcript for additional codes that may have been overlooked. After the research team reached a consensus on necessary revisions, the original two coding researchers would revisit the transcript to apply the recommended changes.

Synthesis of Observational and Interview Data

Researchers then compared each participant's classroom observation data to their self-described experiences implementing AL instruction to create themes explaining the personal and contextual factors contributing to observed changes in their instructional practice over two years. To do this, researchers looked for similarities between participants' descriptions of instructional circumstances and frequency of observed use of AL instruction. Instructional circumstance of interest captured by *in vivo* codes included the stability of teaching assignments, professional responsibilities, classroom resources, and support for their instructional change efforts. The change in frequency of AL instruction use was primarily characterized by comparing the average percent of class time instructors spent lecturing ("Instructor Lecturing" code) relative to the average percent of class time students spent working with peers on course content ("Student Groups" code). These two combined codes were emphasized both for their suitability for characterizing AL instruction and for the frequency they were mentioned by participants regarding their instructional goals.

The qualitative interview data provided explanatory power to observed instructional changes that the quantitative analysis alone lacked. The inclusion of quantitative classroom observations to the interview data verified the participants' self-described use of AL instruction and their experiences using this instructional approach following participation in a PDP or self-directed instructional change effort –addressing previously described deficiencies in assessing PDP outcomes using solely self-reported data (e.g. Ebert-May et al., 2011). The themes created

by combining these two lines of evidence sought to identify overarching factors that support or hinder STEM faculty's efforts to implement AL instruction and how these factors may change over time.

Findings

Classroom Observations

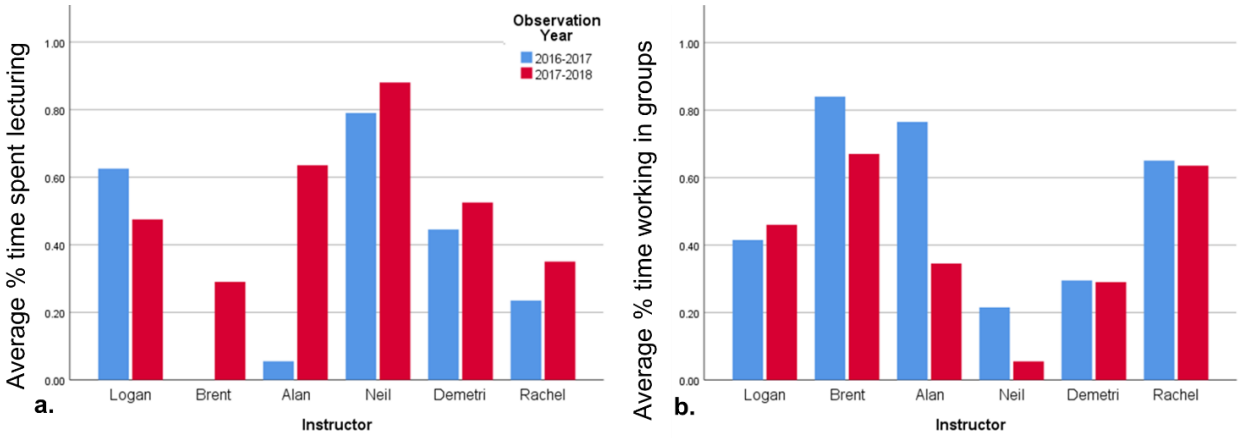

Figure 3.1. Classroom behavioral indicators of AL instructional practices across two years of observed teaching within similar classroom configurations. a) The average percentage of class time instructors spent lecturing to students as a means of introducing course content. b) The average percentage of class time students spent learning course material by engaging in small group in-class assignments.

Logan's classroom observations indicated an overall shift towards more active instruction over time. The first year of instruction involved a majority of his time spent lecturing (62.5%) with a moderate degree of student time spent working in groups (41.5%). In the second year, his lecture decreased to less than half of his time spent in the classroom (47.5%) and student group work increased to nearly half of classroom time (46%) (Figure 3.1). Of note, Logan is the only instructor to demonstrate this pattern.

Brent's circumstances were unique because he was the only instructor with multiple observed sections of the same course within the second year of the study: one within a SCALE-UP classroom identical to his first year of observations, and the other in a large auditorium-style classroom. In Brent's first year of observations, he demonstrated the highest amount of AL instruction in the study, with none of his observed time spent lecturing (0%) and students spending a majority of their time working with peers in groups (84%). In the second year of teaching in a SCALE-UP classroom, the amount of AL instruction decreased somewhat. During this semester, his amount of lecturing increased to 29% of class time and student group work reduced to 67% of class time (Figure 3.1). It is worth noting that 67% time on student group work is higher than all other instructors in this study across both observed years.

An additional comparison was made for Brent between his first year of instruction to his second year teaching the same course in an auditorium-style classroom. In this room, his amount of lecturing increased (33.5%) and is comparable to what was observed in the second year SCALE-UP room. However, the amount of time students spent working in groups constituted less than half of students' time spent in this classroom (46%). Both second year observations were of separate sections of the same course taught during the same semester.

Alan's first observed semester of instruction was highly active and comparable to Brent, with only 5.5% of his own time spent lecturing and over three quarters (76.5%) of student time spent working in groups. In the second year, the instruction appeared to change dramatically. A majority of instructor time was spent lecturing (63.5%) and student time spent working in groups lowered to roughly one third of class time (34.5%) (Figure 3.1). Of note, Alan was the only instructor who taught a different course between the two observed years.

Neil's first series of observations showed a primarily lecture-driven class (79%) with a degree of student group work included (21.5%). However, the second observed year more closely resembled a traditional lecture course with 88% of instructor time spent lecturing while student group work was relatively low (5.5%) (Figure 3.1). Neil was the only participant who did not receive support from one of the PDPs (described above) prior to the start of the first year of observations.

Demetri demonstrated a highly consistent degree of AL instruction between both observed semesters. In this first year, he spent less than half of his time lecturing (44.5%) while students spent 29.5% of their time working in groups. In the second year, his amount of lecturing increased slightly (52.5%) while the amount of student group work was nearly identical (29%) (Figure 3.1). Demetri was able to make use of PLAs during both observed semesters.

Rachel, like Demetri, was very consistent in her degree of AL instruction use over time. However, her implementation of active instruction was comparatively high. In the first year, around one-quarter of her time in class was spent lecturing (23.5%) while students worked in groups during a majority of class time (65%). In the second year, Rachel's amount of lecturing increased slightly (35%) while maintain a similar amount of student group work (63.5%) (Figure 3.1).

Faculty Interviews

Logan was the only instructor in our study to continue innovating his teaching such that he both reduced the amount of time spent lecturing and increased the amount of time students spent working in groups to engage the course material (Figure 3.1). He attributed his continuing use of AL instruction to his ongoing discussions with his original PD mentor from the

experienced-novice instructor pairing PDP. In the first interview, he said that he and the mentor communicated through email frequently and that the mentor both provided content-specific instructional materials and provided suggestions for adapting them to his own class. In the second interview, he mentioned how his continuing discussions with that mentor helped him to reflect on his teaching, specifically with issues he was facing regarding the format of the class, use of case studies, and student dissatisfaction.

> "Last year, the format was I asked the students to work the case study first. And then after that, I gave a lecture to explain the background information…but so many students recommended to give more lecture. So this time, I gave lecture first."

But Logan noted that this change had unintended outcomes for student engagement and enjoyment of the class. When he prefaced case studies with lecture, students believed that they should have been presented with all the information they needed to complete the assignment.

> "This year, students are kind of not actively involved in the case study during the discussion because they had the information already from my lecture…There is so much dependence on my lecture, in comparison to last year…and they have more kinds of complaints this year, 'why didn't you give us enough information to answer the case study?' These kind of complaints."

Logan intends to return to a 'case study first, lecture second' format while creating new case studies with his PD mentor to increase the active orientation of his classes.

Brent was the only instructor observed teaching multiple sections of the same course in differing classroom spaces: a SCALE-UP room designed to facilitate the use of active instruction

techniques and a large auditorium-style classroom. After the first year, Brent's proportion of class time spent lecturing increased from 0% to 29% in the SCALE-UP room and up to 33.5% in the auditorium. This change was reflected in the amount of time students spent engaging with the course material in groups, reducing from 84% of class time in the first year to 67% in the SCALE-UP room and 46% in the auditorium in the second year. However, some of this shift away from strictly no-lecture teaching was an intentional instructional choice based on his reflection on student-feedback received at the end of the first year.

> "I've gone back and forth on how much lecture is appropriate. At the beginning, I was pretty strict about, 'Alright, I'm going to lecture zero and just let you guys work.' And then I saw that some groups are getting frustrated and I was like, 'Okay, maybe I'll put a little bit more [lecture] in there…' And I started doing 30/70 or something like that."

The observational data show that Brent successfully achieved his target of approximately "30/70" in his second year SCALE-UP classroom (Figure 3.1). However, the added challenges of transferring his active teaching strategies into an auditorium likely contributed to the reduction of class time students spent actively engaging with course material to less than half (46%). Brent remarked at the end of his first year of observations that,

> "The only thing that's really stopping me from doing [active learning] in all of my classes is access to the [SCALE-UP] rooms."

These concerns over the compatibility of active instruction and classroom space resurfaced in the second year when he taught in both SCALE-UP and auditorium classrooms. He indicated that his ability to physically reach and communicate with individual groups in the

auditorium classroom was made possible by a drop in overall attendance after the beginning of the semester.

> "There were a couple of class days where I was like, 'Yeah, I don't know what I'm gonna do with you guys in the middle. I'm gonna do my best to get to you, but I don't think I'm gonna be able to get to everyone… I was worried that at first that I wasn't even gonna be able to do the active learning idea."
>
> "That was one of my biggest concerns, is just how are we gonna physically get to every single group? And after the first few weeks, it really wasn't an issue. Not everybody attends the class, which is gonna free up some seats."

Alan's first observed semester of instruction was highly active but the second much more closely resembled traditional lecture. In the second interview with Alan, he described how he suddenly found himself teaching a different course in the second year from what he taught in the first year of the study –a course he had taught "very few times" in his career. This unfamiliar teaching assignment and lack of previously created instructional materials would dramatically decrease AL instruction.

> "So this year I was using active learning in [my class]. I didn't have the time to really prepare a lot of materials for that, so I simply gave them some homework problems that they were supposed to have thought about before the class."
>
> "I didn't have the time or energy or something to prepare a specific task…There's certain material that had to be covered in a short

> amount of time. I had to move on. There's a syllabus that has to be kept here."

Alan conducted an exceptionally active, student-centered class in the first year. However, the sudden change to a new course he had less experience teaching, and no materials previously prepared for, combined with lack of departmental support and expectations for content coverage resulted in a markedly reduced use of active instructional practices in the second year.

Neil was in the process of independently reforming his own approach to teaching without the support of a PDP. In the first year of the study, he demonstrated initial implementation of case-studies that students would work on in groups to learn the target concepts of the lesson. At the end of the first year of observations, Neil expressed his interest and intent to increase his use of case-studies and decrease time spent lecturing in the following year. However, his instruction returned to almost strictly lecture in the second year of observations.

During the second interview with Neil, he described a major change to his teaching context. His department had hired a new faculty member to teach additional sections of the same course and he was paired with this less-experienced teacher, which restricted his instructional and curricular freedoms.

> "… we got paired up with other faculty to teach a section of the same subject at the same time in the same semester, so we tried to make sure that the content and curriculum were parallel. The students in my lecture section and the other teacher's lecture section might be mixed in lab, so they all had to be on the same pace. And I think I got a little concerned that if I made too many changes, the content [coverage] tyranny monster would start to rear

> its head and I'd need to make sure that I was covering what this other teacher was covering."

This administrative restriction necessitated a return to a nearly pure lecture format. Neil indicated that he will not have the same responsibility to new faculty in the following semester and intends to revisit his plans to increase AL instruction in his classes.

Demetri continued his use of PLAs into the second year of observations. Based on the feedback Demetri received from students, primarily through his PLAs, he opted to decrease the amount of time he spent asking questions, posed to the whole class, in his second year to make sure students were keeping up in favor of increasing interaction with students during small group work to accomplish the same end.

> "When we started magnetic fields, they were struggling a little bit and the PLAs brought that home. The fact that they were finding things tough wasn't coming up through the kids asking questions in class."

For Demetri, the use of PLAs was the key resource allowing him to gather feedback on student progress during in-class work. Throughout his second interview, Demetri's experiences with AL instruction were described primarily through the application and support of PLAs. For example, when asked if he had experienced difficulties using AL instruction, he mentioned,

> "One of the challenges that was definitely greater this semester than last semester was just that the PLA to student ratio was lower. And so getting the coverage [of student groups] was a lot more difficult."

> "That was definitely an issue, and that would be something that I need to try and change going forward. I think this semester, that was the biggest issue."

Observations of Demetri's second year were nearly identical to the first, with the amount of class time dedicated to students working in groups remaining the same and a small (+10%) increase in lecture. Demetri expressed general satisfaction using AL instruction and expressed his intent to continue its use.

Rachel's observed instruction followed a similar pattern to Demetri's over the two years, albeit with a higher degree of student group work. Rachel is pleased with the student outcomes she observed and enjoys AL instruction over lecturing, citing an alignment with her personal preferences and view of learning,

> "I do tend to be a little more [comfortable] one-on-one with a student…and less if I'm just lecturing."
>
> "I like to have more on-on-one interaction with students and also to see one student teaching another. I see that as a really good sign of the learning that's going on."

Rachel also shares the same PDP mentor as Logan, has described her adoption of AL practices as being largely based on this support, and that this support continued throughout the second year.

> "I would say a lot of my active learning techniques have come from [my PDP mentor]."
>
> "I adopted most of the case studies she used previously and met with her once per week so I had some guidance."

> "I still ask her for advice sometimes…I'm working less directly with her this year."

While Rachel worked with her PDP mentor to "write a lot of new case this semester," she indicated that she had "not made any huge changes to what [she has] done previously." She expressed satisfaction with her experiences using AL instruction and is interested in continuing her use of AL in the future.

Integration and Discussion

This study sought to examine how STEM faculty's use of AL instruction changes over time and to what faculty attribute these changes in their practice. The instructional practices of the six faculty participants were examined over two years in the context of their interviews following each semester of observation to 1) assess the longevity of their instructional change and 2) determine the difficulties they encountered while continuing their teaching innovation over time in order to 3) determine how better support STEM faculty's continued use of AL instruction. Towards this end, researchers used classroom observations combined with interview data describing instructors' experiences using AL instruction to identify three overarching themes that characterized the factors supporting or hindering their efforts to maintain changes to their instruction over time.

Theme 1: Continuing Support

Logan and Rachel were the only instructors to continue to receive support from their original source of PD throughout the course of the two-year study. Shared teaching materials, frequent discussions, and individualized feedback on practice from a science education expert

within one's own academic discipline is a highly ideal source of instructional support. The benefits of this continuing support were suggested by their classroom observations.

Logan was the only instructor to show continuous reduction in lecture while increasing student group work during class and has expressed interest in further innovation of his practice. Rachel, while content with her current level of innovation, quickly established a highly student-centered learning environment which she successfully maintained throughout the second year of the study.

Both instructors were continuing to work with their PD mentor to create new case studies and are committed to persist in implementing active instructional practices. Of the six participants, they described the fewest difficulties in implementing their instructional reforms while demonstrating sustained and improving use.

Theme 2: Influence of Resources

Demetri and Brent's use of active instruction was notably influenced by their available instructional resources. While the influence of space on Brent's teaching was evident through classroom observations, Demetri's use of PLA support being central to his use of AL instruction only became apparent through discussions of his recent teaching experiences.

Demetri described his experience using AL instruction almost exclusively through the lens of PLAs and their most effective application. For him, they were an invaluable resource for supporting a large number of students engaged in group work, collecting feedback on students' progress and difficulties, and made using AL instruction seem realistic in a high-enrollment course. Both his use of PLAs and the level of active student engagement in his classes remained consistent across both years.

Brent was by far the most thorough adopter of active instruction in our study. During the first year of the study, no lecturing was observed and nearly all of students' time spent in class was dedicated to working on case studies and other activities as a means of engaging with new concepts. In fact, he expressed concern over the frustration he observed in some student groups and made a conscious effort to include some amount of lecture during the second year of the study.

Brent's intended second year adjustment was on-track in the SCALE-UP classroom he had used previously; however, the section of the course he was teaching concurrently in a traditional auditorium-style classroom became less active by comparison. Brent elaborated on how the orientation of the auditorium restricted his ability to engage with student groups and attributed much of his ability to effectively use AL instructional practices to the decreased student attendance, and resulting increase in maneuverability, after the first few weeks of class.

Throughout this study, Brent's degree of active instruction was exceptionally high. And while his auditorium section still included a considerable amount of student-centered instruction, the influence of physical teaching space on his instructional practice was apparent. For Demetri, his AL instruction appeared to be closely tied to his use of PLAs in a large classroom. While his use of AL practices was consistent between years, it is conceivable that his continuation of these practices is dependent in part on the availability of PLA support. These outcomes suggest that teaching resources may strongly influence an instructor's continued use of teaching innovations. If AL instruction is taught to faculty through the use of a specific instructional resource, care should be taken to either ensure its continued availability or else provide specific support for faculty to transfer their practice to teaching contexts without that resource.

Theme 3: Administrative Barriers

Neil and Alan both experienced significant, externally imposed restrictions on their instructional practice that hindered their implementation of AL instruction in their classrooms. Neil was independently working to implement AL instruction using case studies. However, the changes he made to his instruction and plans for further innovations were reversed after he was paired with another, less-experienced faculty member. His new obligation to keep his curriculum in lockstep with another instructor, for both training and logistical purposes, prevented his continued implementation of AL instruction.

Alan demonstrated extensive use of AL instruction during the first year of the study. But after a sudden shift in his teaching assignment to a course he was less experienced instructing, and had no previously created materials prepared, his use of Al instruction fell precipitously. The massive demands on time and energy that the creation of AL instructional material placed on Alan were prohibitive without adequate preparation time or external support prior to the semester.

Department heads and administrators invested in the long-term outcomes of PDPs play a critical role in their success by being responsive to the efforts of participating faculty. Creating changes in an instructor's teaching responsibilities and context of practice can unintentionally derail the ongoing instructional change of faculty and undermine the mission of PDPs' reform efforts. Neil and Alan's cases underscore the importance of administrative collaboration with PDPs and for supporting these leaders' learning about education and instructional reform.

Adult Learning Theory and implications for PDP

Evidence-based teaching is challenging and faculty face numerous personal and situational barriers to implementation that complicate the process of changing one's instruction from lecture to AL (Henderson & Dancy, 2007). And while PDPs are invaluable for supporting instructors to overcome these barriers, the barriers themselves are inconstant and new barriers may arise long after support from the PDP has concluded, contributing to dwindling use of AL instruction over time. In all the above cases of notably diminishing use of AL instruction, the instructor encountered a novel situational barrier that they self-identified as restricting their practice. The data presented here underscore the need for longitudinal forms of support for instructional change.

Adult Learning Theory provides a useful framework for conceptualizing the needs and orientations of faculty learners and how PDPs can best assist the adoption and longevity of AL instruction through longitudinal form of support. The four major assumptions of this learning theory explored by this study are that adult learners (1) have highly self-directed mindsets, (2) have accumulated a considerable reservoir of past experiences and knowledge that can be leveraged as a resource for their learning, (3) are ready and willing to learn largely to the extent that the information is relevant to their professional and/or personal tasks and (4) is immediately applicable to those tasks.

Self-directed mindsets

All six faculty participants voluntarily elected to either take part in a form of instructional PDP or self-initiated their independent efforts to enact AL instruction. As such, the present study cannot directly test the influence of voluntary participation in instructional PDPs, though previous research has found "top-down" reform efforts to be unsuccessful (Henderson, Beach, &

Finkelstein, 2011). Additional studies comparing the instructional outcomes of "top-down" to voluntary participation-based PD initiatives would develop our understanding of the role of faculty volition in instructional change.

Reservoir of experience and knowledge

Faculty's use of past experiences and knowledge to inform their learning appears to be a double-edged sword. For example, prior work has demonstrated that faculty draw upon multiple sources of prior experiences to inform their own teaching practices (Oleson & Hora, 2014) and not all of these experiences support the adoption of AL instruction. This suggests that individualized PD is needed to identify and connect faculty's experiences related to teaching and learning to the use of an instructional innovation while also supporting faculty's learning where experience may conflict with the target change. However, this study provides nuance to this assumption of adult learners by addressing the limitations contextual factors place on the utility of faculty's experience to support their continued use of learned skills.

In the cases of Alan and Brent, both instructors demonstrated their knowledge of evidence-based instruction and aptitude for AL instruction in the first year of the study, but their use of AL instruction declined in the second year. Alan and Brent's changes in instruction coincided with a sudden change in teaching assignment to a less familiar course and assignment to a classroom less suited to AL instructional practices, respectively. The experience they gained from the first year of successful AL instruction could not be fully leveraged to support their independent learning to use the same techniques in a new context of practice.

Because both instructors demonstrated extensive use of AL instruction, it seems likely that they would be able to use this practice in their second-year settings over time. However, their transfer of learned instructional practices was disrupted in the short-term. This focus on the

influence of contextual factors on faculty learning necessitates viewing support for instructional change as dependent upon the context in which the learning takes place.

Relevance and immediacy of application

The assumption that adult learning is most effective when the learned content is relevant to one's practice and is immediately applicable appears to be supported by our data. One way to maintain relevance and immediacy of learned practices is to provide faculty with continuing instructional support. The two cases that demonstrated a high degree of AL instruction that was either sustained or increased across both years shared a common source of PD. Logan and Rachel were both paired with a faculty mentor with expertise in university STEM education and reported ongoing contact and support from this mentor through the second year of the study. Both instructors received teaching materials from their PD mentor and communicated regularly to discuss the use of teaching strategies or to troubleshoot difficulties. By maintaining an ongoing relationship to support AL instruction, the PD mentor was able to provide feedback and support for faculty instruction in response to their needs over time.

However, a notable limitation of these data is the lack of a participant that both received continuing support and experienced changes to their teaching context between the first and second year of observation. This point of comparison would provide needed insight into the extent to which long-term PD supports continued use of AL instruction relative to the simple absence of emergent, contextual barriers.

An expert PD guide who can connect their own STEM pedagogical knowledge to faculty's STEM content knowledge and experiences in the classroom is ideal for developing faculty's pedagogical content knowledge in line with evidence-based practices. There is also evidence that the efficacy of this support would be enhanced by a prolonged period of

association with faculty engaged in instructional change (Emerson & Mosteller, 2000; Ebert-May et al., 2015). Support over prolonged time following participation in a PDP would allow for individually responsive support for emergent situational barriers. In this way, PD for an instructional innovation can maintain its immediate relevance and applicability to faculty's instructional practice over time, supporting the longevity of faculty instructional change.

Future Directions

This longitudinal study describes STEM faculty's experiences enacting AL instructional practices over two years. While the multi-year relationship between Logan, Rachel, and their PD mentor appeared to be associated with maintaining a high degree of AL use over time, the nature of their professional relationship requires additional study. To better understand which forms of ongoing support and the characteristics of a professional relationship that are effective at maintaining sustained AL instruction, detailed qualitative investigations of how these long-term relationships support faculty change are necessary to provide guidance to PDP developers.

This study assessed the degree of AL instruction through the observation of instructor and student behaviors typical of an AL classroom. However, this study does not assess the quality of instructors' AL instruction nor its fidelity to the instructional innovation as it was taught through their PDP. Post-participation in PD, STEM instructors tend to create modifications to research-based instructional practices (Dancy & Henderson, 2010). Faculty who face novel situational barriers without ongoing support are likely to generate modifications that make AL instruction more manageable for their teaching context. Evidence suggests that these modifications to research-based curricula will most likely result in instruction shifting back towards lecture-based teaching (Henderson & Dancy, 2008; Turpen, Dancy, & Henderson,

2010). Additional research assessing the quality of AL instruction is required to improve our understanding of PDP outcomes and necessary forms of faculty support for accurate use of AL instruction.

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References

American Association for the Advancement of Science. (2011). *Vision and Change: A Call to Action, Final Report.* Washington, DC: AAAS.

Andrews, T., Leonard, M., Colgrove, C., & Kalinowski, S. (2011). Active learning not associated with student learning in a random sample of college biology courses. *CBE-Life Sciences Education*. 10: 394-405.

Beavers, A. (2009). Teachers as learners: Implications of adult education for professional development. *Journal of College Teaching and Learning, 6*(7), 25.

Bogdan, R., & Biklen, S. (2006). *Qualitative Research for Education: An Introduction to Theory and Methods* (5th ed.). Boston, MA: Allyn and Bacon.

Brownell, S., & Tanner, K. (2012). Barriers to faculty pedagogical change: lack of training, time, incentives, and tensions with professional identity. *CBE Life Sci Educ, 11*: 339-346.

Cohen, D., & Hill, H. (2000). Instructional policy and classroom performance: The mathematics reform in California. *Teachers College Record, 102*(2), 294-343.

Cotner, S., Loper, J., Walker, J., & Brooks, D. (2013). "It's Not You, It's the Room" –Are the High-Tech, Active Learning Classrooms Worth It? *J. Coll. Sci. Teaching.* 42, 82-88.

Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications.

Dancy, M. & Henderson, C. (2010). Pedagogical practices and instructional change of physics faculty. *American Journal of Physics*, 10, 1056 – 1063.

Darling-Hammond, L., & McLaughlin, M. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan*.

Ebert-May, D., Derting, R., Hodder, J., Momsen, J., Long, T., & Jardeleza, S. (2011). What we say is not what we do: effective evaluation of faculty professional development programs. *BioScience, 61*: 550-558.

Ebert-May, D., Derting, T., Henkel, T., Maher, J., Momsen, J., Arnold, B., & Passmore, H. (2015). Breaking the cycle: Future faculty begin teaching with learner-centered strategies after professional development. 14, 1-12.

Emerson, J., & Mosteller, F. (2000). Development programs for college faculty: Preparing for the twenty first century. *Educational media and technology yearbook, 25*: 26-42.

Ericsson, K. (2008). Deliberate practice and acquisition of expert performance: A general overview. *Academic Emergency Medicine*. 15, 988-994.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410-8415.

Garet, M., Porter, A., Desimone, L., Birman, B., & Yoon, K. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal. 38*(4), 915-945.

Gast, I., Schildkamp, K., & van der Veen, J. (2017). Team-based professional development interventions in higher education: A systematic review. *Review of Educational Research*, 87, 736-767.

Henderson, C. & Dancy, M. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Phys. Rev. ST Phys. Educ. Res. 3*(2), 020102.

Henderson, C., & Dancy, M. (2008). Physics faculty and educational researchers: Divergent expectations as barriers to the diffusion of innovations. *American Journal of Physics*. *76*, 79.

Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating Change in Undergraduate STEM Instructional Practices: An Analytic Review of the Literature. *Journal of Research in Science Teaching*, *48*(8): 952-984.

Hurtado, H., Eagan, M., Pryor, J., Whang, H., & Tran, S. (2012). Undergraduate teaching faculty: The 2010-11 HERI faculty survey. *Los Angeles: Higher Education Research Institute*.

Kirk, J., & Miller, M. (1986). *Reliability and validity in qualitative research*. Newbury Park, CA: Sage.

Knowles, M. (1980). *The modern practice of adult education. From Pedagogy to Andragogy: Revised and updated*. Cambridge press. NJ: Englewood Cliffs.

Levinson-Rose, J., & Menges, R. (1981). Improving college teaching: A critical review of research. *Review of Educational Research, 51*(3): 403-434.

Luft, J., Diamond, J., Zhang, C., & White, D. (2020). K-12 STEM professional development programs: Building teacher knowledge and practice through the lens of transfer. In M. Schoeder, C. Johnson, & T. Moore (Eds.), *Handbook of research on STEM education*, London: Routledge.

Manduca, C., Iverson, E., Luxenberg, M., Macdonald, R. H., McConnell, D., Mogk, D., & Tewksbury, B. (2017). Improving undergraduate STEM education: The efficacy of discipline-based professional development. *Science Advances, 3*(2), e1600193.

Merriam, S. (2009). *Qualitative research: A guide to design and implementation: Revised and expanded from qualitative research and case study applications in education*. San Francisco, CA: Jossey-Bass.

Miles, M., Huberman, A., & Saldana, J. (2014). *Qualitative Data Analysis: A Methods Sourcebook* (3rd ed.). Los Angeles, CA: Sage.

Miller, C., & Metz, M. (2014). A comparison of professional-level faculty and student perceptions of active learning: its current use, effectiveness, and barriers. *Adv. Physiol. Educ*. 38, 246-252.Stoltzfus, J., & Libarkin, J. (2016). Does the Room Matter? Active Learning in Traditional and Enhanced Lecture Spaces. *CBE-Life Sci. Educ*. 15, ar68.

Murray, K., & Macdonald, R. (1997). The disjunction between lecturers' conceptions of teaching and their claimed educational practice. *Higher Education*, 33, 331-349.

Oleson, A., & Hora, M. (2014). Teaching the way they were taught? Revisiting the sources of teaching knowledge and the role of prior experience in shaping faculty teaching practices. *Higher Education*, 68, 29-45.

Prince, M. (2004). Does Active Learning Work? A Review of the Research. *Journal of Engineering Education*. 93, 223-231.

Smith, M., Jones, F., Gilbert, S., Wieman, C. (2013). The Classroom Observation Protocol for Undergraduate STEM (COPUS): A New Instrument to Characterize University STEM Classroom Practices. *CBE-Life Science Education*. 12, 618-627.

Steinert, Y., Mann, K., Anderson, B., Barnett, B., Centeno, A., Naismith, L., Prideaux, D., Spencer, J., Tullo, E., Viggiano, T., Ward, H., & Dolmans, D. (2016). A systematic review of faculty development initiatives designed to enhance teaching effectiveness: A 10-year update. *Medical Teacher, 38*(8), 769-786.

Stes, A., Min-Leliveld, M., Gijbels, D., Van Petegem, P. (2010). The impact of instructional development in higher education: The state-of-the-art of the research. *Educ. Res. Rev.*, 5, 25-49.

Stewart, C. (2014). Transforming professional development to professional ldearning. *Journal of Adult Education,* 43, 28-33.

Stoltzfus, J. & Libarkin, J. (2016). Does the Room Matter? Active Learning in Traditional and Enhanced Lecture Spaces. *CBE-Life Science Education*. 15(4): ar68

Turpen, C., Dancy, M., & Henderson, C. (2010). Faculty Perspectives on Using Peer Instruction: A National Study. *Proceedings of the 2010 Physics Education Research Conference*. DOI: 10.1063/1.3515235.

Whitt, B., Luft, J., Idsardi, R., Wingfield, J., Barriga, P., & Lang, J. (in review). The Influence of Physical Classroom Space on Efforts to Reform Instruction in Undergraduate STEM.

CHAPTER 4

CONCLUSIONS

Major Contributions

The research in this dissertation explored the experiences of university STEM faculty learning to implement active learning (AL) instructional practices post-participation in various forms of professional development programs (PDP). This dissertation expands the field of research related to PDP in higher education by investigating two under-examined aspect of instructional chage: (1) the influence of classroom space on STEM faculty's early efforts at using AL instruction and (2) the factors influencing the longevity of faculty's AL instruction use over time.

The first major contribution of this dissertation is evidence of a strong relationship between the physical orientation of a classroom and the degree of AL instruction STEM faculty use post-participation in PD. While studies have assessed the relationship between classroom space and student learning and or attitudinal outcomes (e.g. Gaffney et al., 2008; Brooks, 2011; Cotner et al., 2013; Stoltzfus & Libarkin, 2016), this is the first study directly assessing its relationship with STEM faculty's teaching practices. Instructors who teach in classrooms designed with AL instruction in mind (i.e. SCALE-UP) tend to conduct classes that most resemble an ideal model of AL instruction. In these classrooms, the instructors spent less time lecturing and more time interacting with individual or small groups of students as the students worked to solve problems related to course content. Additionally, instructors in SCALE-UP rooms conducted more student-centered teaching than instructors in more traditionally arranged

classrooms irrespective of the type of PDP they took part in. While the design of this study does not allow for causal determination, there is strong evidence to support the idea that mindfully designed rooms can support faculty's early efforts to implement AL instruction following participation in PD.

The second manuscript of this dissertation provides evidence that faculty who successfully innovate their instruction towards AL following participation in a PDP may rapidly return to lecture-based instruction when encountering significant changes to their context of instruction. However, faculty who received continuing instructional support from their source of PD demonstrated a sustained or increased degree of AL instruction over one year post-PDP. This evidence is consistent with claims that PDP should occur over prolonged time (e.g. Emerson & Mosteller, 2000; Ebert-May et al., 2015) and suggests that PD for lasting change towards AL instruction should be delivered in such a way that provides faculty with long-term access to expert support to respond to faculty's changing instructional challenges.

This manuscript also offers an example of how Adult Learning Theory (Knowles, 1980) may be used to inform the creation of PDPs that support STEM faculty's continued use of AL instruction long after initial participation in PD. By conceptualizing effective support for faculty learning as maintaining relevance and immediate applicability of the instructional innovation to faculty's own practice, PD designers can develop long-term supports for faculty equipped to respond to changing contextual barriers to AL instruction over time. This framework unites claims from prior research emphasizing the importance of prolonged support for STEM faculty (Emerson & Mosteller, 2000; Ebert-May et al., 2015), and viewing faculty as learners of teaching practices (Beavers, 2009) who are shaped by their prior knowledge and experiences

(Oleson & Hora, 2014) which should be leveraged in their learning of teaching innovations (Henderson & Dancy, 2008).

Future Research

Continuing the use of the classroom observation protocol used in Chapters 2 and 3 (COPUS), I am interested in examining the influence of STEM subject matter on the ease of adopting active instructional practices. Because individual and context-specific barriers may differ by discipline or department, a one-size-fits-all approach to supporting instruction change may be ineffective (Lund & Stains, 2015). In the interest of developing more individualized forms of instructional support for faculty, the DBER (discipline-based education research) communities would likely find value in a mixed-methods study examining which STEM disciplines experience the greatest difficulty implementing active instruction following PD and why. For example: are biological subjects, which frequently cover abstracted concepts like evolution or phosphorus cycling, more difficult to teach actively than subjects typically covering more concrete topics such as computer programming?

While the participant sample in the Chapter 2 data set did not allow for robust comparisons between STEM disciplines, trends in the data suggested that students in biology courses were the least active and spent the most class time listening to the instructor when compared against other subjects. I believe that a study designed to investigate this relationship could contribute to our understanding of the degree and manner of support faculty require to successfully implement AL instruction across multiple STEM disciplines.

A necessary extension of a major finding in Chapter 3 should be a thorough investigation of effective long-term PD for STEM faculty learning to implement AL instruction. In Chapter 3,

the two instructors who sustained or increased a high degree of AL benefitted from a prolonged association with their PD provider –a science education researcher and professor within their own STEM discipline. However, the current study lacked detailed accounts of the interactions between mentor and faculty learner, as well as the forms and manner in which support was provided. While a prolonged period of instructional support appears to be beneficial for sustaining instructional change, of equal importance to PDP developers are the ways this support is delivered over time. A mixed-methods research design including classroom observations with an emphasis on qualitative data collection could allow me to investigate this relationship is greater detail. Collected data should include semi-structured interviews with both instructor and PD provider, instructional artifacts, and a timeline of meetings and discussions between the pair.

Last, a major deficit of the two manuscripts presented here are their inability to address the social factors of instructional change in university STEM, particularly at the level of the department and/or institution. A university's culture can contribute to faculty's identity as either researcher or educator (Austin, 1996) and many research-focused universities place a higher premium on the research productivity of their faculty. Changing the culture of instruction at the university-level requires identifying and challenging the underlying values and assumptions of that institution (Kezar, 2001) which "occurs when a number of individuals come together in university basic units and across a university over a number of years to change, by means of organized initiative, how the institution is structured and oriented" (Clark, 2000 p. 5).

To examine how faculty may come together to support one another's instructional innovation and contribute to shifting the norms of an institution, I intend to pursue emerging research efforts using Social Network Analysis (SNA). SNA provides a novel and useful avenue for exploring social structures influencing educational practices in university STEM. Research

suggests that one's network of interpersonal relationships influences their decision to make changes to their behavior (Kezar, 2014). Rigorous analyses of the social networks STEM faculty form will contribute to the science education research community's understanding of how departmental/institutional change efforts related to instructional change are impacted by the social context of STEM faculty's practice.

Conclusion

This chapter has outlined how this dissertation constitutes a novel contribution to the field by building upon limited prior investigations of the relationships between classroom space and PDPs on university STEM faculty's teaching practices, and how those practices persist or change over time. These descriptive data may serve as a foundation for my and others' continued research into forms of professional support for STEM faculty's enactment of evidence-based teaching.

References

Austin, A. (1996). Institutional and departmental cultures: The relationship between teaching and research. *New Directions for Institutional Research. 48*(80), 57-66.

Brooks, D. (2011). Space matters: The impact of formal learning environments on student learning. *Br. J. Educ. Technol*. 42, 719-726.

Clarke, B. (2000). Collegial entrepreneurialism in proactive universities. *Change*. 32, 10-12.

Cotner, S., Loper, J., Walker, J., & Brooks, D. (2013). "It's Not You, It's the Room" –Are the High-Tech, Active Learning Classrooms Worth It? *J. Coll. Sci. Teaching*. 42, 82-88.

Ebert-May, D., Derting, T., Henkel, T., Maher, J., Momsen, J., Arnold, B., & Passmore, H. (2015). Breaking the cycle: Future faculty begin teaching with learner-centered strategies after professional development. 14, 1-12.

Emerson, J., & Mosteller, F. (2000). Development programs for college faculty: Preparing for the twenty first century. *Educational media and technology yearbook, 25*: 26-42.

Gaffney, J., Richards, E., Kustusch, M., Ding, L., & Beichner, R. (2008). Scaling up education reform. *J Coll Sci Teach.* 37: 48-53.

Kezar, A. (2001). Understanding and facilitating organizational change in the 21st century: Recent research and conceptualizations. *ASHE-ERIC Higher Education Report, 28*(4), 1 162.

Kezar, A. (2014). Higher education change and social networks: A review of research. *Journal of Higher Education*. *85*(1), 91-125.

Knowles, M. (1980). *The modern practice of adult education. From Pedagogy to Andragogy: Revised and updated*. Cambridge press. NJ: Englewood Cliffs.

Lund, T., & Stains, M. (2015). The importance of context: an exploration of factors influencing the adoption of student-centered teaching among chemistry, biology, and physics faculty. *International Journal of STEM Education, 2*(13), doi:10.1186/s40594-015-0026-8

Stoltzfus, J. & Libarkin, J. (2016). Does the Room Matter? Active Learning in Traditional and Enhanced Lecture Spaces. *CBE-Life Science Education*. 15(4): ar68