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UNIVERSITY OF CALIFORNIA SAN DIEGO
SAN DIEGO STATE UNIVERSITY

Mathematicians' Use of Evidence-Based Instructional Practices in Advanced Collegiate
Mathematics

A Dissertation submitted in partial satisfaction of the requirements
for the degree Doctor of Philosophy

in

Mathematics and Science Education

by

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The Dissertation of Mariah Gabriella Moschetti is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

Co-Chair

Co-Chair

University of California San Diego
San Diego State University

2026

DEDICATION

In memory of my aunt Didi.

TABLE OF CONTENTS

DISSERTATION APPROVAL PAGE	iii
DEDICATION	iv
TABLE OF CONTENTS.....	v
LIST OF FIGURES	viii
LIST OF TABLES	ix
LIST OF ABBREVIATIONS	x
ACKNOWLEDGEMENTS.....	xi
VITA	xv
ABSTRACT OF THE DISSERTATION	xvi
Chapter 1 INTRODUCTION.....	1
The Teaching of Advanced Collegiate Mathematics	3
The Perspectives of Mathematicians.....	4
Transforming the Teaching of Advanced Collegiate Mathematics	6
Research Questions	8
Chapter 2 LITERATURE REVIEW.....	9
Evidence-Based Instructional Practices in Mathematics Education	9
Contextual Factors Involved in Using EBIPs	20
Individual Factors Involved in Using EBIPs	27
A Gap in the Literature	45
Conceptual Framework	46
Chapter 3 METHODOLOGY.....	55
Positionality	55
Participants and Context	56
Data Collection.....	59

Analysis.....	64
Chapter 4 WHY MATHEMATICIANS USE EBIPS	71
Conditions Supporting Mathematicians' Choice to Use EBIPs.....	72
The Reasons Mathematicians Use EBIPs: Motivations and Ongoing Rationales	78
Chapter Summary: Why Mathematicians Use EBIPs.....	90
Chapter 5 PERSISTENCE USING EBIPS	93
Navigating Constraints on EBIP Use	93
Making EBIPs Work: How Persistence Unfolds	108
Chapter Summary: Persistence Using EBIPs.....	113
Chapter 6 HOW AND WHY MATHEMATICIANS USE THE EBIPS THEY DO	115
The Different Approaches Mathematicians Take to Using EBIPs	115
How Reasons for Use and Challenges Manifest in Practice: Cross-Case Synthesis	141
Chapter 7 DISCUSSION AND CONCLUSION	147
Summary of Findings.....	148
Implications.....	150
Limitations	158
Future Directions.....	159
Concluding Remarks.....	161
APPENDIX A: PRE-SCREENING INTERVIEW PROTOCOL	162
APPENDIX B: BEGINNING OF TERM INTERVIEW PROTOCOL	163
APPENDIX C: PRE-OBSERVATION INTERVIEW PROTOCOL.....	165
APPENDIX D: STIMULATED RECALL INTERVIEW PROTOCOL	166
APPENDIX E: END OF TERM INTERVIEW PROTOCOL	167
APPENDIX F: FIRST CYCLE CODES	169
APPENDIX G: SECOND CYCLE CODES.....	174

REFERENCES	178
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LIST OF FIGURES

Figure 2.1: Visual Representation of the Revised Model. This revised framework models the influences that shape faculty engagement with EBIPs.	54
Figure 4.1: Relationship Between Categories for Why Participants Use EBIPs. Participants described (a) enabling conditions that shaped their openness to using EBIPs, (b) a core motivation to ensure learning happens in the classroom, and (c) two ongoing rationales that functioned as affordances supporting this core motivation.	91
Figure 5.1: Model of Persistence in EBIP Use. Implementation constraints and persistence mechanisms shape participants' experiences with EBIP implementation, with constraints influencing their degree of satisfaction and mechanisms enabling persistence. The bidirectional arrows between experiences and persistence highlight the iterative process: implementation gives rise to dis/satisfaction with the experience, which informs EBIP adaptation, which in turn shapes subsequent implementation.....	114
Figure 6.1: Relationship between Participants' Reasons for Using EBIPs, the Challenges They Face, and Their Implementation of EBIPs. Participants' reasons for using EBIPs manifest in situated participant-specific ways, as seen through their ROGs, which shapes their use of EBIPs, which is also shaped by challenges they encounter during real-life use, resulting in the varied EBIP use seen among participants.....	146

LIST OF TABLES

Table 4.1: Categories for the Reasons Participants Use EBIPs. This table distinguishes the shared motivation from two ongoing rationales and provides descriptions, representative examples, and participants within the category for each.	79
Table 5.1: Categories for Navigating Constraints on EBIP Use. This table provides category names, definitions, examples, and the participants in each category for the three categories of the challenges and tensions mathematicians navigate when using EBIPs in ACM.	94
Table 6.1: How Participants' ROGs Shaped What Ensuring Learning Meant.	142

LIST OF ABBREVIATIONS

ACM	Advanced Collegiate Mathematics
EBIP	Evidence-Based Instructional Practice
MER	Mathematics Education Researcher
IBL	Inquiry-Based Learning
IBME	Inquiry-Based Mathematics Education
IOI	Inquiry-Oriented Instruction
ROGs	Resources, Orientations and Goals
SRI	Stimulated Recall Interview

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ABSTRACT OF THE DISSERTATION

Mathematicians' use of Evidence-Based Instructional Practices in Advanced Collegiate
Mathematics

by

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Doctor of Philosophy in Mathematics and Science Education

University of California San Diego, 2026
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This study explored how and why mathematicians use evidence-based instructional practices (EBIPs) in advanced collegiate mathematics (ACM), courses beyond calculus that are often proof-based. In undergraduate mathematics, traditional lecturing remains dominant (Johnson et al., 2018; Stains et al., 2018) despite decades of research indicating that EBIPs such

as active learning improve student success (Freeman et al., 2014; Theobald et al., 2020). While much prior research has examined factors that influence faculty adoption of EBIPs, particularly in introductory courses (e.g., Apkarian et al., 2021), less attention has been given to why faculty choose to use EBIPs in ACM, how they persist in using them, and why they use them in the ways they do. This study addresses this gap by examining these three questions.

To address these questions, six tenure-track mathematics faculty were recruited from three four-year universities in the Southwestern United States, with two participants from each institution. Data were collected through multiple semi-structured interviews and stimulated recall interviews grounded in video-recorded classroom observations. Semi-structured interviews elicited instructors' motivations and factors contributing to their persistence, while stimulated recall interview data provided detailed accounts of EBIP implementation and instructors' reasoning behind their instructional choices. A two-cycle qualitative coding approach (Miles et al., 2014; Saldaña, 2016) was used to analyze the data.

Findings revealed that mathematicians' use of EBIPs was driven by a core motivation to ensure meaningful learning occurs during class, rooted in the belief that students learn mathematics by actively engaging in it, particularly when they are unlikely to do so independently outside of class. Participants also came to value how EBIPs foster supportive learning environments and make student thinking visible, enabling real-time instructional adjustments. Prior exposure to EBIPs and departmental and collegial support made EBIPs feel viable, though these functioned as enabling rather than motivating factors. At the same time, participants encountered challenges related to content coverage, logistical constraints, and student resistance. Participants persisted by adapting their approaches, for example by switching to a different EBIP or modifying their implementation of the same one. These adaptations were

supported by positive experiences using EBIPs, collegial support, and shifts in how participants framed the challenges they encountered. In practice, participants were generally observed using EBIPs in one of two ways: lecture followed by group work, or lecture interspersed with activities. However, participants' varied goals, orientations, and resources shaped how and why these practices were used.

By centering mathematicians' existing reasons for using EBIPs, this work points toward more effective, discipline-specific support for EBIP adoption in mathematics that engages directly with instructors' motivations. In this way, this study contributes to broader efforts to understand and sustain instructional change in undergraduate mathematics.

Chapter 1 INTRODUCTION

Unlike many disciplines, mathematics is unique in the societal role it holds. Mathematics is associated with logic, objectivity and neutrality and is viewed as a competitive, individual activity (Hottinger, 2016). Because of this unique role, mathematics has served as a signifier of inherent worth and intelligence, and hence as an educational and economic gatekeeper (Stinson, 2004). At all educational levels, these narratives have led mathematics classrooms to serve as spaces to marginalize students whose identities are viewed as antithetical to mathematics, such as women and students of color (e.g., Joseph et al., 2017; Leyva et al., 2021). Thus, how mathematics should be taught has been the subject of a particularly heated debate spanning decades (Klein, 2007; Schoenfeld, 2004).

In the last half century, mathematics education research has promoted ways of doing and teaching mathematics that engage students actively in meaningful mathematics (Laursen & Rasmussen, 2019; Leron & Dubinsky, 1995), while often disrupting dominant narratives that serve to marginalize (Gutiérrez, 2013). However, this philosophy has not been universally accepted, especially outside of mathematics education. For example, in the 1990s, many mathematicians expressed their disapproval of the standards proposed by the National Council of Teachers of Mathematics and associated curricula, believing that they were imprecise and unrigorous, even accusing mathematics education of attempting to redefine what it means to do mathematics (Klein, 2007). Much of this debate has taken place in K-12 education due its formative and determinative nature (Oakes, 2005; Schoenfeld, 2004), but as access to higher education has continuously increased, more attention has turned to the teaching of collegiate mathematics (Melhuish et al., 2022; Rasmussen & Wawro, 2017; Speer et al., 2010).

One area that has received increased attention is advanced collegiate mathematics (ACM), collegiate mathematics courses taken after calculus sequences, such as differential equations, linear algebra, discrete mathematics, abstract algebra, and real analysis (Rasmussen & Wawro, 2017; Melhuish et al., 2022). Due to the gatekeeping role of introductory mathematics courses like calculus (Ellis et al., 2016; Leyva et al., 2021; Seymour & Hunter, 2019), much of the research has focused on how calculus courses are taught (e.g., Bressoud et al., 2015). However, a focus on how ACM courses are taught is also important for a few reasons.

First, ACM courses differ from other collegiate mathematics courses. Service courses like calculus are often large, serving students from various disciplines such as engineering, physics, or chemistry, while ACM classes are typically smaller and often cater more to mathematics majors and minors (Hochmuth, 2020). Second, service courses are primarily computation-based, whereas ACM courses often involve more theoretical mathematical concepts and proof construction, a conceptual shift many students grapple with (Solomon & Croft, 2016). This highlights how ACM courses can further serve as gatekeepers of the field of mathematics, providing additional opportunities for students to be pushed out of the discipline beyond the introductory courses where this most often occurs. The third reason that makes ACMs a unique environment worthy of study is that they are predominantly taught by research mathematicians. While most introductory mathematics classes are taught by visitors, instructors, teaching assistants, adjuncts, and lecturers (Levy, 2019), AMC courses are largely taught by tenured or tenure-track mathematics faculty (Blair et al., 2018). These faculty have a PhD in mathematics, do research in mathematics, and are not typically trained in mathematics education research.

By teaching ACM courses, mathematicians form a crucial subset of collegiate mathematics teachers. Using the lens of a community of practice, Goodchild (2023) discusses

how becoming a collegiate mathematics teacher involves adopting a shared set of goals and tools developed over years of studying mathematics and observing its instruction. All mathematics majors will take ACM courses, initiating a potential journey into the community of collegiate mathematics teachers, including those who teach gateway courses. Indeed, collegiate mathematics teachers draw upon a wealth of their experiences to develop their teaching practice, including those as students, instructors, and researchers (Lortie, 1975; Oleson & Hora, 2014). Hence, mathematicians are positioned to wield significant influence in shaping the shared goals and tools that determine what it means to do, learn, and teach collegiate mathematics. This makes understanding their teaching of particular importance.

The Teaching of Advanced Collegiate Mathematics

Traditionally, mathematicians have taught collegiate mathematics courses via lecturing, a tradition that persists today (Artemeva & Fox, 2011; Johnson et al., 2018). Within mathematics, lecturing is an instructional practice ingrained through years of mathematicians' practical experience and countless hours spent observing its instruction (Artemeva & Fox, 2011; Goodchild, 2023; Woods & Weber, 2020). Research consistently characterizes lectures as prevalent in collegiate courses (Stains et al., 2018), including mathematics (Johnson et al., 2018), where they seem to transcend national and linguistic boundaries (Artemeva & Fox, 2011). Research has revealed that this practice is not only prevalent among mathematicians but is associated with a cohesive set of instructional practices, including frequent factual questions, short wait times, and oral expositions of informal mathematics (Artemeva & Fox, 2011; Fukawa-Connelly, 2012; Paoletti et al., 2018).

However, lecturing in collegiate mathematics has been scrutinized for decades by mathematics education researchers (MERs) who advocate for more student-centered approaches that engage students meaningfully with disciplinary practices (e.g., Leron & Dubinsky, 1995;

Laursen & Rasmussen, 2019). A large body of research within mathematics and science education has supported the use of these evidence-based instructional practices (EBIPs), like active learning strategies, over lecture (Freeman et al., 2014; Theobald et al., 2020). These practices seek to promote student-centered instruction, engaging students in their own learning, and promoting higher-order thinking, often involving group work or other collaboration (Theobald et al., 2020). This has led mathematical communities to advocate for collegiate mathematics teachers to move away from the use of lectures in favor of using such EBIPs (e.g., Conference Board of the Mathematical Sciences, 2016; Saxe & Braddy, 2015). For example, initiatives like inquiry-based mathematics education (Laursen & Rasmussen, 2019), commonly referred to as IBME, have developed a vision for teaching collegiate mathematics based on engaging students in meaningful mathematical experiences and fostering student collaboration to promote sensemaking. In this approach, instructors actively inquire into their students' thinking, and they attend to equity in their teaching.

As the primary teachers of ACM, mathematicians are important change agents for transforming mathematics education. Yet, mathematicians' perspectives have been largely excluded from mathematics education research (Dawkins & Weber, 2020; Goodchild, 2023). Consequently, it is perhaps unsurprising that, despite an apparent consensus among MERs on the use of EBIPs and an abundance of available resources from their research initiatives, lecturing and its associated practices persist among mathematicians (Johnson et al., 2018; Woods & Weber, 2020).

The Perspectives of Mathematicians

It is well-documented that research-based curricular innovations for ACM are not well utilized by mathematicians and that mathematicians, for the most part, staunchly adhere to lecturing (Henderson et al., 2011; Johnson et al., 2018). At first glance, this may seem perplexing

because, within ACM educational research, multiple research-based teaching innovations have been produced by MERs (e.g., Larsen et al., 2013; Wawro et al., 2013). Some of these curricular innovations, such as inquiry-oriented abstract algebra, are relatively well-known, and yet the uptake of these materials among mathematicians appears to be scarce (Dawkins & Weber, 2023). Some MERs suggest that this limited adoption by mathematicians may result from the traditional methods of mathematics education research, which have largely excluded mathematicians' beliefs and perspectives (Dawkins & Weber, 2023; Goodchild, 2023; Stewart, 2023).

Until relatively recently, little research had been done to understand or include mathematicians' perspectives on teaching and learning. Some of this research has focused on how mathematicians think about doing, learning, and teaching mathematics (e.g., Alcock, 2010; Woods & Weber, 2020) and the pedagogical challenges they face in their dual roles as mathematicians and mathematics educators (e.g., Hannah et al., 2011; Paterson et al., 2011; Stewart & Schmidt, 2017; Wagner et al., 2007). These studies suggest that, while mathematicians have some different perspectives and priorities than MERS, the two communities also share several objectives, such as valuing students' engagement, conceptual understanding, and appreciation of mathematics.

Research from STEM education more broadly indicates that many factors, both contextual and individual, influence faculty's decision to use EBIPs (e.g., Apkarian et al., 2021). Within mathematics education, some studies suggest that many mathematicians may find EBIPs to be too time and energy intensive given their priorities and overall satisfaction and familiarity with lecturing (Johnson et al., 2018, 2019; Woods & Weber, 2020). However, research does suggest that some mathematicians engage in EBIPs (e.g., Johnson et al., 2018), but why they use these practices remains largely unknown.

Transforming the Teaching of Advanced Collegiate Mathematics

To better understand mathematicians' perspectives, some research has delved into why they choose to lecture. In addition to mathematicians lecturing because it is traditional and how they were taught, this research suggests that mathematicians favor lecturing as it grants them control over the structure, pacing, and precision of mathematical content, while still allowing engagement through occasional questioning (Woods & Weber, 2020); moreover, it suggests that mathematicians value authentic mathematical thinking and see lectures as a means to model various aspects of doing mathematics (Rasmussen & Wawro, 2017; Woods & Weber, 2020). Some MERs acknowledge the potential benefits of lectures that mathematicians value, suggesting that they can captivate and impart wisdom, especially to those with higher levels of mathematical maturity (Larsen, 2017; Rasmussen & Johnson, 2023).

In response to this, some MERs advocate for small changes to incorporate EBIPs into lectures, such as think-pair-shares (Dawkins & Weber, 2023; Rasmussen & Johnson, 2023). However, others argue that such incremental changes are insufficient to fully harness students' learning potential, asserting the necessity of a radical shift toward student-centered teaching (e.g., Lahdenperä et al., 2019). Indeed, much of the research on pedagogy in ACM has been conducted through this lens of change, resulting in predominantly interventionist studies. These studies involve research teams influencing a course's pedagogy to be more student-centered, either by teaching the course themselves or by having mathematicians adopt their innovations (Melhuish et al., 2022); moreover, unlike lectures, no single set of EBIPs seems to dominate such instruction with a wide variety of instructional practices—such as group work, student presentations, and whole class discussions—being implemented in many ways.

Advocates for incremental change propose a nuanced perspective on student-centered teaching, viewing it as a spectrum rather than a strict binary (Braun et al., 2017). From this

perspective, any instruction that includes EBIPs can be considered a form of student-centered instruction. Hence, instead of pushing for an immediate and universal adoption of inquiry approaches like IBME, some propose identifying ways to modify lecturing, making it more engaging for students and, thus, more student-centered (Alcock, 2018; Dawkins & Weber, 2023). Even strong supporters of inquiry approaches acknowledge that the advantages of EBIPs (e.g., group work, clicker questions) stem from a broad definition covering various active learning strategies, including cases where minimal class time was devoted to them (Rasmussen & Johnson, 2023).

Research has indicated that some change strategies to promote the use of EBIPs are more effective than others. In 2011, Henderson and colleagues noted that researchers in STEM education mostly discuss change efforts by disseminating curriculum and pedagogy, which involves designing and testing materials and then making these materials available. However, Henderson and colleagues found this strategy to be highly ineffective for transforming undergraduate STEM education, reflecting the current trend in mathematics education. Moreover, they further identified that change strategies that attend to (or seek to change) the beliefs of instructors are more effective in transforming STEM education.

Many efforts in professional development for STEM instructors have sought to foster such change (e.g., Archie et al., 2022; Goldberg, 2023; Yoshinobu et al., 2022), with a few geared toward engaging mathematicians in meaningful reflection on their teaching (e.g., Paterson et al., 2011). Yet, attending to stakeholders' current beliefs and practices is also an effective change strategy. Some studies have sought to understand why mathematicians lecture (e.g., Woods & Webers, 2020), and many have sought to understand the teaching of gateway courses (e.g., Bressoud et al., 2015; Vishnubhotla, 2022); yet none to my knowledge have investigated

why mathematicians engage in EBIPs in ACM outside of interventionist contexts (Melhuish et al., 2022).

Therefore, for my dissertation, I aim to investigate why mathematicians use EBIPs in their ACM courses. Mathematicians are positioned to significantly impact defining what it means to do and teach mathematics through their own teaching. Those who use EBIPs are well-positioned to partake in important dialogues and serve as role models and mentors within their departments (Shadle et al., 2017). Hence, it is crucial to understand why these mathematicians use EBIPs.

Research Questions

In this dissertation, I investigate the following research questions:

1. Why do mathematicians use EBIPs in their ACM instruction, including their initial motivations and their ongoing rationales?
2. What challenges and tensions do mathematicians encounter when using EBIPs in their ACM instruction, and how do they persist in using these practices despite those challenges?
3. What does mathematicians' use of EBIPs look like in ACM, and how is it shaped by their resources, orientations, goals, and other factors?

Together, these three research questions address three research goals; namely, to understand (a) why mathematicians use EBIPs, (b) how they persist in using EBIPs, and (c) why they use EBIPs in the ways they do. By addressing these questions, I hope to gain insight into mathematicians' motivations and experiences using EBIPs. This understanding may enable more productive collaboration between the communities of mathematics education and mathematics and inform future change initiatives to transform collegiate mathematics teaching.

Chapter 2 LITERATURE REVIEW

In this dissertation, I investigate why mathematicians use evidence-based instructional practices (EBIPs) in their advanced collegiate mathematics (ACM) instruction. Therefore, this literature review aims to demonstrate the importance of studying why mathematicians implement EBIPs in their ACM courses and illuminate what is currently understood about this phenomenon. In the first section, I define EBIPs in mathematics education and explore why it is important that mathematicians adopt them. In the second section, I delve into various contextual factors that may impede or promote mathematicians to use EBIPs. In the third section, I highlight individual factors as highly influential in mathematicians' choice of instructional practice. Lastly, I present the theoretical framework informing my research.

Evidence-Based Instructional Practices in Mathematics Education

An EBIP is often described as an educational method guiding instructors toward approaches demonstrated to improve student outcomes (Knowles et al., 2023). Within mathematics education, the most common sets of EBIPs fall under the categories of active learning and inquiry learning, which guide instructors toward student-centered approaches (Wright, 2011). A student-centered approach describes instruction in which the students take responsibility for their own learning. Student-centered instruction is often directly compared to lecturing, in which communication of content is directed primarily from the instructor to their students (Pritchard, 2010). Over the past decades, research has consistently demonstrated that student-centered instruction leads to improved learning outcomes compared to traditional lecture-based approaches (e.g., Freeman et al., 2014). In this section, I first explore active learning and inquiry learning, respectively. I address (a) how these EBIPs came to be within mathematics education, (b) what they look like, and (c) the research supporting their use. I then

shift to a discussion on how these EBIPs relate not only to student learning, but also to equity. Lastly, I conclude with the perspective on EBIPs that I adopt for this dissertation.

Active Learning

In sharp contrast to the passivity of lectures, active learning strategies require students to analyze, synthesize, and evaluate information through in-class activities and peer discussions (Laursen & Rasmussen, 2019). EBIPs that promote active learning include strategies and activities that foster these higher-order thinking skills, often involving group work or other forms of collaboration (Theobald et al., 2020). Active learning within higher education stems from dissatisfaction with the state of education at large. In 1983, *A Nation at Risk* was published, concluding that American public education was doing a disservice to its students. Several indicators of success, such as scores on standardized tests and the National Assessment of Educational Progress suggested that students were not mastering topics, instead they were learning to perform basic skills, solve routine problems, and recite facts. At that time, it was apparent that few students could use their knowledge and skills to solve complex problems (Bruer, 2001).

Similar concerns were expressed within collegiate STEM education, particularly within mathematics. In 1986, the National Science Board released the Neal Report which called for National Science Foundation (NSF) programs supporting improved undergraduate STEM education (Ferrini-Mundy & Güçler, 2009), and in 1987 the Mathematical Association of America (MAA) found that only about 47% of students who enrolled in calculus courses for STEM majors passed the course with a grade of D or better during the 1986-87 academic year. That is, over half of calculus students across the country either failed, dropped, or withdrew from their calculus courses (Anderson & Loftsgaarden, 1987).

The calculus reform of the 1980s and 90s clearly illustrates the emergence of active learning within collegiate mathematics education. This reform period was prompted by observations from faculty outside mathematics, who noted students could not apply calculus concepts across disciplines and noted students primarily learned rote memorization rather than conceptual understanding (Hallet, 2000). Consequently, major reform efforts ensued, with one prominent trend being the rule of three. This principle advocated for students to engage with calculus concepts symbolically, numerically, and graphically, later extending to include writing and speaking (Smith et al., 1994). This led to the creation of new learning environments; these were aimed at fostering active student engagement so students could interact with the course material in all five representations, such as presenting their work orally or collaborating in small groups. The underlying philosophy of these reforms echoed the sentiment that "telling is not teaching, and listening is not learning" (Sally Berenson, North Carolina State University, as cited in Smith et al., 1994), aligning closely with the principles of constructivism. Constructivist theories of learning emphasize that knowledge is actively constructed by learners rather than passively transmitted, necessitating students' active participation in the learning process (von Glasersfeld, 1982; Sjøberg, 2010; Yale University Media Studio, 1977). As a result, active learning became a central tenet promoted by reformists.

Research on active learning strategies has demonstrated that they generally enhance student success compared to lecture-based courses. Indeed, in 2014, a comprehensive meta-analysis conducted by Freeman et al. suggested that active learning strategies lead to a slight improvement in examination scores and a significant reduction in failure rates. Notably, Freeman and colleagues found that traditional lecture-based courses exhibited a 55% increase in failure rates compared to those incorporating active learning. Furthermore, the improvements in exam

performance correlated with, on average, a half-letter grade increase in final grades. The broad definition of active learning used for this meta-analysis included strategies such as small group work, in-class worksheets, clicker questions, and studio or workshop designed courses, with as little as 10% of class time spent engaged in these activities. Moreover, they found that active learning was effective for even large classes with upwards of 110 students.

In general, active learning has been widely shown to improve student outcomes (Deslauriers et al., 2019; Freeman et al., 2014; Hake, 1998; Theobald et al., 2020), leading to calls to move away from traditional lecturing (e.g., Conference Board of the Mathematical Sciences, 2016; Mathematical Association of America, 2017; Saxe & Braddy, 2015). Research suggests that students benefit most when active learning is used extensively during class time (Lahdenperä et al., 2019; Theobald et al., 2020), and that the effectiveness of some course formats—such as flipped classrooms—may stem more from their active learning components than from the format itself (Jensen et al., 2015).

However, active learning encompasses a wide range of instructional strategies that vary in intensity and impact. Some strategies, such as partial notes, clicker questions, think-pair-share, or small group problem solving, can be flexibly integrated into traditional lectures (Alcock, 2018; Braun et al., 2017; Dawkins & Weber, 2023). Others require substantial restructuring of the course, such as flipped classrooms (Milman, 2012), inquiry-based mathematics education (Laursen & Rasmussen, 2019), or the Extreme Apprenticeship method (Rämö et al., 2015). Given this variation, it is important to understand how mathematicians adopt and implement EBIPs, including the different ways they enact active learning in their classrooms. Indeed, research has shown that mathematicians use a variety of EBIPs (e.g., Johnson et al., 2018), highlighting the need to examine this (Knowles et al., 2023).

Additionally, some researchers have advocated viewing assessment as part of active learning (e.g., Katz, 2022; Sisneros-Thiry, 2024), arguing that traditional assessment practices are less consistent with the principles underlying active learning. This encompasses alternative assessments such as standards-based grading, as well as formative assessment strategies. The former emphasizes mastery of specific learning outcomes over point accumulation and provides multiple opportunities for reassessment and feedback (Elsinger & Lewis, 2020; Lewis, 2020), while the latter include practices such as clearly communicating learning objectives and success criteria, using discussions to elicit evidence of understanding, providing feedback that promotes improvement, engaging students as resources for one another's learning, and supporting students in taking ownership of their learning (Black & Wiliam, 2009).

Inquiry Learning

A specific form of active learning that is very salient in mathematics education is inquiry learning (e.g., Laursen & Rasmussen, 2019). This form of active learning has a particularly rich history in American and European education, stemming from the American philosopher and educator John Dewey (1859-1952). Dewey rejected traditional instructional practices that focused on drill and practice that became prevalent in the 20th century (Artigue & Blomhøj, 2013); instead, Dewey, along with many other philosophers, worked toward a vision of education in which knowledge was not memorized or taken on faith, but rather based on one's own thinking, reflection, and experimentation. Hence, inquiry learning emphasizes the role of autonomy and thinking for oneself. Within mathematics education, this was reflected in research on problem-solving, which was prompted by observations that students struggled with non-routine problems. This aligns with the observations in American education that led to much of mathematics reform, such as in college calculus. Indeed, by 1996, the NSF recommended that all undergraduate STEM students should learn STEM subjects "by direct experience with the

methods and processes of inquiry” (p. 1). Much of the research on student-centered instruction in collegiate mathematics instruction has thus centered on inquiry (e.g., Melhuish et al., 2022; Rasmussen & Wawro, 2017).

While inquiry has had a significant role in educational reform efforts in the U.S. and Europe (Artigue & Blomhøj, 2013), a specific type of inquiry learning called inquiry-based learning (IBL) originated from ACM education. IBL stemmed from the work of the mathematician R.L. Moore (1882-1974), who developed its predecessor: the Moore Method (Mahavier, 1999). In his proof-based ACM classes, Moore prohibited students from accessing outside sources and collaborating with peers. Instead, he provided them with axioms and examples in class, subsequently requiring students to independently prove theorems and present their proofs in class to promote independent inquiry (Zitarelli, 2004). This method became known as the Moore Method, and various forms of it have persisted among mathematicians due to the prominence of Moore’s Ph.D. students within the fields of mathematics and mathematics education (e.g., Whyburn, 1970). While Moore is rightly considered problematic due to his many bigoted beliefs and behaviors (Parker, 2005), the Moore Method and its legacy are associated with students not only taking an active role in doing mathematics but engaging in inquiry learning.

Over time, connections between inquiry learning movements in education and the Moore Method led to the development of IBL as recognized today (Haberler et al., 2018). Historically, IBL served as an apprenticeship into mathematics, mirroring research mathematicians' practices (Yoshinobu & Jones, p. 307). While the Moore Method prohibited collaboration (Parker, 2005), IBL has come to encourage it to model mathematicians' collaborative work (Burton, 2004; Yoshinobu & Jones, 2012). Over time, IBL shifted to first having students engage in independent

inquiry followed by peer collaboration, but as the IBL community has continued to expand, collaboration has become even more central (Ernst et al., 2017; Haberler et al., 2018). By the 2010s, IBL became widely recognized as a form of active learning guided by two core principles: (a) students should engage deeply with rich mathematics and (b) students should have opportunities to collaborate (Ernst et al., 2017; Johnson, 2019). This "big tent" approach to IBL, as it became known, embraces diverse strategies to promote authentic mathematical practices (Haberler et al., 2018; Hayward et al., 2016; Laursen & Rasmussen, 2019). Yet, within the IBL community, a range of approaches still exist, with early adopters favoring a more traditional Moore Method, benefiting students that they view as potential future mathematicians, and with newer IBL users prioritizing equity and collaboration (Haberler et al., 2018).

Another line of inquiry salient to ACM education is inquiry-oriented instruction (IOI). Unlike IBL, IOI emerged from design-based research and Realistic Mathematics Education (Laursen & Rasmussen, 2019). IOI encompasses research-based curricula covering many mathematical topics within ACM, like abstract algebra, differential equations, and linear algebra. The contributions of Paul Cobb and Erna Yackle were pivotal in IOI's development, with inquiry being a notable feature of the elementary school classrooms they studied. In these classrooms, students regularly explained their thinking, made sense of others' thinking, and collaborated with others. In this vein, IOI research aligns with design-based research principles, conducted authentically in classrooms with instructor involvement. Also grounded in Realistic Mathematics Education, IOI curricula use imaginable situations, guiding students to reinvent key mathematical concepts. The curricula offer carefully sequenced materials to prompt student thinking and connect emerging ideas to formal mathematics (Rasmussen & Kwon, 2007). In an IOI classroom, one would observe small groups of students working collaboratively on

challenging mathematical problems, sharing their solutions, and actively seeking and receiving feedback. Many curricular materials for ACM have emerged from the research in IOI, such as inquiry-oriented abstract algebra (Larsen et al., 2013), differential equations (Rasmussen et al., 2017), and linear algebra (Wawro et al., 2013). Research in this field has focused extensively on the teaching methods employed by instructors using IOI curricula to promote inquiry (e.g., Kuster et al., 2017; Kwon et al., 2008; Rasmussen et al., 2009) and the impact of IOI on student learning outcomes.

Both IBL and IOI have shown promise in enhancing student achievement compared to traditional lecture-based approaches. Most research into transforming ACM education falls into one of these two lines of inquiry (e.g., Melhuish et al., 2022). In their review of the proof-based ACM education literature, Melhuish and colleagues identified 19 papers that studied instructional practices in student-centered classrooms; of these, nine came from IBL research and 10 came from IOI research. Most of this research has taken the form of intervention studies, where some change (e.g., using new curricular materials) is occurring, reflecting the vision to transform ACM education to be more student-centered. For instance, Kwon et al. (2005) discovered that students in an IOI differential equations class retained more conceptual knowledge than those in traditional lecture-based courses, while exhibiting comparable procedural knowledge when tested a year later.

Similarly, Laursen et al. (2014) found from observations of over 100 classes that, in non-IBL courses, women reported lower levels of mastery compared to men, a gap not observed in IBL courses. This research suggests that IBL courses may significantly bolster women's confidence in mathematics, shedding light on how lectures might contribute to the inequities seen in mathematics education. Furthermore, Kogan and Laursen (2014) compared the

subsequent course selection and grades of students enrolled in either IBL or non-IBL ACM courses. They found that IBL had a particularly positive impact on previously lower-achieving students, as evidenced by their subsequent course grades. Moreover, women reported experiencing positive affect in response to IBL.

Due to the similar visions behind IOI and IBL, inquiry-based mathematics education (IBME) arose as an integration of the two (Laursen & Rasmussen, 2019). This initiative envisions mathematics education and research guided by four pillars: (a) students engage deeply with coherent and meaningful mathematical tasks; (b) students collaboratively process mathematical ideas; (c) instructors inquire into student thinking; and (d) instructors foster equity in their design and facilitation choices (p. 138). IBME's vision for teaching places greater emphasis on how instructors and students engage than on specific instructional activities. In particular, Kuster et al. (2019) described seven instructional practices that support the principles of IOI: facilitating student engagement in meaningful tasks, eliciting and actively inquiring into student reasoning and contributions, being responsive to student input to inform lessons, engaging students in each other's reasoning, guiding and managing the mathematical agenda, and supporting the formalization of student ideas and contributions through the introduction of formal language and notation. Similarly, Hayward et al. (2016) describe measuring IBL as decreases in instructor lecturing and increases in student-led whole-class and small-group discussions, as well as student-led presentations of solutions. They also mention the potential of instructor-led whole-class and small-group discussions, and small-group work as part of IBL, as well as the incorporation of other forms of active learning not associated with IBL, such as asking conceptual questions and individual problem-solving in class.

Equitable Teaching

While the calls for reforming STEM have focused on increasing students conceptual understanding and moving away from traditional lecturing to student-centered approaches that use active learning, they have also been driven by equity concerns, such as attracting and retaining more people and increasing diversity within STEM fields by improving collegiate STEM experiences (Ferrini-Mundy & Güçler, 2009). For example, in 2012, the President's Council of Advisors on Science and Technology reported that U.S. colleges would need to increase the number of students completing STEM degrees by 33% to meet workforce demands. This report identified the persistence of students in STEM as a major barrier to this goal, finding that fewer than 40% of students in U.S. colleges who begin a STEM degree graduated with one; for women and students of color, this number was only 20%. Mounting evidence suggests that experiences with mathematics contribute significantly to this, with women and students of color being dissuaded from mathematics not because of ability but because class experiences negatively impact their sense of belonging, identity, and confidence (Ellis et al., 2016; Leyva et al., 2021). Thus, addressing equity has also guided the implementation of active learning, and particular inquiry learning, as EBIPs within mathematics education.

By 2020, active learning had been strongly linked to improved student outcomes (Freeman et al., 2014), and inquiry learning had been associated with improving learning conditions for women in mathematics (Kogan & Laursen, 2014; Laursen et al., 2014), as previously discussed. This positioned active learning as a potential tool to address inequity in collegiate mathematics classrooms. This was seemingly validated when Theobald et al. (2020) published a disaggregated meta-analysis on active learning. They found that active learning narrows the achievement gap between overrepresented and underrepresented students by 33%, and the gap in passing rates by 45%, but that this effect became even more pronounced in

courses implementing higher levels of active learning (i.e., longer engagement in class), reducing the achievement and passing rate gaps by 42% and 76%, respectively.

However, additional research has indicated that active learning does not guarantee equitable outcomes. Some studies have indicated that the benefits of active learning may be inflated, disproportionately benefiting white, male, and higher-achieving students (Johnson et al., 2020; Setren et al., 2019; Voskoglou, 2019). For example, Johnson et al. (2020) compared data from 522 student content assessments, including 147 from students who had taken inquiry-oriented abstract algebra and 375 from a national comparison sample. They found no difference between men and women's performance within the national sample, but men in IOI classes outperformed women in IOI classes, while women performed similarly in both IOI classes and the national sample. These findings suggest that male students in their study benefited disproportionately from IOI. Similar findings have been observed in flipped classrooms (Setren et al., 2019). Johnson et al. (2020) noted that a preliminary analysis suggested that instructors using IOI may have asked men more substantial questions at higher rates than women. This is supported by subsequent research that identified a high correlation between women's performance and their participation in IOI classes (Reinholz et al., 2022). These findings align with research indicating that mathematics classrooms can implicitly marginalize minoritized students' identities due to underlying biases held by both instructors and students (Ernst et al., 2019; Hottinger, 2016; Leyva et al., 2021)

From this, it is clear that carefully attending to equity is integral to attaining the benefits of EBIPs. Indeed, the fourth pillar of IBME was added to address these rising concerns that inquiry learning does not automatically result in more equitable student outcomes (Laursen & Rasmussen, 2019). That is, equitable instructional practices – those that address the needs and

conditions necessary for each individual student to succeed – are an important part of implementing EBIPs (Yu et al., 2023); such practices include addressing student identity, addressing stereotypes and biases in the classroom, being intentional with language choices, addressing access to resources to meet students’ needs, in addition to EBIPs.

Contextual Factors Involved in Using EBIPs

As discussed, the uptake of EBIPs among mathematicians appears to be sparse (Johnson et al., 2018), reflecting a broader trend in collegiate STEM education (Froyd et al., 2013; Henderson et al., 2012; Stains et al., 2018). Consequently, much of the research on why faculty use EBIPs comes from STEM education. This body of research has identified two types of factors that are salient to faculty’s decisions to engage in EBIPs, which I call individual and contextual factors. This current section focuses on contextual factors, which are external, institutional, and departmental influences (Sturtevant & Wheeler, 2019). Common contextual factors include physical resources like class size and space (Apkarian et al., 2021; Foote et al., 2014; Henderson et al., 2012; Henderson & Dancy, 2007; Knaub et al., 2016; Lund & Stains, 2015); teaching evaluations and student buy-in (Apkarian et al., 2021; Deslauriers et al., 2019; Froyd et al., 2013; Hayward et al., 2016; Michael, 2007; Shadle et al., 2017); and the time constraints (Andrews & Lemons, 2015; Froyd et al., 2013; Henderson & Dancy, 2007; Henderson et al., 2012; Johnson et al., 2018, 2019; Lund & Stains, 2015; Shadle et al., 2017; Turpen et al., 2016), support, and incentives institutions and departments provide (Henderson & Dancy, 2007; Johnson et al., 2018, 2019; Lund & Stains, 2015; Shadle et al., 2017; Sturtevant & Wheeler, 2019). Each of these common contextual factors will be discussed respectively.

Classroom Factors

In STEM education, large class size and fixed-seating classrooms have been associated as barriers to implementing EBIPs. Fixed-seating classrooms may be less favorable to the

collaboration many EBIPs involve (e.g., IBL, flipped classrooms), as opposed to more accommodating spaces. For instance, Foote et al. (2014) and Knaub et al. (2016) found that when physics faculty had access to studio-style rooms with round tables, whiteboards on the walls, and no clear front to the room, faculty were more likely to adopt EBIPs and sustain their use. Similarly, studies have associated large class enrollment with faculty using fewer EBIPs (e.g., Henderson et al., 2012), suggesting that faculty view large classes as a barrier to using EBIPs. In short, research has shown that both class size and physical classroom spaces influence faculty's use of EBIPs (Apkarian et al., 2021; Archie et al., 2023; Henderson et al., 2012; Lund & Stains, 2015).

It is important to note that much of the research on EBIPs in collegiate mathematics, such as IBL, has stemmed from ACM courses, which are typically characterized by smaller class sizes (Ernst et al., 2017). Yet even mathematicians teaching these classes have been found to primarily lecture (e.g., Johnson et al., 2018). Consequently, while smaller class sizes may facilitate mathematicians' use of EBIPs, it cannot be the primary reason. In their national large-scale observation survey of STEM courses at 24 doctoral-granting universities in the USA, Stains et al. (2018) found that – while instruction in classrooms with flexible seating arrangements was more likely to be student-centered – about half of STEM classes taught in these spaces, as well as half of those classified as small or medium class size, were taught using lecture. This research indicates that simply providing facilitative classroom spaces and smaller enrollment does not guarantee that instructors will use EBIPs. Therefore, other important factors must be at play.

Teaching Evaluations and Student Buy-In

Another factor influencing the decision to adopt EBIPs is student buy-in. Many STEM faculty report concerns about student resistance (Froyd et al., 2013; Henderson & Dancy, 2007, 2011; Michael, 2007), fearing it may lead to negative teaching evaluations (Apkarian et al.,

2021). Instructors often perceive students as being resistant to EBIPs like active learning (Michael, 2007), where resistance refers to negative reactions to its implementation (Nguyen et al., 2021), fueling these concerns. Studies have suggested that concerns about student resistance can influence instructor uptake of EBIPs (Apkarian et al., 2021; Froyd et al., 2013; Hayward et al., 2016). For instance, Hayward et al. (2016) analyzed the effectiveness of an IBL workshop on faculty participants after a year, assessing if they continued to use IBL and what supported this. They found the workshop was effective – with 58% of instructors using IBL a year later – and addressing common concerns was key to their sustained use of IBL, with one of the most common concerns being student resistance.

Importantly, faculty concerns about student resistance to EBIPs are well-founded. This is supported by research on student experiences with EBIPs. For example, Owen et al. (2020) surveyed science majors in an undergraduate biology class that incorporated active learning. Some students expressed resistance due to the increased effort active learning required and a lack of understanding about its purpose. Similarly, Deslauriers et al. (2019) explored physics students' perceptions of learning in active learning versus traditional lecture settings. Interviews revealed that the unfamiliarity and increased cognitive effort associated with active learning contributed to student resistance, with students reporting they learned less despite tests indicating higher learning outcomes. These studies highlight that faculty concerns about student buy-in are legitimate. However, some research indicates that just a few positive experiences with using EBIPs may convince STEM faculty to continue using them (e.g., Anderson & Lemons, 2015), suggesting that experiences using EBIPs are an important part of adopting them.

Time Constraints

While positive experiences with implementing EBIPs may lead to their use, research also indicates a lack of time may inhibit the uptake of EBIPs among STEM faculty or contribute to

their discontinuance (Andrews & Lemons, 2015; Froyd et al., 2013; Henderson & Darcy, 2007; Henderson et al., 2012; Johnson et al., 2018, 2019; Lund & Stains, 2015; Shadle et al., 2017; Turpen et al., 2016). Time constraints often involve a lack of time to cover enough content while using EBIPs, and a lack of time preparation time, and time to learn to implement them effectively (Andrews & Lemons, 2015; Froyd et al., 2013; Lund & Stains, 2015). For instance, some STEM faculty express that learning to use an EBIP – or even the EBIP itself – can hinder their ability to cover content (Andrews & Lemons, 2015; Lund & Stains, 2015), while some express that they do not have enough time to prepare for class due to other obligations (Andrews & Lemons, 2015; Froyd et al., 2013).

Notably, concerns about content coverage appear to be pronounced among mathematics faculty. Some mathematicians experience pressure to cover content (Hayward et al., 2016; Johnson et al., 2018, 2019; Woods & Weber, 2020), such as to cover prerequisite skills for subsequent courses (Hayward et al., 2016), or to control the pace and presentation of mathematics (Woods & Weber, 2020), leading them to prefer lecture-based approaches over EBIPs (Johnson et al., 2018, 2019; Woods & Weber, 2020). However, some research indicates that the content pressures mathematicians feel may not stem directly from their institutions (Johnson et al., 2018, 2019), such as departmental pressures to cover specific prerequisite skills, but may be rooted in individual factors, such as perceived obligations to the discipline of mathematics (Johnson et al., 2013; Mesa et al., 2020; Woods & Weber, 2020). The tensions between time, coverage, and pedagogy can be understood through the lens of opportunity to learn, a framework that encompasses three components: content coverage (topics covered), content exposure (time devoted to instruction), and content emphasis (which topics receive priority) (Reeves et al., 2013). Interestingly, Hagman et al. (2017) found that calculus instructors

who used student-centered practices did not report that these practices constrained their time to provide opportunities to learn, further suggesting that the relationship between EBIPs use and content coverage constraints may be more nuanced than previously understood.

Additionally, time constraints are associated with the high rate of EBIP discontinuance STEM faculty exhibit, especially with more intensive EBIPs like inquiry learning. For example, Froyd's (2013) survey of engineering faculty found that, while engineering faculty were highly aware of inquiry learning approaches, their use of it exhibited a 50% discontinuance rate. Likewise, in their survey of 722 physics faculty, Henderson et al. (2012) found that, although 72% of instructors had tried at least one EBIP, 32% of those had discontinued its use. This discontinuance has been associated with a lack of time or support to learn to implement EBIPs, with faculty using EBIPs needing support to implement them successfully (Turpen et al., 2016). In total, this literature suggests that time constraints can inhibit both the adoption and sustained use of EBIPs.

Institutional Support

Implementing EBIPs can be very difficult and time-consuming. This is reflected by the fact that much of the research on mathematicians using EBIPs focuses on their challenges and progress in implementing them (e.g., Andrews-Larson, 2015; Johnson et al., 2012; Mesa et al., 2020). Hence, support in adopting EBIPs is vital (Andrews & Lemon, 2015; Froyd et al., 2013; Lund & Stains, 2015; Shadle et al., 2017). Institutional support can range from explicit incentives (Froyd et al., 2013; Shadle, 2017) to a generally supportive culture (Henderson & Dancy, 2007; Lund & Stains, 2015; Shadle et al., 2017). For instance, institutions may incentivize research over teaching via tenure or promotion criteria (Shadle et al., 2017).

Institutional incentives like this can be highly influential in shaping one's professional identity, which describes "the core beliefs, values, and assumptions about one's career that

differentiate it from others” (Sturtevant & Wheeler, 2019, p. 5). Research expectations can prioritize research over teaching, potentially hindering the incorporation of teaching into one's professional identity. For example, tenure criteria may prioritize research, making faculty less likely to utilize EBIPs (Sturtevant & Wheeler, 2019). This may leave even faculty who have an interest in improving their teaching feeling unmotivated to pursue this interest (Andrews & Lemon, 2015; Shadle et al., 2017). Thus, it is perhaps unsurprising that high research productivity has been associated with decreased usage of EBIPs; that is, while research and teaching identities are not necessarily at odds with one another (Sturtevant & Wheeler, 2019), higher research activity may reflect an institution's priorities, leaving faculty with little time or motivation to innovate their teaching (Apkarian et al., 2021; Henderson et al., 2012; Lund & Stains, 2015; Shadle et al., 2017). Hence, while many faculty do not conduct research to the extent that it impedes their use of EBIPs, those who do may need support to not drastically increase their time commitments (Apkarian et al., 2021).

However, incentives are just one piece reflecting an institution's culture. Higher education research has identified institutional cultures as a significant factor influencing teaching among faculty (Salazar et al., 2010), which is often reflected in incentives like those discussed. Yet, even within the same institution, departments can vary widely in the barriers they present or mitigate, echoing Henderson et al.'s (2011) observation that institutional complexity is vital to understand. For example, Lund and Stains (2015) surveyed and observed faculty in chemistry, physics, and biology at one institution and found that the physics faculty were observed using three times as many EBIPs as the chemistry faculty. This was associated with the physics department having stronger student-centered norms, which was reflected in physics faculty

having more extensive teacher training, and positive attitudes and beliefs toward student-centered teaching when compared to faculty in the other two departments.

Norms supportive of EBIP adoption may involve cultivating student-centered teaching through various methods. These could include offering or incentivizing professional development opportunities and incorporating teaching into tenure criteria (Andrews & Lemons, 2015; Lund & Stains, 2015; Shadle et al., 2017). Additionally, institutions could facilitate awareness and knowledge of EBIPs by expanding faculty's communication channels to learn about these methods (Andrews & Lemons, 2015; Lund & Stains, 2015; Shadle et al., 2017); this could be achieved by fostering connections with faculty proficient in EBIPs to serve as mentors or role models or encouraging regular and meaningful discussions about teaching within the department (Andrews & Lemons, 2015; Lund & Stains, 2015; Shadle et al., 2017). Other resources such as reading education journals and attending conferences can also be useful, but require more time and energy; indeed, some research indicates that faculty most often utilize their colleagues with teaching or educational expertise for advice about teaching, such as professors of practice and educational researchers, over sources like journals and conferences (Lund & Stains, 2015).

Altogether, this literature suggests that many contextual factors influence faculty's use of EBIPs. Large classes, fixed-seating arrangements, and concerns student-resistance may make faculty hesitant to use EBIPs. If instructors feel time constraints are a factor, then they may hold the view that EBIPs slow their pace and sacrifice content, or they may otherwise view the required time and energy to prepare or learn to implement EBIPs as incongruent with their situations. Lastly, if the institution is unsupportive of EBIPs, such as prioritizing research over

teaching, and does not facilitate or incentivize faculty to improve their teaching, then faculty may feel unmotivated or unconfident to use EBIPs.

Individual Factors Involved in Using EBIPs

Unlike contextual factors, which depend on specific contexts, individual factors involve personal influences, including one's orientations (e.g., beliefs, values, dispositions), goals, (Schoenfeld, 2010), identity, and prior experiences (Sturtevant & Wheeler, 2019). These individual factors are highly influential in shaping one's instructional practice. Indeed, like contextual factors, STEM education researchers have associated individual factors with one's instructional practice (Andrews & Lemons, 2015; Johnson et al., 2018, 2018; Sturtevant & Wheeler, 2019; Shultz, 2022; Vishnubhotla et al., 2022). However, some research indicates that the influence of individual factors may have a stronger impact than contextual factors, which in turn constrain or facilitate an instructor's choice to adopt a particular EBIP (Andrews & Lemons, 2015; Johnson et al., 2019). Hence, in this section, I explore studies that illuminate how dis/satisfaction with lecturing, driven by various orientations, goals, and experiences may make mathematicians more or less inclined to use EBIPs, a choice that is then constrained or facilitated by contextual factors.

Experiences

Mathematics is deeply rooted in tradition, handed down from one generation of mathematicians to the next through the observation of how mathematics is taught, practiced, and discussed (Artemeva & Fox, 2011; Goodchild, 2023; Sfard, 2014; Woods & Weber, 2020). In general, educational research suggests that one's experiences with teaching, both as a student and as a teacher, greatly shapes one's instructional practice (Lortie, 1975; Oleson & Hora, 2014). Additionally, experiences using EBIPs themselves are thought to contribute to their continued use (Andrews & Lemons, 2015; Sturtevant & Wheeler, 2019). Because of this and research

indicating that one's dissatisfaction with lecturing is associated with seeking out alternatives (Andrews & Lemons, 2015; Johnson et al., 2018, 2019), it is important to understand the different experiences that may influence one's choice to engage in EBIP.

Experiences as a Student

When teaching ACM courses, mathematicians most often elect to lecture (Artemeva & Fox, 2011; Johnson et al., 2018), making lecturing the most frequent instructional experience a mathematician likely had as a student. The typical ACM lecture features a mathematician standing before an audience of students, presenting definitions, problems, and solutions on a chalk or whiteboard while discussing the mathematics aloud, a soliloquy only broken by the occasional question from the mathematician or their students. This style of lecturing in mathematics, coined chalk talk (Artemeva & Fox, 2011), is widespread, having been observed across the world. Chalk talk features a mathematician writing mathematics while providing a running metacommentary, organizing information on the board, and asking students questions to prompt reflection or check understanding. Additionally, many mathematicians use the definition-theorem-proof (DTP) format in their proof-based courses, where lectures consist of providing a mathematical definition, stating a theorem, and proving it, emphasizing the logical structure of mathematics and the ability to reproduce rigorous proofs (Weber, 2004).

Within ACM, the significance of the chalk talk – a medium encountered throughout a mathematician's educational and professional trajectory – may lead novice instructors to reflect on refining this traditional instructional activity, thus reproducing it in their own teaching, much like the apprenticeship of observation (Lortie, 1975), in which student teachers primarily base their teaching on the countless hours they spent observing it as students. It is important to note that not experiencing EBIPs as a student does not preclude one's adoption of EBIPs (e.g., Lund

& Stains 2015). However, past experiences with EBIPs as a student can shape novice instructors' orientations toward and decisions to engage in these practices (Kraft et al., 2024)

Because those who enter teaching roles in ACM were successful in the ways they were taught – typically lecture – their satisfaction with lecturing may lead them to replicate those techniques (Luft et al., 2004; Woods & Weber, 2020). Indeed, mathematicians have discussed the historical success of chalk talk as a tradition with a good track record spanning at least over the past 200 years, mentioning their own success with the method as students, and saying they saw no reason to explore alternative approaches for their own students (Woods & Weber, 2020). This raises the question of what experiences motivate mathematicians to seek out lecture alternatives.

Experiences as a Teacher

Research with STEM faculty has indicated that their experiences as a teacher are salient in shaping their instructional practice, particularly regarding their willingness to try new practices, such as EBIPs. For instance, Oleson and Hora (2013) found that while some STEM faculty reflect on their experiences as researchers (e.g., wanting to model authentic practices), many more reflect on experiences they had as teachers. Most STEM faculty in this study reported that experimenting with different methods – including new approaches and identifying challenging content for students – significantly shaped their teaching, more so than professional development, feedback from evaluations, and interactions with colleagues.

Additionally, Oleson and Hora (2013) found that, for some faculty, once they established a successful method, they indicated a tendency to stop reflecting on their teaching, describing that they had stopped seeking advice and trying new things once they developed a satisfactory “recipe for instruction” (p. 41). This tendency to stop reflecting on one’s teaching has also been observed among mathematicians. Artemeva and Fox (2011) found that novice mathematics

instructors – those teaching for six or fewer years – were more adept at articulating why chalk talk was good for teaching mathematics than more senior faculty, who often responded with statements like, “It’s just what we do in mathematics” (Artemeva & Fox, 2011, p. 367).

Artemeva and Fox hypothesized that novice instructors were more cognizant of these reasons because they had more recently observed mathematics instruction as graduate students or postdocs, and many were receiving mentorship from more senior faculty, and thus they were likely reflecting on their instruction to improve their practice, whereas senior faculty were more set in their ways.

Satisfaction with Teaching. Understanding experiences as a teacher are important because findings from STEM education at large support that one’s dis/satisfaction with teaching may play a salient role in the choice to use EBIPs (Andrews & Lemons, 2015; Shadle et al., 2017; Sturtevant & Wheeler, 2019). Andrews and Lemons (2015) found biologists were primarily motivated to adopt lecture alternatives by their dissatisfaction with their own teaching. Many discussed a desire to have more fun while teaching and a desire to improve their teaching as reasons for using case studies. Some were even motivated to find lecture alternatives due to their perception that students were bored with lectures. In a similar vein, Johnson et al. (2019) found that mathematicians who viewed lecture favorably were more likely to lecture more. Those who lectured most extensively often agreed that lecturing is the best method to cover content, indicating more satisfaction with this teaching method than those who lectured for less class time.

Notably, a few biologists in Andrews and Lemons (2015) who reported dissatisfaction said they had gone years being dissatisfied with lecturing before using case studies. Biologists who expressed this cited contextual factors, such as a lack of time due to other job obligations or

a lack of pedagogical support (e.g., professional development), as the reason it had taken them so long to find an alternative. From this, Andrews and Lemons suggested that those who express inadequate time to use EBIPs in their classes may be saying more about how their work environment and individual factors together have influenced their priorities. Research in higher education has made similar conjectures, suggesting that instructors will use their preferred teaching approaches – which are largely informed by their beliefs about teaching – unless contextual factors (e.g., institutional influences, workload, large classes, etc.) are not conducive for doing so (Kember & Kwan, 2000). Similarly, Johnson et al. (2019) found no association between reported contextual factors and mathematicians' instructional practice. While those who lectured extensively and those who lectured in limited amounts both tended to report feeling inadequate time to cover content, neither group reported external pressures to do so. Together, this suggests that one's satisfaction with their teaching may be heavily influenced by individual factors, which are then constrained or facilitated by contextual factors.

In my literature review, I found one qualitative study that discussed how teaching satisfaction may drive mathematicians to adopt EBIPs. Johnson et al. (2013) documented the experiences of three mathematicians using IOI for the first time. In this documentation, Johnson and colleagues included brief biographies of the events that led these three mathematicians to volunteer to try out the IOI curricular materials. These biographies revealed that the three mathematicians were largely driven by a desire to improve their teaching, with all three attending professional development opportunities. Two of the mathematicians expressed dissatisfaction with their ability to develop their own materials as influential in volunteering to use IOI, while one expressed wanting to develop his group work facilitation skills as his primary motivation. This supports that dissatisfaction is an important factor that prompts mathematicians to innovate

their instructional practices and highlights the potential to investigate how different sources of dissatisfaction (e.g., group work facilitation, ability to create worksheets) could contribute to what EBIPs a mathematician finds useful.

Satisfaction with EBIPs. Satisfaction is also thought to play an important role in the continued use of EBIPs (Andrews & Lemons, 2015; Sturtevant & Wheeler, 2019). As discussed, some researchers hypothesize that faculty discontinue using EBIPs because they lack the time or support to implement them properly. This may lead to modifications that may not yield expected student outcomes. These unexpected outcomes may create dissatisfaction with the EBIPs and lead faculty to stop using them. For instance, the participants in Hayward et al.'s (2016) study frequently expressed concerns about their skills and ability to implement IBL. The researchers found that faculty's confidence in their ability to implement IBL was crucial for continued use of it. Andrews and Lemons (2015) likewise found that biologists reported that not feeling prepared to implement case studies inhibited their adoption of it; specifically, some biologists reported that feeling like they did not have enough time to prepare to use case studies led to perceived failures in their implementation.

This perceived failure is a salient reason that may lead to dissatisfaction with the EBIP. As discussed, research supports that faculty may experience negative responses from students, hindering some of the positive experiences that encourage faculty to use EBIPs. Indeed, dissatisfaction with EBIPs has been associated with common barriers, particularly viewing students as barriers and having negative prior experiences with EBIPs (Sturtevant & Wheeler, 2019). Additionally, some empirical data supports that modified implementation of EBIPs may not lead to other expected outcomes, such as learning gains. Andrews et al. (2011) investigated active learning's efficacy in 29 introductory biology courses across 28 institutions, finding only

modest learning gains despite the frequent use of active learning strategies. Notably, they found no significant association between using active learning and students' learning of course topics. Andrews and colleagues believed that due to the representative nature of their sample, the literature supporting the effectiveness of active learning may be due to educational research experts implementing the techniques with fidelity compared to the average faculty member. In this vein, Andrews and Lemons (2015) hypothesized that resilience is important for sustained use of an EBIP. They believe that faculty who anticipate failures in their use of EBIPs and identify problems will be more likely to keep trying, and that this may be related to a teacher's self-efficacy.

Together, these studies indicate that when contextual factors are conducive to adopting EBIPs and faculty experience dissatisfaction with lecturing, they may be more inclined to innovate their practice. When they have positive experiences using EBIPs, this may encourage and motivate faculty to keep using them. However, these early experiences appear to be fraught with barriers, such as negative experiences with implementation. Andrews and Lemons (2015) found that more experienced case study users expressed viewing student engagement as a positive outcome and described encouraging others to use the EBIP, while inexperienced users expressed more dissatisfaction with lecturing, frustration with case study implementation, and grappling with unsupportive colleagues. They believe that this highlights the need to offer more support to faculty during these early stages of adoption. Hence, it is important to understand how and why mathematicians persist in using EBIPs to become experienced users. To this end, much research has investigated the challenges, tensions and growth mathematicians experience as they begin using EBIPs like IOI or IBL (Andrews-Larsen, 2015; Johnson et al., 2013; Mesa et al., 2020). However, none to my knowledge have investigated why mathematicians continue to use

EBIPs outside of specific professional development programs (e.g., Archie et al., 2022; Hayward et al., 2016).

Orientations and Goals

Individual factors like orientations and goals significantly influence teachers' decisions and play a key role in how mathematics is taught (Phillipps, 2007; Schoenfeld, 2010).

Educational orientations, such as teacher efficacy, views of knowledge, attributions for performance, identity, and self-efficacy, as well as orientations toward specific disciplines, impact teaching methods (Pajares, 1992). Relationships between teaching conceptions and approaches have also been studied (Kember & Kwan, 2000). Others have looked at mathematics teachers specifically, such as Kuhs and Ball (1986), who identified four distinct views on teaching mathematics, each reflecting different orientations and goals, such as whether procedural skills or conceptual understanding should be a key learning outcome. While inconsistencies in teacher beliefs and practices have been documented, some argue that beliefs are still sensible (Leathem, 2006) and that inconsistencies are often influenced by contextual factors like student resistance (DeFranco & McGivney, 2001) or other orientations and goals (Paterson et al., 2011).

Notably, an EBIP's perceived compatibility with one's teaching orientations and goals is crucial to its adoption (Kraft et al., 2024; Sturtevant & Wheeler, 2019). Hence, it appears important to understand mathematicians' orientations and goals when teaching ACM. In my review of the literature, I found a small body of literature investigating how mathematicians' orientations and goals influence their instructional practice, including the use of EBIPs (e.g., Johnson et al., 2018, 2019; Shultz, 2022; Vishnubhotla et al., 2022; Woods & Weber, 2020). These studies suggest that orientations and goals undergirding dissatisfaction with lecturing can motivate them to seek out lecture alternatives like EBIPs.

One such qualitative study I found in my literature review was conducted by Woods and Weber (2020), who interviewed eight mathematicians about their orientations, goals and common lecturing practices when teaching proof-based ACM classes. From these interviews, they concluded that these mathematicians' stated goals for teaching included (a) teaching authentic mathematical thinking; (b) teaching informal content; (c) covering important mathematical content; and (c) preparing future mathematicians. They also expressed valuing student engagement, being mathematically precise, and embracing tradition. Notably, the most common instructional activities these mathematicians use – chalk talk and the DTP format– may seem at odds with some of these orientations and goals. Woods and Weber suggested that how mathematicians make sense of these goals via their orientations may inform their practice, including not only the choice to lecture but also common lecturing practices, such as factual questions and short wait times (Fukawa-Connelly, 2012; Paoletti et al., 2018; Viirman, 2015). Thus, in this subsection, I explore how mathematicians' orientations and goals, both regarding the discipline of mathematics and their students, may explain their instructional practices.

Regarding Mathematics

Mathematicians often use lecturing to model mathematics – demonstrating how mathematicians talk, think, and write about mathematics (Fukawa-Connelly et al., 2017; Pinto et al., 2019; Sfard, 2014; Viirman, 2014). This typically involves writing formal symbolic mathematics on the board and discussing informal mathematics, such as heuristics and conceptual understandings, orally (Fukawa-Connelly et al., 2017). Woods and Weber (2020) suggested that modeling mathematics is how many mathematicians promote their goal of teaching authentic mathematical thinking.

Indeed, lecturers assert that they are well-positioned to communicate the importance of specific mathematical practices and how they should be executed, believing that lecturing is

effective because it allows students to observe genuine mathematical thinking before actively engaging with it outside the classroom (Sfard, 2014; Woods & Weber, 2020). Artemeva and Fox (2011) found that mathematics instructors value chalk talk for introducing students to what it means to do mathematics, including specific ways of thinking, disciplinary practices, and common procedures. Similarly, the mathematicians Woods and Weber (2020) interviewed largely expressed that lectures were useful to model the thought processes inherent in mathematical exploration in real-time while also controlling the pace to cover important formal content. Thus, it appears that lecturers believe that lectures effectively fulfill various disciplinary goals, serving as a platform to model mathematics via writing formal mathematics on the board and discussing informal mathematics aloud.

Some MERs have acknowledged that mathematicians are not wrong in their belief that lectures are useful for modeling mathematics (e.g., Larsen, 2017; Rasmussen & Johnson, 2023). Larsen (2017) argues that lectures can model mathematical behaviors, but realizing these outcomes requires students to engage with mathematics beyond the classroom, a challenge for those still learning what it can mean to do mathematics. In further support of this claim, Rasmussen and Johnson (2023) highlight the work of Weber and Fukawa-Connelly (2023) who interviewed 13 mathematicians who attended lectures given by other mathematicians during a two-week workshop. These mathematicians gained an appreciation of the "big picture" of the topic, understanding how experts think about it and feeling prepared to study the material themselves. Rasmussen and Johnson believe that this demonstrates that lectures are indeed capable of modeling mathematics, but perhaps the distance between the mathematical maturity of students and mathematicians requires different pedagogical approaches than those typically found in lectures.

However, lecturing is also often criticized because it limits student opportunities to see the intuitive, creative, and explanatory aspects of informal mathematics, let alone for them to engage in mathematics themselves. For instance, Fukawa-Connelly et al. (2017) discovered that students predominantly take notes based on what is written on the board instead of the orally conveyed informal mathematics, which encapsulates many of the intuitive and creative ways of doing mathematics, and Lew et al. (2017) similarly found that students primarily attended to what was written on the board over ideas their instructor emphasized orally. Yet, in their interviews, Woods and Weber (2020) found that the mathematicians tended to write down formal mathematics exactly because students tend to prioritize what is explicitly written. While they acknowledged the importance of informal mathematics, they viewed it as conversational and opted against writing it on the board, deeming it unnecessary and potentially impeding their instructional flow. Six of the eight mathematicians explicitly said that the chalk talk was useful because writing on the board allowed them to convey formal information precisely, which they viewed as important because they valued being accurate and precise in mathematics, such as when writing down notation or definitions.

Based on their interviews, Woods and Weber (2020) concluded that lecturing aligned with these mathematicians' goal to promote authentic mathematical thinking because it enabled them to model mathematics while also maintaining control over what content is presented and how. Similarly, the mathematics instructors Artemeva and Fox (2011) interviewed expressed how the act of writing mathematics slows down their presentation of it, making it more digestible for students. From this, it appears that lecturers may believe that writing mathematics dictates their pace, which can be beneficial for students, but it may also make them extremely careful in their choice of what they write down or say.

Covering enough content, modeling authentic mathematical thinking, and demonstrating mathematics with precision and accuracy could be considered disciplinary obligations to the field of mathematics. Supporting this notion, a quantitative study by Shultz (2022) found a strong sense of disciplinary obligations predicted less use of student presentations, which further suggests mathematics instructors with this obligation may indeed wish to control what content is presented and how. From this, it appears that lecturers may be satisfied with lectures because they allow them to fulfill these obligations to cover content and ensure that mathematics is presented accurately and precisely. Mathematicians using IOI materials have also experienced similar tensions with disciplinary obligations (Fukawa-Connelly, 2016; Johnson et al., 2013). For instance, Fukawa-Connelly (2016) observed an instructor using IOI materials who did not devolve much responsibility to his students for crafting definitions or conjectures, which he hypothesized may be due to a concern that students would draft versions too far from those accepted by the mathematical community.

However, other mathematicians may interpret these disciplinary obligations differently, with some valuing pedagogical goals over mathematical accuracy (Paterson et al., 2011) and others valuing mathematical experiences over content coverage (Dawkins et al., 2019; Johnson et al., 2013). For example, Dawkins et al. (2019) observed a mathematician using traditional IBL who valued the authentic mathematical activity of creating mathematics, and thus encouraged his students to restructure mathematical content and proof techniques, even if they were less elegant, efficient, or even non-standard. Similarly, Johnson et al. (2013) discussed a mathematician who viewed his content goals while using IOI materials as secondary to ensuring students had opportunities to engage in authentic mathematical activities. He believed that by working to ensure students had these opportunities, they would develop both mathematical curiosity and

content knowledge. To this end, when implementing the curriculum, he focused on supporting the ideas students came up with without straying too far from the focus of the class to balance his content obligations. These studies demonstrate the different ways mathematicians may make sense of their disciplinary obligations to mathematics.

Regarding Students

Literature suggests that orientations and goals regarding student potential and where student learning should take place, alongside perceived obligations to meet the needs of individual students and create an inclusive or engaging classroom, are associated with instructional practice (Johnson et al., 2018, 2019; Shultz, 2022; Vishnohubla et al., 2022). For instance, Johnson et al. (2019) discovered that mathematicians who favored traditional lecturing had lower beliefs in student potential and preferred explaining material before allowing student engagement. In contrast, those who lectured less used more EBIPs and held stronger beliefs in student potential. Similarly, Vishnubhotla et al. (2022) found distinct clusters among mathematics instructors using IBL, with some closely resembling non-IBL users in their instructional practices. IBL-users whose practice was more like non-IBL users were less inclined to report that students should struggle before direct instruction. Shultz (2022) further explored these dynamics, revealing associations between instructor beliefs and perceived professional obligations with the use of IOI practices. For instance, beliefs favoring modeling mathematics to students correlated with increased lecturing, while perceived obligations towards the individual or interpersonal needs of students, along with a belief in productive struggle, predicted the adoption of IOI practices like group work and open-ended problems. In short, orientations and goals regarding student potential and student engagement are salient for mathematicians.

Student Potential. There is some literature discussing teacher deficit perspectives on students, which appears especially prevalent in teacher education literature (e.g., Scheiner,

2023), but has been documented at all levels (e.g., Adiredja, 2019). Quantitative research in STEM education broadly has identified that fixed mindsets about student potential – that is, the belief that intelligence and ability is a fixed characteristic – act as a barrier to using EBIPs (Aragón et al., 2018). In the ACM literature, I found two qualitative studies in which mathematicians teaching proof-based ACM lecture-based courses expressed fixed mindsets about student potential. Firstly, in her interviews with five mathematicians, Alcock reported that one stated the following:

I think there are many people in this department and in every math department who think that those things [how to write definitions correctly, that statements may be proved but noun phrases may not, etc.] are somehow so obvious that anybody who is not a complete moron and has some grasp, some ability to do mathematics should be able to see that. Therefore it is a waste of time to teach that because, the people who need to be taught are the people who are hopeless anyhow. [. . .] And I would have been vehemently opposed to that idea a few years ago. And now I'm less sure because you know. . . I'm certainly trying to teach that and I cannot. . . say that it works, so. . . maybe these people have a point! (p. 95).

This quote seems to suggest that frustrations with students led this mathematician to believe some students are unable to learn mathematics. In a similar vein, two of the eight mathematicians that Woods and Weber (2020) interviewed expressed the belief that their lectures were not supposed to benefit the average student, but rather the high-performing students they believed could become future mathematicians, echoing the sentiments of traditional IBL users (Haberler et al., 2018). One explicitly stated that they geared their classes toward the top 10% of mathematics majors in their classes whom they believed would go on to become future mathematicians. Both mathematicians expressed that chalk talk was adequate for teaching the strongest students, supporting this by observing that, since chalk talk had worked for them and had produced generations of successful mathematicians, it must be a successful format.

From this, it appears some mathematicians lecture because they are satisfied that lectures do not harm those they believe should become mathematicians. That is, there is no reason to search for lecturing alternatives since the future mathematicians will make it through. The mathematician I quoted above from Alcock's (2010) interviews alludes to how dissatisfaction with student learning outcomes may catalyze limited beliefs in student potential, something I hypothesize the mathematician may not have attributed to lecturing due the beliefs some mathematicians hold that lectures are a historically successful instructional method or that lectures are the only way to cover content (Johnson et al., 2018, 2019; Woods & Weber, 2020). While this belief might be more prevalent in proof-based ACM courses – as many of these studies were conducted with mathematicians teaching proof-based ACM lectures – it is still noteworthy and could extend to other ACM courses. Additionally, I believe that the view expressed by the mathematicians Woods and Weber (2020) interviewed may allude to low perceived individual and interpersonal obligations to their students. Namely, they did not appear to believe they had an obligation to meet individual students' needs because future mathematicians would succeed and did not consider the hostile environment this could create for other students.

On the other hand, mathematicians who use EBIPs have expressed growth mindsets for student potential. For instance, Johnson et al. (2013) found that, when using IOI materials, all three mathematicians manifested different priorities for student learning that suggested a balance between covering content, developing deep understandings, and engaging in authentic mathematical activity. One mathematician expressed that he believed that by working to ensure students had opportunities to engage with mathematics authentically, they would develop both mathematical curiosity and content knowledge. Another expressed that covering less content at a

deeper level can enable students to make sense of the content she did not cover. Both statements may allude to the belief that, when given adequate opportunities and resources, all students have the potential to learn ACM deeply.

Student Engagement. While mathematicians value student engagement, their beliefs influence their pedagogical approaches, such as their lecturing practices. For instance, if a mathematician believes students should do most of their learning outside the classroom, they may not see lecturing's limitations in facilitating active sensemaking as a weakness. Sfrad (2014) recalled asking a retiring mathematician why he and his colleagues stuck to lecturing. The mathematician responded: “Only I can make the learner understand what is important and what is much less so.” Sfrad replied, “But most of the listeners don't understand what you are saying...They are just copying symbols from the blackboard.” To this, the mathematician responded, “I don't expect them to understand in real time...Understanding is something a person can only achieve while working on her own in the quiet of her room” (p. 201). While the belief that students should learn outside the classroom may stem from limited beliefs about student potential, this anecdote aligns with findings suggesting instructors may primarily lecture if they believe students should have material explained before making sense of it on their own (Johnson et al., 2019; Vishnubhotla et al., 2022). In contrast, Johnson et al.'s (2013) study's preceding statements may also hint at beliefs about students learning outside the classroom. However, these mathematicians seem to discuss how fostering skills in class via IOI may enable students to independently grasp more content.

Yet, some mathematicians may indeed believe that students are learning during lectures via the limited opportunities they give them to engage, which may indicate differing views on meaningful student engagement between mathematicians and MERs. While MERs often point to

research supporting the role of inquiry as a potential avenue for improving mathematics education for all, many also believe in-class participation can actively engage students in meaningful ways, such as through frequent questioning and student explanations. Indeed, educational research indicates that when students explain their answers, processes, and ideas, they learn and remember better (Chi et al., 1989, 1994; Jacoby, 1978). Moreover, opportunities to speak, exposure to multiple problem-solving approaches (Banes et al., 2018, 2020; Callahan et al., 2021) and opportunities to receive feedback (Hattie & Timperley, 2007) can contribute significantly to student success. MERs also frequently attend to disparities in participation that disproportionately affect minoritized students that have been associated with less in-class participation and lower achievement (Ernest et al., 2019; Johnson et al., 2020; Reinholz et al., 2022).

In contrast, lecturers have typically been observed engaging in limited question-posing routines (Viirman, 2015), typically asking numerous questions that require students to recall factual information rather than questions that promote inquiry (Fukawa-Connelly, 2012; Paoletti et al., 2018; Viirman, 2015) and giving wait times for questions that are often less than three seconds (Paoletti et al., 2018), which limits students' opportunities to generate their own content and develop deeper understandings. However, when asked about these question-posing routines, the mathematicians Woods and Weber (2020) interviewed were able to provide reasons lecturers may engage in these behaviors. For example, seven of the eight mathematicians suggested that asking questions engaged students by prompting them to actively think about the content. That is, asking students questions was considered an important way to engage students with content, hinting at a potential belief that asking questions during lectures fosters active learning in class. Moreover, only four of the eight mathematicians Woods and Weber interviewed argued that

three seconds was not enough time to answer questions meaningfully. The mathematicians suggested that waiting longer for answers is difficult for a few reasons, such as a small number of students answering every question, students being hesitant to respond, the mathematicians being uncomfortable with awkward silences, and experiencing pressures to quickly cover material.

Accordingly, Woods and Weber concluded that the practice of posing numerous fact questions during lectures and then promptly guiding students to answers or answering questions themselves is a method employed by mathematicians to engage students, while also addressing perceived challenges associated with long wait times, such as facing awkwardness or slowing their pace. In turn, I hypothesize that this is connected to the way these instructors perceive their interpersonal obligations – such as avoiding one student dominating the classroom or social awkwardness – and disciplinary obligations like content coverage. While some of the mathematicians Woods and Weber (2020) interviewed agreed that traditional lectures are not the most ideal instructional format for promoting student engagement, it did not appear to disrupt their belief that lecturing was the best option. In other words, because they believe lectures effectively model mathematics and cover content precisely, while also allowing students to engage via thinking about questions, these mathematicians favored lecturing. Together, the literature in this subsection may highlight how the orientations and goals underlying how mathematicians engage their students are highly influential in their choice of pedagogical approach.

In total, I have aimed to illustrate the spectrum of individual factors that may lead mathematicians to feel dis/satisfied with traditional lecturing. While some mathematicians acknowledge the suboptimal nature of traditional lectures for promoting student engagement and

learning, their overall contentment with this method – guided by individual factors and constrained or facilitated by contextual factors – appears to outweigh the perceived benefits of alternative approaches for mathematicians who choose to lecture. Yet, many mathematicians have been documented using a variety of EBIPs (Johnson et al., 2018), and there is an ever-growing community of those using IOI or IBL (Haberler et al., 2018; Laursen & Rasmussen, 2019). Exploring how individual and contextual factors lead these mathematicians to use specific EBIPs instead of lecturing can inform mathematics education's understanding of how mathematicians come to innovate their instructional practice, while also garnering insights into the affordances and constraints of specific EBIPs from a mathematicians' perspective.

A Gap in the Literature

From this literature review, I identify a gap in our understanding of mathematicians' own perspectives on the various factors that influence their decisions to use EBIPs. While some research has begun to examine the perspectives of those who favor lecture-based approaches (e.g., Alcock, 2010; Woods & Weber, 2020), and several large-scale surveys have contributed valuable insight into broader faculty attitudes and experiences (Johnson et al., 2018, 2019; Shultz, 2022; Vishnubhotla et al., 2022), qualitative studies that explore how mathematicians themselves understand the individual and contextual influences on their teaching decisions remain limited. To my knowledge, only one such study (Johnson et al., 2013) has investigated mathematicians' adoption and use of an EBIP, and that study focused on three instructors using a single approach (IOI) for the first time. In contrast, my dissertation examines mathematicians who have sustained the use of a wider range of EBIPs outside of interventionist settings. By centering mathematicians' own perspectives and experiences, this study sheds light on how and why they use EBIPs, and on the specific affordances and constraints they find most influential in their ongoing instructional practice as research mathematicians.

Conceptual Framework

In my dissertation, I investigate how and why mathematicians engage in EBIPs in their ACM instruction. Thus, I draw on a conceptual framework that integrates and adapts theoretical models to explain how faculty make decisions about adopting and implementing instructional innovations. Specifically, I build on Lattuca and Pollard's (2016) model of faculty decision-making, as modified by Sturtevant and Wheeler (2019), and integrate Schoenfeld's (2010) resources-orientations-goals (ROG) theory, which complements the terminology and structure of the decision-making model while offering a unique lens on how faculty decisions manifest in classroom practice. I also incorporate refinements based on my review of the literature.

Defining EBIPs in This Study

While using EBIPs is vital, implementing them with fidelity requires skills and knowledge that take time and effort to develop (Andrews-Larson et al., 2019; Archie et al., 2022; Fukawa-Connelly, 2016; Hayward et al., 2016; Johnson & Larsen, 2012). Some therefore suggest viewing the implementation of EBIPs as a continuum or spectrum rather than a strict binary (Braun et al., 2017). For instance, rather than urging all mathematics instructors to immediately abandon lecture in favor of fully inquiry-based approaches, scholars have emphasized ways in which lecture can be modified to engage students and become more student-centered and equitable (Alcock, 2018; Dawkins & Weber, 2023; Rasmussen & Johnson, 2023). Others point out that evidence of the effectiveness of EBIPs (e.g., Freeman et al., 2014) often reflects a broad range of implementation, including studies where only small portions of class time involved active learning (Rasmussen & Johnson, 2023).

In this study, I conceptualize EBIPs broadly as instructional practices that support active student engagement in learning mathematics and are grounded in research evidence. This includes both flexible and transformative strategies, and spans a range of approaches such as IOI

materials, IBL-inspired approaches, and partial integration of active learning techniques. My research interest lies in how mathematicians use and persist with EBIPs in ways that guide them toward practices shown to improve student outcomes.

Model of Faculty Decision-Making About Engaging in EBIPs

To understand how and why mathematicians engage in EBIPs, as broadly defined above, I draw upon models of faculty decision-making and instructional behavior. Lattuca and Pollard (2016) developed a model for what they called curricular change. Curricular change refers to any change a faculty member makes to their academic plan. Broadly, an academic plan includes views of the purpose of education, the actual content and sequences of content taught, instructional methods, and assessment methods. Given that instructional methods are an integral part of the academic plan, and one which research on EBIP uptake focuses on, this model has been adapted to focus on the decision to engage in EBIPs among STEM faculty (Sturtevant & Wheeler, 2019). In short, this model presents a theoretical relationship between what Sturtevant and Wheeler (2019) renamed extra-institutional, external, and internal influences on faculty's motivation for change and hence their decision to engage in EBIPs. In the following sections, I describe each of these factors, including their relationship to contextual and individual factors detailed in my literature review, and outline the overall model.

Extra-Institutional Influences

Lattuca and Pollard (2016) highlight how any decision takes place within a broader socio-cultural context which emphasizes the influence of extra-institutional factors. They describe how educational changes take place on a backdrop of important social events and movements, such as the Civil Rights movement of the 1960s and rise of technology, which influence educational decisions in ways that are often unnoticed. For example, most faculty readily incorporate technology and digital resources into their classes, including EBIPs such as

the use of clickers. However, just a few decades ago, this would have been impossible. More recently, the COVID-19 pandemic and George Floyd protests served as a backdrop for decisions that expanded the use of digital meeting software, increased critical consciousness (e.g., Yeh et al., 2021), and both exacerbated existing inequalities in access to resources and heightened faculty awareness of these inequalities (Lederer et al., 2021). Currently, increases in extracurricular commitments (Irwin et al., 2023; Perna & Odle, 2020), the rise of generative-artificial intelligence (Digital Education Council, 2024; Golding et al., 2024; Ketsman et al., 2026), wars overseas (Kim, 2024) and cultural conflicts within the US (Abrica & Andrew, 2024; Lange & Lee, 2024) serve as the context within which educational decisions are made.

In particular, the socio-cultural context can give rise to influential extra-institutional factors, such as labor market competition and calls from professional and governmental organizations (Sturtevant & Wheeler, 2019). For example, in 2012, the President's Council of Advisors on Science and Technology served as a call to action to improve STEM education for all due to economic pressures the USA was experiencing to meet workforce demands to remain competitive. This led many professional organizations to call for active learning strategies to improve education for STEM students (Conference Board of the Mathematical Sciences, 2016; Saxe & Braddy, 2015). Hence, as part of their model, as modified by Sturtevant and Wheeler (2019), Lattuca and Pollard (2016) emphasize that extra-institutional influences cannot be ignored and are an important part of faculty decision-making.

External Influences

Lattuca and Pollard (2016) define what Sturtevant and Wheeler (2019) call external influences as influences shaped by the institution and department where faculty work. Aligned with contextual factors, these influences include organizational culture, disciplinary culture, and departmental culture. As described in my literature review, the culture of an institution itself can

have a large impact on faculty's professional identities and their work prioritization. Similarly, Lattuca and Pollard emphasize that an organization's culture can influence faculty's prioritization, such as through the value an institution or department places on research and teaching for tenure, promotion, or salary increases, while departmental cultures can encourage authentic change by promoting open and ongoing discussions between faculty.

Another type of external influence that Lattuca and Pollard (2016) include in their model is disciplinary influences. By grouping faculty in discipline-based departments, faculty continue to socialize within the disciplinary ways of thinking that start in graduate school, continuing to shape their professional identities. In particular, Lattuca and Pollard discuss how disciplinary norms influence the orientations of faculty regarding the purpose of education, their goals for teaching their subject, and preferred instructional practices. For mathematicians, this could be reflected in disciplinary obligations such as accuracy and a preference for the chalk talk.

Internal Influences

Lattuca and Pollard's (2016) model emphasizes that faculty have agency. While faculty decisions may be facilitated or constrained, such as by extra-institutional and external influences, they ultimately retain agency in their teaching choices. In their model, the internal influences Lattuca and Pollard consider include faculty's beliefs, knowledge, identity, and experiences, which align with my definition of individual factors. In this section, I will briefly discuss each of these internal influences.

In this framework, beliefs refer to conceptions of teaching, such as the nature of teaching within one's discipline, the role of the teacher, the role of faculty, and the role of students (Lattuca & Pollard, 2016). In turn, knowledge is considered heavily related to beliefs. Knowledge primarily refers to understanding how and why EBIPs should be used, which presents both conceptual and practical barriers to implementation (Lattuca & Pollard, 2016). As

discussed in my literature review, many faculty express that they do not have time to learn to use EBIPs while balancing other obligations. Moreover, when they do try using EBIPs, they often discontinue due to negative experiences in the classroom (Froyd, 2013; Henderson et al., 2012). Hence, the knowledge faculty form about EBIPs is vital to their engagement in these practices.

Next, Lattuca and Pollard (2016) conceptualize identity as a socially and culturally constructed aspect of the self that guides one's actions, primarily constructed from beliefs and knowledge formed through engaging in activities in the world. In particular, they consider one's academic identity pertinent to the decision to engage in EBIPs. Therefore, like Sturtevant and Wheeler (2019), I consider professional identity most salient to this framework. Professional identity is determined by the orientations one holds that differentiate one's career from others. These orientations are highly discipline specific, with professional identities developing when faculty are students. Professional identities are both shaped by the value an institution places on aspects of being faculty, such as research and teaching, along with the individual value one places on them.

Lastly, according to Lattuca and Pollard (2016), experiences may include prior experiences with formal or informal student feedback, including instances of student resistance, experiences using EBIPs, or hearing about the experiences of trusted peers or mentors. Sturtevant and Wheeler (2019) amended this model to include additional prior experiences, such as those faculty have as students or as teachers. These influences, shaped by extra-institutional and external factors, orient faculty toward certain goals and actions.

Influences on Motivation

According to Lattuca and Pollard's (2016) model, each of these influences (extra-institutional, external, and internal) affect faculty's motivation for change. In short, extra-institutional influences shape both external and internal influences, while external influences also

shape internal influences; in turn, external and internal influences shape faculty's motivation for change, which results in their decision to engage in EBIPs or not. Lattuca and Pollard conceptualize motivation as follows: they believe people are primarily motivated to engage in a task by (a) its perceived utility in achieving a salient goal of theirs or external rewards; (b) their own personal interest or enjoyment of the task; (c) how personally fulfilling they find the task, such as how it aligns with their values or identity; and (d) the perceived cost of the activity. For example, if teaching excellence is not weighed heavily for tenure but research is, then faculty may not use EBIPs despite these practices aligning with their values and interests due to the perceived cost of engaging in EBIPs (e.g., time) and their low utility in their career aspirations (e.g., tenure).

As discussed in my literature review, faculty's decisions often appear to be the result of discontentment, such as the dissatisfaction faculty may experience. Hence, Sturtevant and Wheeler (2019) modified Lattuca and Pollard's original model to include dissatisfaction with current practice as a key motivator. They also included dissatisfaction with EBIPs as the primary reason for EBIP discontinuance to align with the literature. When faculty experience this dissatisfaction, they either persist or quit engaging in EBIPs.

Revisions to the Model

For my dissertation, I make some revisions to Lattuca and Pollard's model. This modified model is depicted in Figure 2.1. First, since many individual and contextual factors from my literature review align with the influences in the model, I adjusted it to use this terminology. Specifically, I expanded internal influences to include all individual factors and external influences to include all contextual factors, renaming them individual factors and contextual factors, respectively. I also embedded the model within the socio-cultural context to capture extra-institutional influences. Additionally, I use the term *degree of satisfaction* instead of

dissatisfaction to account for the nuance of how different experiences can lead someone to be more or less satisfied, though not necessarily completely dissatisfied.

Next, I incorporated Schoenfeld's (2010) ROGs theory into the model. While Lattuca and Pollard's model offers a framework for understanding faculty's decisions to engage in EBIPs, Schoenfeld's ROG framework provides a finer-grained lens for understanding how those decisions manifest in the classroom. This theory conceptualizes mathematics teachers' decision-making based on three key features: resources (encompassing both physical and knowledge-based assets used to achieve goals, with knowledge being the most crucial), orientations (the beliefs, values, and preferences that teachers hold), and goals (their desired outcomes). Mathematicians may have specific ROGs related to teaching and learning mathematics. In familiar situations, decision-making is automatic, while in unfamiliar situations, decisions are consistent with their orientations and goals, leading them to consider certain instructional approaches and not others. By incorporating ROGs into the model, I can examine not only why instructors choose to adopt EBIPs, but also how their classroom choices reflect the interplay between their ROGs.

Although other perspectives, such as Herbst and Chazan's (2012) practical rationality, examine how instructional actions are justified in context, Schoenfeld's ROG framework aligns more directly with the structure and aims of the modified Lattuca and Pollard model used in this study. I saw ROGs as fitting well within Lattuca and Pollard's (2016) model because their framework includes both knowledge and beliefs as individual factors, as well as physical resources as contextual factors. Moreover, although the model does not explicitly include goals as a factor, it does address how beliefs and knowledge can shape one's educational goals. However, in contrast to Lattuca and Pollard, Schoenfeld uses knowledge in a much broader

sense, referring to any information a teacher can bring to bear in the moment. This includes content knowledge, pedagogical routines, and prior experiences. By comparison, Lattuca and Pollard define knowledge more narrowly as one's understanding of how and why EBIPs work. Given Schoenfeld's broader conception, I treat instructors' understanding of how to use EBIPs as knowledge, while their beliefs about why EBIPs are desirable or appropriate align more closely with orientations. I also include prior experiences as knowledge, insofar as they constitute information instructors can draw upon during instruction. As a result, to integrate ROGs, I expanded the set of individual factors to include goals and replaced beliefs with orientations, while redistributing Lattuca and Pollard's original knowledge construct across both knowledge (e.g., procedural understanding and prior experiences) and orientations (e.g., beliefs, values, and preferences).

As a further revision to Lattuca and Pollard's model, I added an explicit implementation phase to address a limitation in prior versions of it. In versions such as Sturtevant and Wheeler's (2019), the pathway from the decision to engage in EBIPs to the outcome of persistence or discontinuation is underdeveloped, leaving unexamined the experiences that shape instructors' satisfaction or dissatisfaction and hence persistence. In practice, these outcomes emerge through the implementation of EBIPs, where instructors encounter a range of challenges and supports. By including an "Implementation of EBIPs" phase, I make visible how individual and contextual factors continue to influence instructional choices after the decision to use EBIPs is made. As others have argued, implementation experiences can profoundly influence whether faculty continue using EBIPs (e.g., Andrews & Lemons, 2015), highlighting the need to understand not just decisions to adopt, but the lived enactment of these practices in context. Hence, this addition enables me to examine not only whether mathematicians choose to use EBIPs, but also how they

come to use them in specific ways and how those experiences contribute to persistence. This approach sheds light on both the substantial variation seen in EBIP implementation and the role of these experiences in shaping persistence.

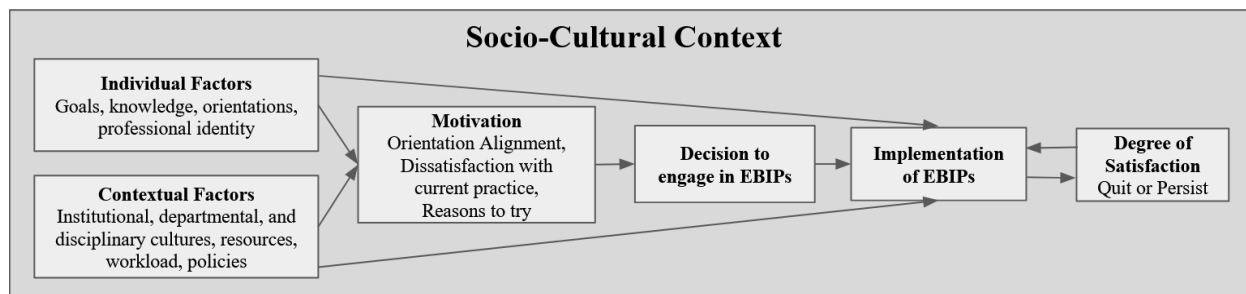


Figure 2.1: Visual Representation of the Revised Model. This revised framework models the influences that shape faculty engagement with EBIPs.

This model (Figure 2.1) provides a comprehensive cycle of EBIP use, not only looking at initial adoption but ongoing experiences. It distinguishes between individual and contextual factors, with contextual factors shaping individual ones. Individual factors include goals, knowledge, orientations, identity, and experiences. Contextual factors encompass institutional and departmental culture, resources (e.g., mentors, institutional support, classroom dynamics), policies, and workloads. These factors, situated within a broader socio-cultural context, influence faculty motivation to engage in EBIPs and ultimately their decision to do so. Experiences implementing EBIPs, which are also shaped by individual and contextual factors, then influence whether faculty persist with or discontinue these practices continually (as indicated by bidirectional arrows in Figure 2.1)

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Chapter 2, in part, has been accepted for publication of the material as it may appear in *Proceedings of the 28th Annual Conference on Research in Undergraduate Mathematics Education*. SIGMAA on RUME. The dissertation author was the author of this paper.

Chapter 3 METHODOLOGY

This dissertation aims to understand how and why mathematicians use EBIPs in their ACM. To this end, I conducted a multiple case study (Creswell, 2007) of six mathematicians who actively use EBIPs in their ACM instruction. In this design, multiple cases are purposefully selected to provide insight into an issue (here, mathematicians' use of EBIPs) while allowing for comparison across cases. I collected qualitatively rich data sources, including multiple interviews and classroom observations of each participant in the fall 2024 semester, and conducted a two-cycle coding analysis (Miles et al., 2014; Saldaña, 2016) of interview transcripts, informed by my conceptual framework, to examine how and why they use EBIPs. In the remainder of this chapter, I detail my dissertation's methodology, including my methods for recruiting and selecting participants, and collecting and analyzing data.

Positionality

As a PhD student in mathematics education studying EBIPs in ACM, my research reflects both my academic journey and personal standpoint. My transition from experiencing mostly traditional lectures as an undergraduate to engaging in collaborative and creative mathematical activities during my master's program inspired my interest in instructional practices that promote student learning and engagement. Additionally, my identity as a neurodivergent queer person informs my understanding of how EBIPs might impact students with historically marginalized identities. This perspective shapes my view of EBIPs as tools for promoting equity, though I recognize that these practices are not a panacea.

While I identify as a mathematician, my current role as a MER may have positioned me as an outsider to the mathematicians in my study. This may have influenced how my research was perceived by participants, potentially leading them to view me as bringing judgment rather than genuine inquiry and respect for their lived experiences. I remained mindful of this dynamic

throughout the study and intentionally worked to build trust and rapport in my interactions with participants.

By reflecting on my positionality, I aimed to conduct a rigorous and reflexive study that provides valuable insights into the teaching practices of mathematicians in higher education. At the same time, I acknowledge that my beliefs and experiences likely shaped my interpretation of the data. To address this, I employed several strategies to support validity and reliability (Maxwell, 2005; Yilmaz, 2013). Specifically, I gathered comprehensive data, including video recordings and transcripts; used a constant comparative method during coding; and engaged in frequent reflexive analytic memoing to surface and examine potential biases. I also transparently reported discrepant evidence. To support reliability, I clearly outline and justify my methodological choices in this chapter. These practices, along with the use of rich data excerpts and transparent analytic reasoning, allow readers to assess the credibility of my interpretations. Together, these steps support a rigorous and transparent approach to my research.

Participants and Context

Recruitment

I recruited participants using purposive sampling (Miles et al., 2014) to identify individuals with relevant knowledge of and experience with EBIPs to address my research questions. My sampling strategies were reputational case selection and snowball sampling based on both criteria and accessibility. Initially, I identified potential participants who were geographically accessible to me using the expert recommendations of my committee. These potential participants were emailed to set up an unstructured screening interview (Hall & Hall, 2008) to discuss my study, to determine their interest in participating, and if they met the inclusion criteria. I prepared general questions (Appendix A) to remind me of the information I needed to obtain from the interview but did not necessarily ask all questions directly nor ask

them in a predetermined order. I also asked potential participants for their expert recommendation of any faculty they knew at their institution or other nearby institutions who used EBIPs in their ACM courses to expand my pool of potential participants.

I selected participants based on the criteria that they (a) had earned a Ph.D. in mathematics or applied mathematics; (b) were tenured or tenure-track in a mathematics department; (c) regularly teach at least one ACM course per academic year; (d) have used EBIPs in their instruction for at least two years (according to the definition of EBIP provided in Chapter 2); and (e) planned to use EBIPs in at least one ACM course in the upcoming fall term. I chose these criteria to ensure that the participants in my study were mathematicians who had developed experience using EBIPs in their instruction, though they were not necessarily experts (i.e., five or more years teaching with this practice, [Berliner, 2004]) and would be using EBIPs while teaching ACM during the fall 2024 term.

In total, I screened nine potential participants across three institutions in the western United States, and seven both expressed interest in participating and met the inclusion criteria. I invited six of these mathematicians to participate in my study, two from each of the institutions. Since my prospective participant pool allowed for it, I invited one pre-tenure and one tenured participant from each institution to capture perspectives at a variety of career points. As a secondary selection criterion, I invited participants so that my pool of participants was maximally diverse, reflecting a broader array of perspectives than solely the white male perspectives that have traditionally dominated the field of mathematics. That is, while I did not formally collect demographic information, when selecting among the seven qualified candidates, I considered how each person's inclusion might contribute to this diversity of perspectives. All six accepted the invitation and consented to participate.

Participant Profiles

In this section, I detail the six participants in this study. At the time of data collection (fall 2024), these participants were mathematics faculty at one of three universities in the western United States, which I call Universities A, B, and C. I use the pseudonyms Natalie, Hasan, Joel, Shaun, Ian, and Noah for these participants.

University A. Natalie and Hasan were from University A, a large suburban public university. Natalie, a tenure-track Assistant Professor, had been at University A for three years with at least six years of experience teaching ACM and using EBIPs. She reported using active learning techniques including groupwork, flipped classrooms, and interactive lecturing. During the fall 2024 term, she taught a Mathematical Structures class using in class problem-solving and interactive lecturing. This class functioned as a “midway point between students taking [their] first [introduction to] proof class and then going on to take either abstract algebra or real analysis,” with content ranging from the natural numbers to the complex numbers and drawing on elements of both algebra and analysis. Hasan was a tenured Full Professor with over 20 years of experience using group worksheets and eight years using flipped classrooms to teach Introduction to Proof and Abstract Algebra. In fall 2024, he taught Introduction to Proof using group worksheets and introduced a new practice: standards-based grading.

University B. Joel and Shaun were from University B, a large city public university designated as a Hispanic-Serving Institution. Joel was a tenure-track Assistant Professor entering his second year in this position who reported using EBIPs since his time as a graduate student, where the policy was to use active learning in recitation sections. He continued this practice into his post-doc and current position. During fall 2024, Joel taught Abstract Algebra using a rotating lecture/problem-session format in which the first session per week was a lecture and the second session focused on small group problem-solving. Shaun, a tenured Associate Professor at

University B, reported seven years using active learning techniques, typically using lecture to motivate topics followed by in-class problem-solving. In fall 2024, he taught an advanced differential equations course for seniors and graduate students using this approach.

University C. Lastly, Ian and Noah were from University C, a medium-sized urban private research university. Ian, a tenure-track Assistant Professor, gained experience using EBIPs during his graduate studies. He had at least two years of experience using inquiry-based learning in combinatorics with minimal lecturing and reported implementing in-class problem-solving in other courses (e.g., Calculus) since he was a graduate student. In fall 2024, he taught Discrete Mathematics using think-pair-share activities. Noah, a tenured Associate Professor, had six years of experience using flipped classrooms in calculus, had flipped an Abstract Algebra course once, and incorporated some active learning into other courses. He also had two years of experience using standards-based grading in calculus. During fall 2024, he taught Discrete Mathematics using group work, interactive lecturing, and introduced standards-based grading.

Of these six participants, five remained in the study until completion, with Shaun withdrawing during data collection and providing consent to use the partial data collected from him. I now detail the data collection procedures used with these participants.

Data Collection

To address my research questions, I collected data from semi-structured interviews, classroom observations (including field notes and video recordings), and individual stimulated recall interviews (Zhai et al., 2024) during the fall 2024 academic term from September 2024 to December 2024. For each participant, I conducted a beginning-of-term interview, two stimulated recall interviews, and an end-of-term interview. All interviews were conducted either in-person or via Zoom videoconferencing, based on participant preference and scheduling logistics. Of the 33 total interviews I conducted, 16 were in-person and 15 were via Zoom. All interviews,

regardless of modality, followed their respective semi-structured protocol (see Appendix A) and were video recorded with participant consent. For all interviews, I used Zoom's built-in recording feature to record the interview from my computer. This allowed for clear audio quality needed for accurate transcription. All interviews were transcribed using Rev transcription software (Rev, n.d.). For the remainder of this section, I detail each interview.

Beginning-of-Term Interviews

I conducted a 60-minute individual semi-structured interview with each participant within the first two months of the fall term of their institution, for a total of six such interviews in my data corpus. The focus of the beginning-of-term interview was primarily in addressing research question one (RQ1). These interviews focused on eliciting the individual and contextual factors influencing each participant's motivations for using EBIPs, particularly their prior experiences with these practices and their current orientations and goals for teaching ACM. The protocol for this interview can be found in Appendix A. The beginning-of-term interviews were conducted within the first two months of the term to elicit their specific goals for teaching to inform my subsequent classroom observations for the stimulated recall interviews.

Individual Stimulated Recall Interviews

I conducted a total of 11 individual stimulated recall interviews (SRIs): one with Shaun and two with each of the five remaining participants. This type of interview involves using artifacts, such as video recordings, to evoke a participant's memories of a teaching situation (Zhai et al., 2024). Each SRI data set consisted of a brief semi-structured interview about an upcoming lesson, a classroom observation of that lesson, and a 60-minute interview using selected clips from the recorded lesson as stimuli. The SRIs primarily focused on addressing research question three (RQ3) by exploring instructors' use of specific EBIPs. I selected the SRI

format because it allowed me to explore how participants' resources, orientations and goals influenced their implementation of EBIPs, grounded in real examples of their teaching.

I conducted these SRIs in two rounds. The first round of SRIs occurred five to eight weeks into the fall 2024 academic term at each participant's respective institution. This timing ensured I could complete and review all beginning-of-term interviews, while allowing classes to finalize enrollment and instructors to establish pedagogical routines.

To prepare for the first round of SRIs, I reviewed each participant's beginning-of-term interview and created a list of the EBIPs they reported to use and how they reported using them, dividing this into practices I could expect to see, ones I did not expect to see, and aspects of implementation to monitor for. I selected the aspects to monitor for if it was (a) a feature of their teaching that was unclear to me after reviewing their beginning-of-term interview or (b) a feature of their teaching related to preliminary goals and orientations I identified from my review of their beginning-of-term interview. For example, when reviewing Ian's beginning-of-term interview, I identified that he planned to use think-pair-share activities, but I was unsure how often or how he chose when to use this EBIP in class (unclear feature), and I identified that he seemed to value productive struggle as conducive to student learning (orientation), leading me to add "How often does Ian use think-pair-shares or other student-centered activities, and how does he decide when to use them?" and "How does Ian support students with productive struggle and comfort with failure?" to my SRI list.

I then corresponded with each participant to schedule a brief interview about an upcoming ACM lesson in which they planned to use EBIPs. I asked participants to select which lesson I would observe. These semi-structured pre-observation interviews lasted 5-20 minutes and occurred within two days of the lesson, most frequently 15 minutes before class. The focus

of these interviews was on the participant's lesson plans for the upcoming class they selected for me to observe. Following each interview, I conducted the classroom observation, video recording the participant's teaching while taking field notes guided by my SRI list.

After concluding a classroom observation, I scheduled the SRI with the participant. SRIs ideally occur immediately after the event. However, video recordings effectively recreate original decision cues, allowing some flexibility in scheduling (Stough, 2001). I aimed to conduct the individual SRIs with each participant as soon as possible after the observed class session, with the typical timespan being four to seven days after the lesson due to scheduling logistics. All the SRIs were conducted via Zoom to improve scheduling flexibility and to improve accessibility to seeing and hearing video footage for myself and the participant.

To create the protocol for each SRI, I first reviewed the pre-observation interview footage and finalized my list of practices to expect, not expect, and monitor for, with additions to the list typically specific to the lesson. For example, for Ian's first SRI, I observed a class covering mathematical induction and based on Ian's comments during the pre-observation interview, I added "What strategies does [Ian] employ when students struggle with the 'leap' to inductive reasoning?" as a feature to monitor for, as this was something he anticipated students would struggle with and related to his productive struggle orientation. I then selected clips of interest from the video recordings that either illustrated or contradicted points raised during data collection (i.e., expect or not expect) or highlighted significant aspects of the participant's use of EBIPs (i.e., something I monitored for). The protocol for the SRI was then uniquely developed for each interview around these clips (e.g., Nguyen et al., 2013).

A major concern when conducting SRIs is researcher bias (Gass & Mackey, 2016); by prompting participants to respond to specific actions, they may craft explanations based on their

beliefs about how the action is linked with the researcher's intentions. However, this must be balanced with other concerns, such as participants' responses straying too far from the researcher's aims (Lyle, 2003) or participants not responding at all without prompts from the researcher (Nguyen et al., 2013).

To mitigate these concerns, I followed a modified version of the procedure outlined by Johnson et al. (2013). During the session, the participant and I viewed the video clips I selected together using Zoom's screenshare feature. I instructed the participant to stop the video whenever they recalled why they made an instructional decision or remembered something significant (e.g., a specific thought or feeling). Additionally, I posed prepared open-ended questions to encourage discussion (e.g., Nguyen et al., 2013) at specific points in the clips related to why I selected the clip, such as "What made you decide to have the students engage in this activity?" After discussing the video clips, I asked the participant if they recalled anything from the class that they felt was important to review and discuss. If they did, we would watch these aspects of the video recording together. This occurred three times, once in both of Joel's SRIs and once in Noah's first SRI. By selecting targeted clips, I kept the interview focused on my research aims. However, by allowing the participant to primarily choose which instances within the clips to discuss, and asking them for other instances to review, I hoped to mitigate researcher bias, while having general open-ended prompts helped avoid a lack of discussion.

After the first round of SRIs, I then conducted a second round with the five remaining participants approximately three-quarters into the term. This second round of interviews followed identical procedures to the first round, with one modification: rather than generating new SRI lists for each participant, I revised the original SRI lists based on insights gained from the first SRI and the second pre-observation interview.

End-of-Term Interviews

Lastly, I conducted a 60-minute semi-structured individual interview with the five remaining participants at the end of the fall 2024 term at their institution, resulting in a total of five such interviews in my data corpus. Like the beginning-of-term interviews, these end-of-term interviews were semi-structured, allowing for flexibility in exploring the participants' experiences with EBIPs throughout the semester. The end-of-term interviews primarily addressed research question two (RQ2). The focus of these interviews was on the participants' engagement with EBIPs during the fall 2024 term, comparing their experiences with previous years and investigating any changes or developments in how they engaged in EBIPs. This retrospective interview enabled me to explore the challenges and tensions they experience using EBIPs and how they navigate these to persist.

Analysis

For my analysis, I used a two-cycle coding process to analyze qualitative data, guided by the approaches outlined by Saldaña (2016) and Miles et al. (2014). This process emphasized analytic memoing, constant comparison, and the identification of meaningful patterns across cases to generate explanatory themes to address my research questions.

Data Familiarization and Preliminary Analysis

The first phase of my analysis involved familiarizing myself with the data to generate initial conjectures and observations (Miles et al., 2014). This entailed reading and re-reading interview transcripts and watching video recordings to identify relevant information related to my research questions.

During data collection, I engaged in ongoing preliminary analysis through memo writing. I kept a running document to record observations of salient ideas, guided by my conceptual

framework. In particular, I attended to individual and contextual factors that appeared to shape participants' motivation to use, implementation of, and persistence using EBIPs.

After data collection, I generated and cleaned interview transcripts using Rev software (Rev, n.d.), rewatching the recordings to ensure transcript accuracy. Throughout this process, I continued analytic memoing to document additional insights and patterns.

As part of data familiarization, I also engaged with non-interview data while constructing the SRI protocols. This included generating lists of observed practices and selecting video clips for participant review (see Data Collection section). I later watched these clips alongside participants during the SRIs and created transcripts of the selected video segments, which became part of the SRI transcript set.

First-Cycle Coding

For my first-cycle coding, I employed open coding within structural categories that emerged as salient from my conceptual framework. While my framework identified individual factors (e.g., orientations, goals, experiences, identity) and contextual factors (e.g., departmental culture) as potentially important influences on faculty's use of EBIPs, I focused my coding on the categories that emerged as meaningful in participants' accounts – primarily goals, orientations, departmental culture, and experiences. Within each category, I developed open subcodes to reflect the specific content of the individual and contextual factors participants cited as influential. For example, Learning Math by Doing Math and Student Engagement were two open codes categorized as orientations. I also created inductive codes to capture salient ideas that my structural categories did not capture related to persistence. For example, one inductive code included Modifying EBIPs to capture participants' responses to their experiences using EBIPs.

To distinguish between orientations and goals, which the literature indicates can be difficult to differentiate (e.g., Hannah et al., 2011), I followed criteria based on Woods and

Weber (2020). Goals were coded when participants described specific desired outcomes for classes or lessons, or when they evaluated practices based on their ability to achieve those outcomes. For example, one goal I coded was a goal of teaching mathematical proof as an outcome of an introductory proof-based class. Orientations (beliefs, values, and preferences) were coded when participants described features of classrooms or practices that they considered conducive or detrimental to learning, desirable or appropriate, or personally pleasant or unpleasant. For example, when a participant described an engaged classroom as conducive to learning mathematics, I coded this as an orientation toward student engagement. When another participant rejected practices such as journaling or math autobiographies for being "too touch-feely" (i.e., personally unpleasant), I coded this as an orientation toward personal fit. Moreover, in line with my conceptual framework, I coded knowledge primarily as the prior experiences that informed participants' instructional decisions while participants' conceptual understandings of why EBIPs support learning were coded as orientations.

Several of these individual and contextual factors and inductive codes were identified during my data familiarization phase. Using insights from those memos, I generated a list of ideas for codes and preliminary patterns in the data. As I applied these to the data, I used a constant comparative method in which when I noted a new salient piece of information, I compared it against previous pieces of information to see similarities and differences to modify existing codes or create new codes as needed (Corbin & Strauss, 1990).

I began by coding the six beginning-of-term interview transcripts to test and refine my codebook and write additional analytical memos. This initial round of coding resulted in a revised initial codebook and new analytic memos documenting emerging thoughts and patterns. I then applied the revised codebook to the five end-of-term interview transcripts, and lastly the 22

SRI transcripts. The resulting codebook (Appendix F) included over 30 subcodes grouped under categories aligned with my conceptual framework along with my inductive codes. These codes served as the foundation for my second-cycle analysis.

Second-Cycle Coding

Whereas my first-cycle coding focused on identifying the individual and contextual factors participants described as shaping their teaching, my second-cycle coding sought to explain how these factors interacted to influence their motivation, implementation, and persistence with EBIPs. To this end, I used axial coding, as described by Saldaña (2016), to identify explanatory patterns across my first-cycle codes that connected participants' beliefs, contexts, and strategies for using EBIPs. While axial coding is traditionally associated with grounded theory, I adopt Saldaña's broader application of the method to studies which seek to explain how interrelated factors shape meaning and behavior; this approach was appropriate for my study given the nature of my research goals (i.e., to understand how and why mathematicians use EBIPs) and my data corpus, which included a wide variety of data forms, including pre-instructional interviews, classroom observations, field notes, and retrospective interviews. Together, these features necessitated an analytic approach capable of connecting influences across contexts, such as axial coding

In this phase, I moved from my open codes to explanatory axial codes by examining how individual and contextual factors interacted to shape participants' decisions for how and why to use EBIPs. To develop these axial codes, I systematically reviewed all first-cycle codes and associated memos, examining how each related to participants' motivations, implementation decisions, and persistence with EBIPs. I tagged memos with these functions (e.g., motivation, shaping practice, persistence) and noted frequently co-occurring codes or factors that appeared to interact. These memos served as the basis for identifying cross-case patterns and constructing

axial categories. For example, I examined how a desire to foster student engagement interacted with course-level constraints and content coverage goals to influence decisions about implementing active learning.

Each axial code reflected a recurring pattern across multiple cases in how and why participants use EBIPs. While some axial codes centered on shared instructional challenges and the range of ways participants responded to them, others focused on common rationales and the varied conditions driving them. This flexibility allowed me to capture different kinds of explanatory patterns depending on the focus of the category. To define each category, I identified a set of properties – key characteristics that defined the category – as well as dimensions that captured how the category varied across cases, highlighting the range of behaviors, orientations, or experiences that existed within the category. For example, the category Managing the Content Trade-Off was defined by the core goal of content coverage and limitations with time in class driving the use of lecture (properties) but had variations (dimensions) in how beliefs about learning and concerns about preparing students for future courses influenced how they experienced this pressure to cover content and thus lecture.

Throughout this process, I continued writing memos to refine category boundaries, test emerging hypotheses, and compare within- and across-case variation. I also used visual aids to track relationships between first-cycle codes and to clarify how different patterns co-occurred or diverged across participants. The resulting axial codes (Appendix G) include categories such as Managing the Content Trade-Off, Seeing and Responding to Student Thinking, and Navigating Logistical Constraints on EBIP Use. Each category captures a distinct pattern salient to how and why participants use EBIPs.

Analytic Approach for Each Research Question

RQ1. For RQ1, I used axial coding to identify categories that captured the reasons why participants use EBIPs, capturing variation in how individual and contextual factors enable or drive the choice to use EBIPs. For this, I drew primarily on beginning-of-term interviews, where participants described their motivations and rationales for using EBIPs, alongside relevant portions of end-of-term interviews and SRIs. This approach allowed me to capture three aspects of why participants use EBIPs: (a) how participants' adoption of EBIPs was enabled, (b) their initial motivations for using EBIPs, and (c) their ongoing rationales for using EBIPs.

RQ2. For RQ2, I used axial coding to explain how participants persisted in using EBIPs in the face of challenges. I constructed categories that captured shared constraints on EBIP use and the range of ways participants responded to them (Managing the Content Trade-Off, Navigating Logistical Constraints, Responding to Student Feedback). I drew mainly on end-of-term interviews, with beginning-of-term interviews and SRIs included when participants spoke to these issues. During this analysis, I noted that my persistence-related inductive codes cut across all constraint categories, with participants sustaining EBIP use through adaptation, modifying or substituting practices rather than abandoning them. I also analyzed first-cycle coded segments in which participants reflected on why they continued using EBIPs or described supports for doing so. I clustered these codes into themes that explained how persistence was enabled across cases. The resulting persistence themes included reframing challenges, drawing on positive feedback and experiences, and leveraging departmental and collegial support.

RQ3. For RQ3, I examined EBIP use in practice and the factors that shaped implementation. Drawing primarily on the SRI dataset (transcripts, pre-observation interviews, field notes, SRI protocols), I first identified two broad implementation approaches: lecture followed by small-group problem solving and lecture interspersed with activities. I then

examined these approaches through detailed participant cases to understand individual rationales and highlight variation in implementation. The SRI data allowed me to move beyond reported use (e.g., "I use group work") to examine actual practice and participants' in-the-moment navigation of constraints. SRI protocols, fieldnotes and memos documented teaching practices, while coded SRI transcripts provided participants' rationales for their decisions. For example, I observed one participant giving each group of students only one dry-erase marker and during an SRI, they said they did this to encourage students to work together, which was coded as a collaboration orientation in practice. Using this data (alongside other data where relevant for context), I created situated accounts of participants' EBIP use, organized around the contextual factors, resources, orientations, and goals influencing their decisions – factors my conceptual framework identifies as theoretically salient to implementation. Finally, I synthesized this analysis across cases in relation to my categories for RQ1 and RQ2, examining how participants' reasons for using EBIPs and the challenges they faced translated into practice. Overall, this approach allowed me to examine both the common EBIP implementation structures used and the distinctive meanings those structures took on based on each participant's resources, orientations, and goals in context.

Chapter 4 WHY MATHEMATICIANS USE EBIPS

In this chapter, I explore my first research question: *why do mathematicians use evidence-based instructional practices (EBIPs) in their advanced collegiate mathematics (ACM) instruction, including their initial motivations and their ongoing rationales*. My analysis identified five salient categories that capture the conditions, beliefs, and affordances participants described as shaping their use of EBIPs. Early exposure to EBIPs and the influence of departmental culture created conditions that supported participants' openness to trying these practices. A shared disciplinary belief – namely, that learning mathematics requires doing mathematics – provided a core motivation for bringing EBIPs into their classrooms, often reinforced by experiences that made this use feel necessary. Many participants also described additional rationales, highlighting two affordances EBIPs offered: the ability to create the social-emotional conditions that support mathematical engagement and the ability to see and respond to student thinking to improve their instruction. These categories are analytically distinct but often intertwined in participants' accounts, reflecting how enabling conditions, a core motivation, and valued affordances together informed their reasons for using EBIPs. Notably, while this study focuses on EBIP use in ACM, participants often described their reasons for using these practices as broadly applicable across their mathematics teaching.

I present my results as follows: In the first section of this chapter, I describe the conditions that supported participants' initial choice to use EBIPs. The second section focuses on the key reasons participants gave for using EBIPs. In that section, I first discuss the motivation that most directly prompted their adoption of EBIPs and end with a discussion of their ongoing rationales, which were not always explicitly identified as initial motivators, but nonetheless reinforced many participants' sense that EBIPs were worth using as they provided them with

specific affordances for teaching. I then close with a summary of the chapter that examines the relationship between the categories presented in this chapter.

Conditions Supporting Mathematicians' Choice to Use EBIPs

In my analysis, I identified two categories that highlight how prior experiences with EBIPs as a student or novice instructor and contextual factors (namely, one's department and peers) may influence mathematicians' initial openness to using EBIPs. These were discussed by all participants in the study and capture how these influences shaped participants' assumptions about what kinds of teaching were possible.

Early Exposure to EBIPs: Expanding Views of What Teaching Can Be

Across participants, early experience with EBIPs – whether as students or novice instructors – exposed participants to different ideas of what teaching mathematics could look like. This early exposure ranged in form, from structured exposure through graduate teaching assistant (GTA) training or to more informal experiences such as observing peers. This variation shaped both how viable EBIPs felt and how emotionally salient they became as teaching models. For some, like Joel and Noah, EBIPs were introduced as part of their GTA roles. Joel described a departmental culture in which active learning was simply assumed: “It was just what we were supposed to do... the coordinator for the department was just focused on us doing active learning.” In these sections, graduate students facilitated discussion-based problem-solving sessions, reinforcing the idea that students should actively do mathematics. For Joel, this aligned with formative experiences from his parents, both educators, and his own tutoring work, which made active learning feel “logical” and intuitive. Noah, too, experienced EBIPs early in his teaching career, serving as a TA for an honors calculus course taught using inquiry learning. Observing students invent ideas and give each other feedback was powerful for him: “I really liked seeing how the students sort of invented all these things for themselves.” Such early

experiences appeared to shape both what kinds of teaching felt possible and what it meant to support meaningful student learning.

Others first encountered EBIPs as students of ACM themselves, often in emotionally memorable ways. Natalie recalled a powerful undergraduate experience in an inquiry-based abstract algebra class: “We figured [the absorption property] out for ourselves... And then [the professor] was like, this thing you discovered is what makes something an ideal.” The memory of this experience became a reference point for the kind of mathematical ownership she later sought to support in her own teaching, stating “...that class was just one of the best classes I think I’d had as a student...And I kind of have always aspired to do something like that [as a teacher].”

Likewise, Ian described a similarly transformational student experience in a graduate combinatorics course, which became a model for how he now teaches that subject. Though he found the class “overwhelming and intimidating,” it also felt deeply satisfying: “I’m building up to a larger theory that I can piece together... [I]t worked really well with combinatorics.” The course shaped his eventual research area (he later chose this instructor as his advisor) and also became a blueprint for how he taught the subject. Beyond his student experiences, Ian also described using EBIPs as a graduate student instructor. Worried that he could not sustain students’ attention for hours during a summer calculus course, he introduced in-class problem solving. This experience appeared to reinforce that EBIPs were a viable way to teach mathematics. As he reflected:

...the time that I very first started using these practices is when I was assigned to teach over the semester...in a two or three hour block...I realized, oh, that's not going to fly if I just spend two plus hours a day for five days in a row just lecturing...I have to split this up. So...I did basically...50 minutes of lecture, a little break, and then the rest of the time would be problems...And ultimately it was just because, oh, I don't think that I can hold their attention for lecturing two hours straight. And I was right about that.

Ian's personal experiences also shaped which EBIPs he didn't find viable. For example, he avoided group projects, citing consistent inequities in workload he experienced both as a student and instructor: "There are always going to be students who don't pull their weight." Natalie and Ian's cases illustrate how student experiences with EBIPs can develop instructor buy-in for using these practices to teach mathematics, shaping their orientations toward which forms of engagement are conducive for learning.

However, not all participants encountered EBIPs as students. For some, their first exposure came during early faculty roles. Shaun, for example, first encountered EBIPs as a postdoc, when he was teaching full courses for the first time. Although this was early in his teaching career, Shaun described how departmental norms and his colleagues' success using EBIPs informed his uptake of these practices, describing how he started using these practices because of "...other people doing it, and definitely a push for it [by the department], but then ultimately a growing conviction that this was useful and a good practice." His case is discussed more fully in the next section.

Taken together, these accounts suggest that early experiences with EBIPs shaped participants' initial orientation toward these practices in different ways, whether through training or memorable learning moments. Student experiences, like those described by Ian and Natalie, were often discussed as personally meaningful, sometimes serving as models for the kind of teaching they hoped to enact. TA experiences, such as Joel's, tended to be framed as simply what was expected, but could still prompt reflection, as in Noah's case, where early exposure appeared to broaden his sense of what was possible. Early faculty experiences, like Shaun's, were described with more caution, suggesting a different trajectory for developing buy-in. While based on a small set of cases, these accounts highlight how early experiences that positioned

EBIPs as effective or empowering, whether emotionally meaningful or institutionally normalized, seemed to play a key role in shaping openness to these practices. This underscores the potential value of such experiences, especially those that go beyond formal GTA training, in fostering openness to using EBIPs.

Culture and Colleagues in EBIP Adoption

This second category illustrates how participants' perceptions of teaching practices as viable or risky were heavily shaped by their academic circles. Departmental culture – particularly the role of colleagues – helped participants evaluate whether to adopt specific EBIPs, and these social signals often carried more weight than formal research. Two areas of variation stood out: whether colleagues' narratives functioned as encouragement or caution, and whether departmental culture signaled support or constraint. These dimensions shaped whether instructors saw experimentation with EBIPs as viable or risky. Indeed, colleagues were not always supportive; in some cases, they provided cautionary tales about practices to avoid. Notably, while the role of colleagues was consistently described as influential, these interactions sometimes extended beyond participants' own departments.

Departmental Culture

Departmental culture – especially colleagues within the department – was influential in supporting participants to use EBIPs. For instance, Shaun's experience illustrates how colleagues in his postdoc department shaped his perception of EBIPs. As a postdoc, Shaun felt a general push to use EBIPs due to departmental norms. Yet, what ultimately persuaded him was watching colleagues use them effectively. As Shaun stated, "The faculty... who seemed to get the most out of their classes... were the best at [using EBIPs]." Seeing others succeed seemed to help him reimagine what effective mathematics teaching could look like.

Unlike participants who encountered EBIPs in TAs or as students, Shaun's adoption of EBIPs was shaped by what he observed in his department, motivating him to use these practices in the hopes that "[his] students [would] get better test scores and... feel like they were getting more out of the class as a whole." Shaun also noted that departmental culture provided support for trying out these practices, even when he met resistance from students: "... the department at the time, especially with regards to how we taught calculus, was very supportive of these practices. So that, in that sense, always felt like someone you know, had my back, as it were."

Noah also described the importance of departmental support. Although he had encountered EBIPs as a graduate student, he did not feel able to implement them until he joined University C as tenure-track faculty:

So, I didn't really do anything like [flipping courses] until I started here [at University C]. As a graduate student, and as a postdoc, I mainly did lecture courses and then sort of when I came here, I think- I think maybe possibly I felt a little bit more free to design courses the way I was interested in, now that I was tenure track and the department that was very supportive of teaching in different ways.

Some participants also shared examples of how departmental support can shape their instruction in more targeted ways. For example, Joel described a suggestion that came after a colleague observed a class of his during the semester I collected data:

[Professor X] observed my class and she had some pointers that I'll probably incorporate in the future because I was asking for a letter of recommendation from her... And she gave a suggestion that students can write their names and each have a dedicated color. And then if by the end... you can just, or over the class in general, you can just gauge their participation by, is every color present on each of the boards? I liked that idea.

These cases illustrate the role of departmental support – particularly colleagues – in creating the conditions that not only can expose participants to EBIPs but actively support their use.

In other cases, participants described peer influence that originated outside their department. For example, Hasan recalled that he had dismissed standards-based grading (standards-based grading) after attending a talk on it until a friend from a community college casually described it as a "game changer" during a casual conversation:

We were in our swimming trunks, just relaxing... He just got out of the pool and he just started talking about [standards-based grading]... And I was like, what? ... That was the most dramatic. I would not have done anything like that if I hadn't had this conversation with him.

Noah, who had used standards-based grading in calculus for two years, also described learning about standards-based grading from a friend, rather than through more formal channels. These examples highlight how trusted peers' suggestions can influence mathematicians' use of EBIPs in tangible ways.

Colleagues as Caution Against Specific EBIPs

On the other hand, some suggestions from colleagues also acted as cautionary tales, prompting hesitation about trying certain EBIPs. For example, as they both worked at University A, Natalie was aware that Hasan was trying standards-based grading for the first time. Due to the logistical issues he had shared, Natalie described feeling hesitant, particularly given her ADHD diagnosis:

One of the downsides is, from what I've heard from [Hasan], is that there's just a lot of grading and a lot more effort. So it's something that I've thought about doing and I would think I need to sit down and have a conversation with [Hasan] and at [Professor Y], who's in our [science] department about [it], and ways to make that sustainable. Because just as we talked about, I have ADHD, I hate grading.

Similarly, Ian described feeling hesitant to use group presentations due to a colleague who described receiving significant student resistance using them in her real analysis class.

In total, these examples suggest that departmental and collegial support shaped both whether they should use EBIPs and what types of EBIPs participants would try. Peers in particular offered informal evidence about what practices were rewarding or risky, while departmental norms shaped whether using EBIPs felt viable or not. In some cases, these social cues held more influence than formal pedagogical training or educational research results, highlighting the central role of colleagues and departments on the decision to use EBIPs.

The Reasons Mathematicians Use EBIPs: Motivations and Ongoing Rationales

In my analysis, I identified three salient reasons participants cited for using EBIPs. As shown in Table 4.1, these reasons fell into two types: motivations and ongoing rationales. Motivations refer to reasons that drove participants' initial use of EBIPs, while ongoing rationales refer to reasons where it was unclear from the data whether they were initial motivations or post-hoc affordances participants had come to value. Only one universal motivation emerged: all participants described the belief that learning mathematics requires doing mathematics, often paired with observations of how students engaged both in and out of the classroom that made EBIPs feel necessary. In addition to this shared motivation, participants also described two ongoing rationales that further justified their use of EBIPs: creating social-emotional conditions that support student engagement and seeing and responding to student thinking.

Table 4.1: Categories for the Reasons Participants Use EBIPs. This table distinguishes the shared motivation from two ongoing rationales and provides descriptions, representative examples, and participants within the category for each.

Category		Description	Example	Participants
Motivation	Ensuring Learning Happens in the Classroom	Participants use EBIPs based on the belief that students learn by doing mathematics, typically prompted by observations that homework didn't reliably produce engagement	"The only way to build any comfort is to work with [the material]. I mean, in some sense, that's what homework is supposed to do." – Shaun	All
Ongoing Rationales	Creating Supportive Conditions for Engagement	Participants use EBIPs to foster positive classroom climates that support student engagement, creating spaces where students feel connected and able to participate.	"...There's more of a sense of community amongst the students, which is huge to me. [...] I do hope that they start meeting outside of class." – Hasan	Joel, Hasan, Natalie, Noah, Shaun
	Seeing and Responding to Student Thinking.	Participants use EBIPs to gain real-time insight into student thinking and to respond by clarifying misconceptions, guiding students, or adjusting instruction	"...a big benefit of having them work in class where they can get feedback from their peers, and also from me on whether what they're doing is right..." – Noah	Hasan, Noah, Shaun

Ensuring Learning Happens in the Classroom: From Belief to Necessity

This category captures the core motivation shared by all participants: supporting student learning by promoting in-class engagement with mathematics. This motivation stemmed from a common disciplinary belief that learning mathematics requires doing mathematics, which led

participants to seek ways to create more opportunities for students to actively engage with mathematics. While this belief was shared, participants varied in the forms of in-class engagement they prioritized – ranging from independent productive struggle to peer collaboration – and in the kinds of evidence that convinced them to move mathematical work into the classroom, whether from their own learning experiences or from observing student disengagement. Most participants concluded that this engagement needed to occur during class rather than just outside of it (e.g., on homework), prompted by observations that students were not engaging productively on their own. This reflects a reorientation from valuing active engagement to structuring it as an in-class necessity. EBIPs thus became a means of structuring the kinds of mathematical activity participants viewed as essential for learning and ensuring it took place by embedding it into class time.

The Core Belief: Learning Mathematics Requires Doing Mathematics

Across the board, participants expressed the belief that to learn mathematics, one must do mathematics. They rejected the notion that passive exposure to content was sufficient, emphasizing instead that mathematical learning arises through active engagement. As Hasan put it, “mathematics, it’s really hard to learn without actually doing mathematics.” For Natalie, this belief was tightly linked to the kinds of thinking demanded in ACM courses and how she believed students cultivated what she called “mathematical maturity” – the fluency one develops with mathematics from working directly with it:

What does a good rigorous proof look like? What are some of the things that we should prove versus things we can just state? How do I rigorously justify everything? ... I think there are things like that in math that are really hard to teach, but you just kind of pick up on as you read more and do more.

Natalie described aiming to help students develop this mathematical maturity and likened attempting this without active learning to trying to master a sport by only watching others: “It is

something they have to experience for themselves...it'd be like, I don't know...climbing, I could watch Adam Ondra [professional rock climber] climb... It doesn't mean I'm going to be able to do that.” This belief motivated participants to create classroom opportunities for students to actively engage in doing mathematics.

Notably, this fundamental belief was often grounded in participants' own experiences as students or mathematicians. For example, as a graduate student, Ian described having "some sort of realization" that "when [students] actually learn stuff is when they go and try to do it themselves." He related this to his own experience attending seminars:

This still happens to me all the time. Someone will give a seminar talk and [I'll think], yeah, yeah, yeah, I totally get that. And then I go back to my office and I try to piece that together. I'm like, oh, no, actually... maybe I saw some big overview, but actually understanding the bits and pieces – when I go to try to do it myself, no, there's nothing.

However, this belief did not immediately make Ian think EBIPs were necessary, as he reflected: "I used to think, whoa, step one, I have a lecture. I tell the students. Step two, they go home and do it. And that go-home-and-do-it is a lot harder than the lecture part." But as he gained more teaching experience, he came to believe that engaging in the struggle inside class, where students have more resources, was a better use of time. Hasan also described a similar realization through his disciplinary lens as a mathematician, comparing how he engages with mathematics to how students approach learning it:

[Students] mostly learn the mathematics when they're doing the problems. It's like when I'm reading a math paper... just reading it – to a mathematician – means something different than it does to a student. So yeah, I'm doing a lot of stuff on the side, on a piece of paper. And that's the only way I can learn it. And so they don't really understand that. And so you kind of have to force them to work.

Because students did not naturally engage in the kinds of behaviors he saw as essential for learning—namely, doing problems—Hasan concluded that he had to "force them to work." Hasan described his rationale for flipping his Introduction to Proofs classes: “I really wanted them to

spend more time actually engaging with the abstraction instead of listening to me and being confused.” That is, EBIPs were a way to shift class time from passive listening to active engagement with practices for proof writing.

Notably, these comments from Ian and Hasan suggest that while most mathematicians may hold beliefs compatible with active learning, that belief alone may not always translate into changing their instructional practice. Instead, specific observations of student disengagement—particularly outside the classroom—may prompt them to see active in-class engagement as necessary. In this way, their belief may become a motivation for using EBIPs when reinforced by a sense that students will not engage productively without doing so in class.

The Inadequacy of Out-of-Class Engagement

Participants’ orientation toward active mathematical engagement took on particular urgency when they reflected on the limitations of traditional out-of-class learning opportunities. Many participants (Joel, Hasan, Noah, Shaun) contrasted classroom-based activity with independent work, concluding that leaving students to do mathematics outside of class (e.g., homework) was insufficient. For example, Shaun expressed that when students do homework or go to office hours, they don’t engage in the critical thinking process he believes is vital to learning mathematics, often copying from him or each other instead of thinking. This led Shaun to wonder:

[I]f those things are happening [outside of class], and the lecture is just a canonical classic I just drone for 50 [minutes]...then where in that system are they really having to spend time with their confusion, address their own issues?

That is, if students are not engaging with mathematics meaningfully outside of class and the class is lecture-based, they will miss opportunities to learn mathematics. Shaun valued productive struggle and metacognition, wanting students to “get constructive feedback about what they do know and what they don’t know” and to spend more time on task with mathematics – both in

class and through homework – to deepen their learning. He viewed EBIPs, particularly in-class problem solving, as a better use of class time to support this type of engagement.

Noah expressed a similar realization. Although he had learned effectively from lectures and, especially, from doing homework as a student, he began to question whether these methods were equally effective for his own students. As he reflected:

I learned fine listening to a lecture and then doing homework, and—but I learned probably most of what I learned by doing the homework. I didn't need to be doing it in class... but I think the reason for that was because I already knew how to do math in sort of a generalized way. And so when I was doing the homework, I could tell whether what I'd done was correct or not. And I think that's one of the things that a lot of my students are really still learning—how to tell whether what they've done is correct or not.

Noah also described how much effort he used to put into his lectures, including using novel ideas like "infinitesimals" to teach calculus, but realized that "no matter how good [his] lectures were," students were not engaging. This recognition strengthened his orientation toward creating in-class opportunities for feedback, which he connected to his goal of developing students' metacognitive skills. As he explained: "I think that's a big benefit of having them work in class where they can get feedback from their peers, and also from me on whether what they're doing is right and whether they're on the right track." Noah's motivation thus aligns closely with the core logic of this category (ensuring that essential mathematical engagement happens in class), though his emphasis on real-time feedback also reflects his rationale for using EBIPs to see and respond to student thinking (discussed in a later section).

Finally, Joel's experience illustrates how observations of student behavior outside of class can motivate mathematicians to use EBIPs even when their preferred instructional approach is lecturing. Joel expressed a belief in active learning, but he appeared to conceptualize it as something that ideally happens outside the classroom, in the form of collaborative problem solving among students. He even remarked that he wished he didn't have to use group work and

indicated a preference for traditional lectures paired with student-driven activity outside of class. This view was shaped by his own learning experience, where he picked up unspoken expectations about office hours and study groups:

Active learning? It's not always provided by the professor... I just learned to succeed that I needed... there were implicit expectations of students working together and spending time out of the classroom that I picked up organically, with no one telling me... learning how to go to office hours and how to get small groups to work with people on.

However, Joel recognized that his students were not organically picking up these behaviors as he had. Like Hasan, this recognition led him to conclude that EBIPs were necessary to compel in-class collaboration. In particular, he saw group work not as a preferred method but as the only way to “force” this kind of engagement to happen.

Overall, these cases illustrate how participants were motivated to bring learning into the classroom by a core belief in learning mathematics by doing mathematics. Many drew on observations and experiences to decide that leaving students to primarily engage in doing mathematics outside of class was insufficient for them to meaningfully learn the subject. Participants often observed that students often did not learn well from lectures and did not engage in productive learning behaviors on their own. Using EBIPs allowed participants to structure their classrooms in ways that “forced” students into the types of active engagement they viewed as essential for learning mathematics. How individual participants' content goals and beliefs about what is conducive for learning mathematics translated into what EBIPs they used in their ACM instruction and how they implemented them is discussed in Chapter 6.

Ongoing Rationales for EBIP Use

Beyond the core motivation described in the previous section, participants also articulated two ongoing rationales for using EBIPs: using EBIPs to address social-emotional needs and to see and respond to student thinking (see Table 4.1). These rationales highlight two specific

affordances that EBIPs offered which participants came to value. While they may represent post-hoc justifications, they were nonetheless discussed by these participants as meaningful reasons for using EBIPs.

Creating Supportive Conditions for Engagement: Addressing Socio-emotional Needs

This category highlights how several participants (Hasan, Joel, Natalie, Noah, and Shaun) viewed EBIPs as tools for creating classrooms where students felt safe and included, thereby enabling students to persist in productive struggle, participate meaningfully, and develop more positive dispositions toward mathematics. This rationale was expressed by the majority of participants and reflected a strong orientation toward supporting students' social-emotional needs. Participants varied in how they conceived these supportive conditions, differing both in the source of support (whether it came primarily from instructors or from peers) and in the scope of support (whether it was confined to in-class dynamics or extended to assessments and out-of-class interactions). They described EBIPs—especially group work and assessment practices—as helping reduce stress or anxiety, normalize struggle, and build classroom community. In this framing, EBIPs directly addressed the social-emotional conditions students needed in order to engage with and succeed in difficult mathematical work.

Natalie, for example, described her interactive teaching style as crucial for creating an environment where students felt safe asking questions and engaging with challenging ideas:

I think that [my teaching practices] were key, I really do. Especially for...creating a safe environment where they can interrogate and ask questions and stuff. I think that, again, keeping everything very interactive and conversational was crucial for that... I want students to have a good experience. I want them to have an enjoyable experience, and I want to try to alleviate a lot of the anxiety that I see, especially in math.

Multiple participants pointed to group work as a way to foster this type of classroom climate.

Shaun saw groupwork as valuable because it reassured students they were not alone in their

confusion, reducing the emotional barriers to engagement “...so that they're communicating with other people, and at the very least understanding that they're not alone in their questions or concerns.” For Hasan, groupwork lowered the stakes of participation by shifting initial problem-solving to peers, which he believed helped reduce student frustration and encouraged persistence: “If they do something stupid in front of me, they feel really stupid. But if they do [it] in front of their peers, then it's like whatever... and they get less frustrated.” Here, the benefit of group work was framed as lowering the emotional stakes of making mistakes or being confused, a form of safety that participants like Shaun and Hasan saw as beneficial for students' engagement.

Participants also valued group work as a way of fostering community, which they saw as essential for students' confidence and willingness to engage both inside and outside class. Joel emphasized that one of the key reasons he used group work was its community-building function, which in turn made students more comfortable seeking help: “I've gotten feedback... like, ‘man, I was able to succeed more in this course because I had people to ask questions’ or ‘man, I wasn't scared to go to office hours.’” He also emphasized that this peer support extended beyond group work through online platforms like Discord. Hasan echoed this benefit: “Definitely there's more of a sense of community amongst the students, which is huge to me...I do hope that they start meeting outside of class.” That is, Joel and Hasan described group work as potentially promoting social community among students, helping them build support networks that could extend beyond in-class collaboration.

This focus on students' affective needs extended to some participants' assessment practices. Joel and Natalie pointed to test corrections as valuable because they reduced test anxiety and reframed mistakes as part of learning, aligning assessment with their orientation

toward affective support. Joel, for instance, saw his test correction policy as part of building a community where students could feel more comfortable making mistakes and learning from them:

They should feel comfortable with failure. So if they do, then they're not worried that that's a failure... I didn't feel like people were apologizing when they did something wrong... I want you to be okay getting something wrong and learning to do that so that you can try and try and you don't feel... uncomfortable with it.

Natalie similarly described how traditional assessments clashed with her own beliefs about what students need to succeed. She reflected on a personal experience with test anxiety, recalling a time when she “bombed” an exam despite knowing the material and left feeling ashamed: “I remember leaving that first test and feeling like I'd let him down and let myself down. And I was like, ‘I know I can do better than that.’” She connected this memory to what she now sees in her own students; namely, how anxiety interferes with performance and creates unnecessary shame around mistakes:

I have students who are just like, I know that they know this stuff... and then on the exam something happens and I see it in real time the way that they're freaking out... So to make up for that, I offer the opportunity to do test corrections.

Here, Joel and Natalie’s assessment practices were deliberately structured to reduce anxiety and restore confidence, reflecting a broader orientation toward affective needs. Hasan and Noah similarly noted that students seemed to enjoy the lower stress that standards-based grading provided, with Noah in particular believing the multiple opportunities to learn disincentivized cheating.

Overall, these accounts suggest that for several participants, EBIPs were valued not only for engaging students mathematically, but also for creating classrooms where students felt safe enough to participate, struggle, and connect, both with the content and with each other.

Using EBIPs to See and Respond to Student Thinking

The other rationale expressed by some participants (Hasan, Noah, and Shaun) was the capacity of EBIPs to make student thinking visible during class and therefore actionable. This rationale involved two properties: the visibility EBIPs provided into student reasoning, and the instructional responses that visibility enabled. These responses ranged from corrective moves to constructive probing, and from pacing adjustments to designing worksheets to tackle issues that arose. Participants described how this visibility allowed them to detect misconceptions, deliver targeted feedback, and adapt instruction in ways that would be far less effective, or even impossible, through delayed methods such as homework or exams.

Notably, this rationale was expressed only by Hasan, Noah, and Shaun—the three tenured professors in the study. Joel and Ian also described monitoring students and adjusting instruction, but did not frame this as a specific benefit of EBIPs. This may suggest that the rationale was more fully articulated among instructors with greater autonomy, confidence, or experience using EBIPs, even though others may also enact or experience this affordance without naming it explicitly.

Hasan, Noah and Shaun described their ability to see and respond to student thinking as fundamentally enabled by students' real-time engagement with mathematics, especially when students were talking and writing about mathematical ideas in class, as these were forms of activity that participants could observe and act upon. As Hasan explained when discussing the benefits of group work:

I think just sort of the transparency, seeing how they're thinking...I can see their scratch work. I can hear how they're talking to each other, so I can address those skills-based things on the spot, and I can catch it early before they sort of integrate it as a bad habit

In this quote, Hasan directly attributes the visibility of student thinking – that is, seeing their work, hearing their discussions – to his ability to teach more effectively by catching and addressing misunderstandings before they become ingrained.

This was especially salient in his Introduction to Proof class where errors on homework or exams could indicate fundamental misunderstandings or just poor proof writing: “if I just see the end product, I can guess what went wrong. But it's just a guess.” Hasan acknowledged that discussions with individual students during office hours might help, but added “you can't do that at [a] large scale, and students don't really come in to talk to you anyway.” These reflections underscore his view that EBIPs were a powerful tool to catch issues as they emerged. As he put it: “with the in-class worksheets, I can really see, I can actually address those kinds of things. And I say, okay, you're thinking about this wrong.” This illustrates how EBIPs can function as more than just a way to engage students in doing mathematics, allowing instructors to hone their instruction by providing them with the opportunity to respond to issues as they arise.

However, for Hasan this ability to respond to student thinking was not confined to class time. Hasan valued standards-based quizzes because, like worksheets, they provided timely feedback on student reasoning and revealed misconceptions early. He reported that more frequent quizzes gave him similar feedback to what he garnered from worksheets, helping him pinpoint unanticipated areas of struggle: “So I was saying this about the worksheets... I get the feedback as to their deficiencies. Well, the more frequent exams did the same work for me.” Like group work, Hasan valued frequent standards-based quizzes because they revealed unanticipated “deficiencies,” which he saw as essential information for guiding his instruction.

Shaun and Noah similarly reflected on this diagnostic function of EBIPs. Like Hasan, Noah compared active learning to office hours:

It's kind of basically kind of like getting everybody to come to office hours and work on homework...If I'm there in class when they're working on it, I can see what they're doing, or they can ask me a question, and then can see that they're doing something wrong and then guide them in the right way. Then they're going to get it right? They're going to learn more – they're going to understand what the right way to do it is.

Here, Noah valued EBIPs because they let him see what students were doing and intervene when they went off track.

Shaun also valued EBIPs because they provided real-time visibility into student thinking, though for him, their central affordance was the ability to calibrate his pacing to students' actual understanding. As he explained:

When doing active learning exercises I can see with my own eyes in real time if they are learning more now, and improving [...] So more than anything, yeah, it just allows me to essentially continue at a minimum...to survey my students and make sure to some extent that I'm trying to meet them where they actually are. Honestly, at the very, very minimum, it just means the lectures don't go by too fast. I mean just that alone.

Overall, these three cases illustrate how EBIPs were valued as tools for supporting their own instruction rather than just automatically engaging students in productive behaviors. EBIPs were seen as tools to provide students with more individualized feedback, monitor the full class's understanding in real time, and better meet students where they were, all in service of helping students make meaningful progress in learning mathematics.

Chapter Summary: Why Mathematicians Use EBIPs

This chapter has highlighted the varied reasons mathematicians gave for using EBIPs. These reasons were shaped by participants' goals and orientations, such as commitments to active student engagement in class, proof writing goals, and attention to students' social and emotional needs. For all participants, the core motivation to use EBIPs was the desire to ensure that meaningful learning occurred during class time. While this motivation was grounded in a belief that students learn mathematics by doing mathematics, the specific decision to use EBIPs

was often catalyzed by observations that students were not engaging productively outside of class. This motivation was then supported and extended by two emergent rationales: the ability of EBIPs to create supportive learning environments and to reveal student thinking in real time. In contrast, early exposure to EBIPs and support from departments and colleagues appeared to function as enabling conditions, making EBIPs feel viable. This relationship between the categories is depicted in Figure 4.1.

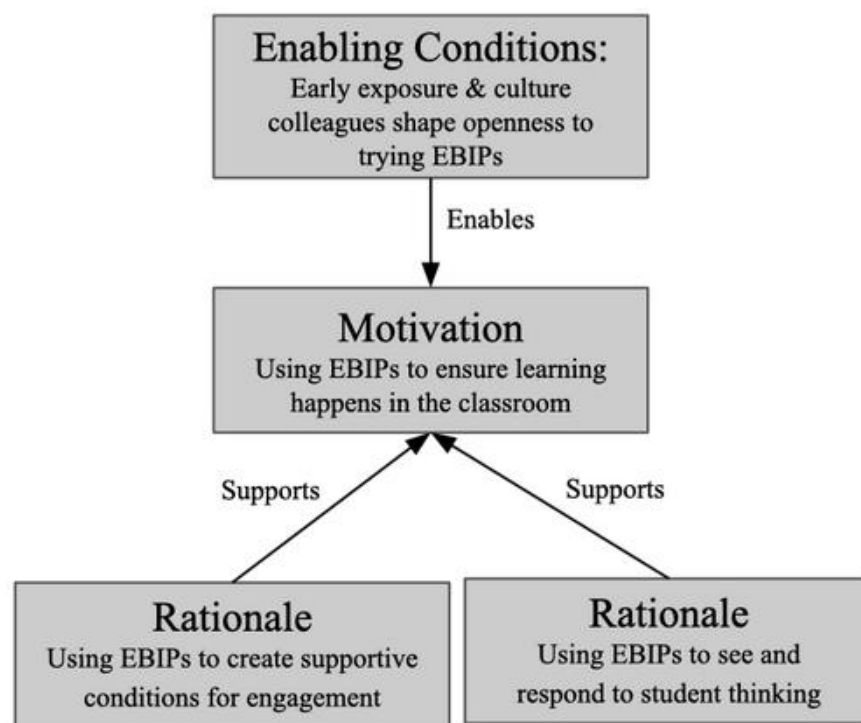


Figure 4.1: Relationship Between Categories for Why Participants Use EBIPs. Participants described (a) enabling conditions that shaped their openness to using EBIPs, (b) a core motivation to ensure learning happens in the classroom, and (c) two ongoing rationales that functioned as affordances supporting this core motivation.

Together, these findings illustrate how participants' goals, orientations, experiences, and contextual conditions interacted to shape their decisions to use EBIPs in their teaching.

Importantly, the reasons they gave for using EBIPs were not specific to ACM but were described as broadly relevant across their mathematics instruction. Where ACM considerations became

most salient was in how these rationales were enacted (e.g., in relation to proof-writing goals), which I discuss in Chapter 6. However, in the next chapter, I turn to the challenges and tensions participants navigated while using EBIPs, and the persistence strategies that allowed them to continue using EBIPs despite these constraints.

Chapter 5 PERSISTENCE USING EBIPS

In this chapter, I present findings to address my second research question: *What challenges and tensions do mathematicians encounter when using evidence-based instructional practices (EBIPs) in their advanced collegiate mathematics (ACM) instruction, and how do they persist in using these practices despite those challenges?* The first section of this chapter examines categories that capture the specific challenges and tensions participants navigated when implementing EBIPs. The second section presents persistence categories that cut across these constraint categories, capturing how participants sustained EBIP use despite challenges. Across cases, persistence was expressed as adaptation; that is, participants modified or substituted EBIPs to make them workable within their contexts rather than abandoning them. The persistence categories that supported this adaptive persistence include reframing challenges, drawing on positive experiences, and leveraging departmental or collegial support. Together, these results highlight the iterative processes through which participants sustained their use of EBIPs in the face of ongoing challenges.

Navigating Constraints on EBIP Use

My analysis revealed a range of individual and contextual factors that constrained participants' use of EBIPs, creating challenges and tensions they had to navigate to persist with these practices. For example, contextual factors included pressures to cover content and prepare students for future courses, perceived time limitations, the logistical complexity of implementing EBIPs, the level and nature of course material, and student responses to EBIPs, while individual factors included personal preferences and beliefs about learning. These factors are organized under three categories (each of which appear in Table 5.1), representing how the factors interacted to create constraints that participants had to navigate. In this section, I present these three categories. As illustrated in Table 5.1, these constraints were reported by most participants,

suggesting that even committed EBIP users continue to face these challenges well beyond initial adoption. However, participants responded to them in ways that enabled their continued use. In this section, I detail each category presented in Table 5.1, examining how participants experienced each constraint and how this led them to adapt EBIPs to persist

Table 5.1: Categories for Navigating Constraints on EBIP Use. This table provides category names, definitions, examples, and the participants in each category for the three categories of the challenges and tensions mathematicians navigate when using EBIPs in ACM.

Category	Description	Example	Participants
Managing the Content Trade-Off	Participants described balancing EBIP use with lecture due to content coverage pressure, often influenced by beliefs about learning and course level	“I worry, oh, will I cover enough content? ... I do think the more time I spend on activities, the slower overall that I will work through content” – Ian	Hasan, Ian, Joel, Natalie, Noah
Navigating Logistical Constraints on EBIP Use	Participants described assessing whether particular EBIPs worked in specific contexts, adapting or swapping out practices that felt too burdensome	“The cryptography class is [a] totally new class. [...] you kind of have to do some coding or you're not really learning [...] But otherwise, I didn't want to do anything special [and just lecture].” – Hasan	Hasan, Ian, Joel, Natalie, Noah
Responding to Student Feedback	Participants described adjusting EBIP use based on student feedback (comments, reactions, resistance), leading them to maintain, modify, or drop certain practices.	“Really structured group work assignments [...] that's ferociously unpopular. [...] I'm pretty sure I'm gonna drop this kind of structured group work – Shaun	All

Managing the Content Trade-Off

A major constraint many participants (Hasan, Ian, Joel, Natalie, Noah) faced was the pressure to cover course content, particularly in more foundational ACM courses. While all participants valued EBIPs, most described them as time-consuming, often leading to anxiety about falling behind in covering content. As Ian explained, “I worry, oh, will I cover enough

content? ... I do think the more time I spend on activities, the slower overall that I will work through content." Joel expressed a similar view: "for group work, I wish I did not have to do it...I feel like I would be able to cover more material and give more examples to them if I just had only lecture." That is, EBIPs and content coverage were viewed as in tension, creating a trade-off between using EBIPs and covering course content.

The previous remarks reflect the salience of content coverage goals among mathematicians and the common perception that EBIPs inhibit this goal, presenting a significant constraint to using EBIPs. In navigating this constraint, participants developed various hybrid instructional approaches that balanced EBIPs and lecturing (e.g., embedding activities into lectures, rotating between class sessions using entirely lectures or group work). However, while time constraints were real, two factors may have intensified how participants experienced these pressures: their beliefs about when learning should occur and their sense of responsibility for preparing students for future courses, making it harder to devote time to EBIPs. This suggests that these participants were continually negotiating the role of lecture in their instruction, treating it as a means of managing the content coverage trade-off rather than using it as their default instructional approach.

The Role of Exposure to Content

Three participants (Natalie, Ian, and Noah) held seemingly contradictory beliefs: while they believed students learn mathematics by doing mathematics (see Chapter 4), they also felt that meaningful mathematical engagement requires prior exposure to content. This tension positioned lecture as a necessary precursor to active learning, contributing to their perceived demands for content coverage. Noah articulated this view most explicitly, stating:

Learning is also how the material is presented to them, right? Because they have to be exposed to the material before they can sort of do things [...] I also think there's some value in having something presented in a clear way...

For Noah, the belief that students needed initial exposure before they could engage actively heightened the content coverage trade-off. While he preferred active learning, he often viewed lecture as a necessary precursor when other options (like flipped materials or assigned readings) were not feasible. This illustrates how participants navigated content pressures by continuing to use EBIPs, but in forms they felt were compatible with the need to provide students with content exposure first.

Natalie and Ian also suggested that they viewed learning as a two-phase process in which exposure to content comes first. Ian described that the bulk of learning occurs via active engagement, but that this something that comes after a lecture. Natalie described a similar process in which she first teaches students and then lets them "play with" material. For these mathematicians lecturing served an epistemic function: creating a foundation from which students could meaningfully engage with mathematical problems in class.

Preparing Students for Future Courses

In addition to beliefs about lecture needing to occur before active learning, participants' felt pressured to cover content by the perceived stakes of the course itself, particularly their sense of responsibility for preparing students for future mathematics classes. Ian, Natalie, and Joel all described managing the content trade-off in light of this responsibility, which heightened the urgency of content coverage in more foundational ACM courses like Discrete Mathematics or Introduction to Proof. In these contexts, participants felt that skipping content could have lasting consequences for students' success in future courses. In contrast, participants reported more flexibility in terminal courses where there was less concern about students' future preparation. Ian, for example, contrasted his use of active learning across courses, noting that while he used minimal lecture in Combinatorics, he relied more heavily on lecture in courses like Calculus II or Discrete Mathematics:

I would say Combinatorics is the most extreme in terms of no lecture...I would be terrified to do that in Calculus [...] with Calc II, there's so much more harm that I can create by having a bad Calc II class [...] With Combinatorics, it doesn't matter. If they don't learn the cycle structure of permutations, okay, that's a shame—but it's not going to be a roadblock down the road [...] That's one of the things I like less about Discrete. I feel like, oh [...] if I do a bad job now, I dunno, I have this absolutist thought that, oh, they see something in my class and it doesn't go well, they're going to be scarred for life... So I do see this as more constrained by where my students are taking it, and I think that affects my instructional practices.

Natalie and Joel both expressed similar tensions. For example, during her second pre-observation interview, Natalie described feeling anxious about limited time remaining in the term and the need to ensure her students were adequately prepared for real analysis; while Joel reflected on how he was able to use more active learning techniques like gallery walks when he was a TA leading a recitation section instead of an instructor of record because students had already been exposed to content, so they could focus on fewer types of problems in his sections. Together, these examples illustrate how participants' sense of responsibility for students' preparation in subsequent courses intensified the content coverage trade-off. Foundational courses like Discrete Mathematics made them more lecture-focused because the stakes of coverage were too high, from their perspectives, to risk falling behind. In contrast, terminal courses were experienced as more flexible contexts where EBIPs could be used more extensively.

Overall, participants viewed lecture as the most efficient tool for covering content, particularly when preparing students for future courses in ACM. Yet instead of abandoning EBIPs, they adapted them by using hybrid approaches that balanced content coverage with opportunities for engagement. In this way, the content trade-off was continually negotiated, with lecture often positioned as a foundation for subsequent EBIP use.

Navigating EBIP Logistical Constraints

Many participants (Hasan, Ian, Joel, Natalie, Noah) reported facing logistical challenges in their EBIP use. These challenges fell into two types: start-up burden (intensive preparation like developing flipped classroom materials or creating new assessments) and implementation complexity (managing activities like student presentations, gallery walks, or standards-based quizzes). While committed to using EBIPs, participants had to make pragmatic decisions about sustainability, sometimes modifying or stepping back from more intensive practices that research suggests may be especially beneficial. This section examines how participants navigated these logistical constraints and how their own standards for what counts as a “good” EBIP sometimes amplified these burdens.

EBIP Start-Up Burden and Implementation Complexity

Faculty’s perception of EBIPs as requiring a high up-front or sustained logistical effort is a well-documented barrier to adopting them in STEM fields. EBIPs like flipped classrooms, standards-based grading, or using activities in class often feel daunting due to their logistical demands (see Chapter 2). This was no different for participants in this study, both in their early experiences using EBIPs and in their ongoing use of these practices. Participants described difficulty finding time to prepare materials to support active learning or flipping their classrooms, as well as challenges implementing more structured EBIPs (e.g., assigned groups, gallery walks, peer review) effectively due to their logistical complexity.

For example, Noah described how intimidating major structural shifts like flipping a class for the first time or introducing alternative assessments could be. Six years ago, he flipped his calculus classes using an active learning textbook, and more recently attempted to implement standards-based grading in Discrete Mathematics:

[A] flipped classroom or active learning is very different organizationally... it's very intimidating... when you're used to lecturing and assigning homework and

the ordinary tests... So it was very helpful to have the [Active Calculus] textbook... with very clear activities... I could say, 'Okay, I'm just going to follow this book'...[Standards-based grading] is like a big switch... it's hard to do, except like all at once... like jumping into a swimming pool—you have to... jump in at some point....Designing the activities for active learning is also a challenge... [The] Active Calculus [textbook] has some good ones... but if I'm trying to do this in a new course, then... it can be difficult to come up with good activities that are at the right level and take the right amount of time and teach them... the right things.

Noah's metaphor of "jumping into a swimming pool" highlights how starting with EBIPs can feel like an all-or-nothing commitment. His contrasting experiences with these two courses illustrate how the presence or absence of instructional materials shaped both types of logistical challenges for Noah. In calculus, the Active Calculus textbook reduced the start-up burden of making flipped materials from scratch by providing ready-made videos, readings and activities. The textbook's activities also eased implementation complexity by offering activities that were well-designed for active learning and calculus learning objectives. While the transition was "still a bit rough," Noah could focus on facilitating rather than also designing materials.

However, Noah lacked such resources for Discrete Mathematics. While he had intended to flip the class, summer commitments prevented him from preparing flipped materials (e.g., videos) as he had intended. This led him to use a mixture of lecture days and small group problem-solving on worksheets he designed instead of flipping the class. Yet even this scaled-back approach presented challenges. At the end of the semester, he reflected:

I appreciate even more how time-consuming it is and how important it is to have good materials prepared going in. Because when, the Calculus is the other course that I've taught in this way [active learning], and I use [the] Active Calculus textbook, which is designed for that. And so it was still a bit of a rough transition starting out, but I had all the material there for me to use and I could basically lay out a schedule looking at sections of that textbook. And this course, I was sort of making it all up myself from scratch and I didn't make up enough of it basically. I didn't plan it out enough. And so maybe, I guess I appreciate now that you really need to have good materials going in and a good plan for how that's the schedule

Creating worksheets from scratch for Discrete Mathematics not only increased Noah's preparation time (start-up burden) but also created an ongoing learning curve as Noah tried to gauge appropriate difficulty levels of his worksheets and timing (implementation complexity). As he noted, "[The] Active Calculus [textbook] has some good ones... but if I'm trying to do this in a new course, then... it can be difficult to come up with good activities that are at the right level." This implementation complexity, evident even when not flipping a course, suggests that had he managed to prepare flipped materials, he likely may have faced similar challenges with activity design during implementation. Thus, Noah's experience highlights how start-up burden and implementation complexity can compound one another in the absence of extant instructional resources. That is, the lack of materials both prevented his intended full implementation and complicated his scaled-back approach. I now turn to how participants navigated such logistical challenges.

Modifying or Swapping EBIPs to Reduce Logistical Burden

Participants' responses to logistical burdens took different forms: some involved modifying how a practice was implemented, while others involved swapping out one practice for another that aligned with their orientations and goals but with fewer logistical demands. For example, Joel described switching from oral exams to exam corrections as an alternative assessment strategy. He had previously used oral exams to support students' conceptual understanding, but found them infeasible in a large undergraduate class:

If each student needs 20 to 30 minutes, and you have 35 students... that's 18 hours to do an exam. But if you have a grad student class with 12 students, that's six hours. Once it starts doubling the amount of time to administer and grade the exam, it's just not worth it to me.

Instead, he adopted exam corrections, a strategy he felt promoted a classroom in which failure was normalized (an important orientation of his) while being more manageable in high-

enrollment courses. He noted that oral exams remained valuable and were something he would return to “in smaller class settings.”

Other participants described modifying their use of EBIPs in response to shifting logistical demands. For instance, Hasan described two major adjustments during the fall 2024 semester. One involved a new course preparation—cryptography—which led him to lecture more heavily while incorporating some coding activities for active learning. The other involved trying out standards-based grading for the first time in his Introduction to Proof class. Hasan had previously flipped this course for nearly a decade but decided to discontinue flipping his class in order to try out this alternative assessment method:

When my friend told me about this... the standards-based approach... I was like, well, for something that's so skill-oriented, this class [Introduction to Proof], it seems like it's really good to introduce this type of assessment. And I guess I probably didn't want to complicate things by also making it flipped. So I was like, let's just do one thing at a time... All the practices take additional work... so I mostly just try to keep it not too complicated.

Although Hasan valued the flipped model, the added workload of both standards-based grading and flipped instruction felt unsustainable in the context of teaching a new course. However, committed to bringing active learning into the classroom, he used group worksheets, describing it as a simpler but still useful alternative to flipping the class.

In some cases, these logistical burdens led to participants discontinuing specific EBIPs. For instance, when asked about practices he had stopped using, Joel described a peer review activity in an undergraduate class. For Joel, wide variability in student responses, low-quality feedback, and limited time to build buy-in and scaffold peer review made the implementation effort feel disproportionate to the student benefit. Hence, even when participants valued the pedagogy behind a practice, logistical constraints could lead to temporary or context-specific discontinuation. Still, consistent with their commitment to EBIPs, all participants described

strategies for finding practices that could work—modifying or swapping one EBIP for another to reduce logistical burdens. Taken together, these examples illustrate how participants navigated logistical constraints by identifying EBIPs that were sustainable in their context. Persistence meant modifying or swapping practices to reduce workload, while remaining committed to engaging students in class.

The Logistics of Personal Fit

While this category primarily involved contextual factors (e.g., resources like time and materials) as constraints, my analysis also revealed that individual factors, such as one's comfort with uncertainty or control, could contribute to perceived logistical challenges. Some participants described concerns about practices that might expose their instructional plans or amplify a sense of failure if things didn't go as intended. For example, Ian explained why he avoided using partially completed notes, despite seeing their pedagogical value:

Even this minor logistical thing of like, 'Okay, Thursday, go back to your Tuesday notes'—this is totally something that would be easy to fix and not at all a problem. But I have a hard time showing them these notes and then having them see, oh, he planned for something... and we didn't actually do that. [...] I think there's some amount of ceding control that happens with all of these things.

Although he acknowledged that logistical issues like not finishing a worksheet could raise similar concerns, he was more willing to use worksheets in courses where he felt confident, such as combinatorics. In other courses, he hesitated to use them, until students explicitly asked him to, because deviations from his plans felt more exposed to student scrutiny.

Like Ian, Noah also expressed logistical concerns that reflected individual factors: a desire to maintain control and ensure that classroom time was spent advancing mathematically productive conversations. Indeed, Noah considered student presentations logistically complex because they might lead to “just trying to get something out of rubbish” rather than fostering the kinds of mathematical conversations he wanted. He also described a related tension: while he

appreciated how premade materials reduced the burden of flipping his Calculus class, he found that similar resources didn't exist, or didn't meet his standards, for ACM. This created a different kind of start-up burden, one imposed by his own disciplinary orientations:

I think another reason that I don't usually completely flip [upper division classes] is that often I have a particular perspective that I think is valuable for the students to get from lecture... and I rarely find a textbook or readings that will really do what I want. [...] I don't want to throw away [that] approach to teaching completely.

Here, Noah reveals how constraints on available resources may not always be just about whether materials exist, but about whether those materials align with mathematicians' disciplinary orientations. His discomfort with using inadequate resources, and his desire to preserve a particular mathematical lens, transformed the task of flipping his Discrete Mathematics course into a larger start-up burden, one that required him to make his own materials. In this way, his disciplinary perspective became part of what made the practice logistically challenging.

Other participants also described decisions that reflected personal or pedagogical values more than logistical fit per se. For example, Natalie chose not to use in-class polling (e.g., Kahoots, clickers) due to concerns about technology access, while Hasan avoided practices that felt overly personal, such as written student reflections. While these choices involved practical considerations, they were shaped more directly by participants' values and perceptions of student needs.

Overall, these examples illustrate that navigating logistical constraints is not solely about contextual factors. Participants' responses suggest that logistical constraints were often informed by personal fit, shaping how feasible an EBIP ultimately feels. That is, what counts as logistically burdensome is often influenced by individual factors. For some, this meant preferring EBIPs that better supported their disciplinary orientations, like Noah, despite the logistical

burden this introduced; while for others, like Ian, it meant avoiding highly scripted formats that clashed with a more improvisational teaching approach, limiting what EBIPs felt accessible.

Responding to Student Feedback

As discussed in Chapter 2, student feedback, particularly student resistance, is a common contextual factor shaping STEM faculty's use of EBIPs. All participants in this study described navigating student feedback, whether through informal comments, course evaluations, or real-time classroom dynamics. The main dimension of this category reflects variation along a continuum in how participants navigated various forms of student feedback. Some scaled back their use of EBIPs to accommodate student preferences; others refined their implementation to better meet their orientations and goals; and still others maintained their approach while adjusting how they communicated or framed their practices to students. These responses were not fixed; many participants described responding differently across time and context, illustrating how navigating feedback became part of the work of persistence. What follows examines the varied ways participants responded to student feedback while maintaining their use of EBIPs.

Responding by Scaling Back

This section examines one end of the response spectrum: two participants, Ian and Shaun, interpreted student resistance as a preference for direct instruction and scaled back their use of EBIPs. For example, Ian noted that students in his Discrete Mathematics class often preferred more direct methods like videos or lectures. This class included a mix of non-math majors (math minors, computer science, and engineering students), a context he felt contributed to their resistance, as they were not convinced the course was relevant. Regardless, Ian experienced a tension between their preferences and his belief in the value of productive struggle. As he explained: "It feels nice and comforting for someone to have already digested that information... But that's really hard. I think it's hard to balance how much I do that versus how much I let them

kind of struggle." To navigate this tension, Ian shifted toward think-pair-share activities. This format helped him preserve a level of active engagement while aligning with students' desire for structure and clarity

Likewise, Shaun described a similar pattern in his ACM courses, experiencing strong student pushback when using group work: "Really structured group work... that's ferociously unpopular... They just kind of feel like they're being asked to teach themselves... they become extremely self-conscious." In response, he shifted to primarily lecturing through proofs and problems, pausing at brief points students could work through so "[t]hey know it's gonna be for a short window of time, and then it'll go back to lecture." Shaun ultimately considered abandoning structured group work in ACM courses altogether, noting that "[t]he pushback was pretty gnarly."

These cases highlight how negative feedback motivated these participants to scale back their EBIP use, at least in specific contexts. Yet, even as they did so, both Ian and Shaun tried to maintain alignment with their orientation toward in-class student engagement. Rather than returning entirely to lecture, they adopted more interactive formats that preserved opportunities for student engagement, albeit in a more limited form. These adaptations reflect their efforts to reconcile student preferences with their desire to engage students in class.

Refining EBIP Implementation in Response to Resistance

While Ian and Shaun responded to student resistance by scaling back their use of structured group work, others (e.g., Noah and Hasan) used this feedback as an opportunity to refine their EBIPs. Rather than interpreting student resistance as a signal that the practice itself had failed, they treated it as a cue that their implementation needed adjustment. For example, during one of my classroom observations, Noah noticed students working independently rather than collaboratively during group work. Dissatisfied with this outcome, he reflected on how to

better promote collaboration and decided to experiment with different grouping strategies. He ultimately assigned student pairs and gave each pair a single marker to encourage joint participation. This new approach proved more successful, with students engaging more collaboratively. Noah's response reflects how he interpreted student disengagement not as a rejection of group work itself, but as evidence that his implementation wasn't yet aligned with his commitment to collaboration. Rather than abandoning the practice, he adapted it to better enact his values.

Using student resistance as information in this way also prompted broader reflection among participants. For example, Hasan reflected on how students had engaged with standards-based grading, noting that many were focused on memorizing solutions rather than developing the conceptual understanding he desired. Still, rather than attributing this to a flaw with the practice itself, Hasan framed it as an implementation issue he could work through with more experience:

I think I will definitely use it at least one more time. And then if I can iron out, I always like to do things twice, once just to try it and another time to see if I can iron out the issues. And if I can do that, then I'll continue using it.

This framing allowed him to persist with the practice while actively working to improve its alignment with his orientations and goals.

Ian, too, used student resistance to reflect on his practice. Although he initially responded to student disengagement by scaling back group work, he later questioned whether that decision aligned with his values. In his end-of-term interview, Ian reaffirmed his belief that confusion and productive struggle should happen in class while support is available, not later in isolation:

That is my main reason why I use the instructional practice that I use. I want them to hit up against that wall and struggle when I'm right there and get that feeling already before they have to do it on their own.

Yet he also questioned whether he had responded to student resistance in a way that unintentionally undercut that aim. His final remarks captured both uncertainty and a renewed commitment to reconsider how he was using EBIPs:

I still am on board [with active learning], but I think it's going to [take] thinking about how do I approach it and how do I integrate it into my class... I'm going to go back and think about it all.

Ian's reflection illustrates how persistence involves an ongoing negotiation, where even decisions to scale back EBIP use can prompt dissatisfaction and hence reconsideration of how to best sustain their use of EBIPs.

These cases highlight how participants viewed student resistance as diagnostic information, revealing gaps between their implementation of EBIPs and their vision for teaching. Rather than abandoning EBIPs, these participants experimented with modifications, adjusting their implementations and reflecting on potential changes to better align their practice with their instructional goals.

Maintaining EBIPs While Incorporating Student Input

Some participants (e.g., Natalie, Joel) navigated student feedback but continued using EBIPs with little structural change. These participants remained committed to their use of EBIPs but welcomed student input as a way to fine-tune implementation and support student buy-in. For example, Natalie described being consistently attentive to student feedback and willing to make changes when something wasn't working. At the same time, she emphasized that she wasn't "trying to be a pushover and having [her] students totally dictate," but rather saw feedback as part of "an open conversation." Similarly, Joel explained that he set clear expectations for group work from the outset: "I put into the syllabus and I just say, this is the expectation." When students resisted, he addressed them individually to promote the engagement he expected in class. Like Natalie, Joel sought feedback mid-semester, even using anonymous Google Forms to

assess how students were responding and make small adjustments where needed. These participants illustrate how instructors can remain open to input while maintaining committed to their use of EBIPs

Ian also described navigating feedback in this manner when he first taught Combinatorics using an inquiry-based approach. Concerned that students might resist the format, he initially asked them for feedback and input on a weekly basis “to get a gauge on how close we were to the students revolting.” As Ian described this experience:

One of the things that I asked this class, sticking in my mind after the fact, was early on I would ask them like, oh, do you want me to spend a little bit of time lecturing on this or that? And generally the feedback was, ‘no’. And then I did less and less lecture... I basically didn't do any lecture and I just kind of stopped asking them about it.

In this case, student feedback gave Ian the confidence to follow through using minimal lecture in his Combinatorics class and hence helped him persist in using these practices, as remaining open to student feedback quelled his fears of resistance and revealed that students were open to the inquiry-based structure of the class.

Making EBIPs Work: How Persistence Unfolds

This section examines cross-cutting themes in how participants persisted in using EBIPs over time. Whereas the preceding section focused on specific challenges participants navigated when implementing EBIPs, this section presents persistence categories that cut across those constraint categories, capturing how participants sustained EBIP use despite challenges.

Across cases, persistence was expressed as adaptation; participants modified or substituted EBIPs to make them workable within their contexts rather than abandoning them. This adaptation was evident across cases. Participants modified EBIPs in response to constraints related to content coverage, logistical complexity, or student feedback—changes they often described as necessary compromises or pragmatic solutions. For example, most balanced EBIPs

with lecture to manage content coverage, others replaced demanding practices with more feasible alternatives (e.g., Joel using test corrections instead of oral exams; Hasan using worksheets instead of a flipped model), and still others modified implementations to reduce student resistance (e.g., Noah restructuring group work in the middle of the term). While participants sometimes discontinued specific practices (e.g., Joel abandoning peer review, Hasan stepping back from flipping), they did so selectively, often substituting alternatives aligned with their goals and contexts. I viewed these decisions as part of adaptive persistence rather than counterexamples, since participants remained committed to EBIP use overall.

My analysis revealed three categories that supported this adaptive persistence: (a) reframing challenges, (b) drawing on positive experiences, and (c) leveraging departmental or collegial support. For the remainder of this section, I detail each of these categories.

Reframing Challenges

For many participants (Hasan, Ian, Joel, Noah, and Shaun), adapting their use of EBIPs appeared to be enabled by their ability to reframe challenges. These participants described difficulty as an expected part of using EBIPs, whether they were implementing a practice for the first time or refining one already in use. This often involved managing their own expectations and anticipating imperfection as a normal part of the process. Hasan, Noah, and Ian, for instance, framed struggles as natural and something to learn from. Comments about refining EBIPs were common, as were reflective accounts of missteps and planned changes. For example, when Noah described introducing standards-based grading during the the term I interviewed him, he remarked:

Well, it's the first time [I'm] using standards grading in this class, and something new is always sort of awkward when you first start figuring out what the standards should be and how to grade them. And I didn't do a great job of letting the students know where they are regularly.

Here, Noah appeared to anticipate awkwardness and partial failure as part of the learning curve, normalizing it as a feature of trying out something new. Hasan echoed this, describing a personal rule to always try a new practice at least twice in order to “iron out the issues,” reflecting his expectation that initial implementation would be flawed. Likewise, Shaun reframed struggle and failure as a natural part of teaching with EBIPs:

Really managing your expectations... 99% of the time is failure, inability, no progress... aside from your best students, on your best day, with the best circumstances. You just have to put all that out of your mind... You are trying to get them to have a... conversation with themselves... and constructively start chipping away.

This quote from Shaun highlights his belief that EBIPs won’t necessarily lead to immediate success, but that they’re essential for engaging students in the learning process. He stayed committed to the value of student engagement, even though, as discussed in the *Responding to Student Feedback* category, student resistance had prompted him to scale back his use of group work. Shaun’s case highlights that adapting EBIPs can mean continuing to use EBIPs in some form rather than sticking with a specific EBIP like group work.

Taken together, these accounts illustrate how participants engaged in emotional and cognitive reframing to persist in using EBIPs. In particular, their persistence seemed to involve an active effort to see adapting to challenges as inherent to teaching and to view perceived failures as learning opportunities, rather than as signs that EBIPs were not working and should be abandoned, which seemed to enable them to flexibly adapt their EBIP use.

Drawing on Positive Feedback and Experiences

Participants also often described positive feedback and experiences as reinforcing their commitment to using EBIPs. Even those who had struggled with student resistance cited moments of student appreciation as validation that supported their persistence. Indeed, regardless of how participants navigated student feedback, many (e.g., Hasan, Joel, Natalie) pointed to

positive student reception as a key factor in their long-term commitment to using EBIPs. In their end-of-term interviews, these participants often cited student appreciation and enjoyment as evidence that their efforts using EBIPs were worthwhile.

Natalie, for instance, shared that students frequently expressed how much they valued the interactive, conversational nature of her classes. She added that the payoff of these practices extended beyond just sentiment and was visible in student performance: "They've just done extremely well." Joel similarly emphasized how recurring positive comments in his student evaluations reinforced his use of small group problem-solving, especially those praising his "problem sessions" as the place they learned the most. He explained that this kind of feedback had remained consistent across semesters, reinforcing his commitment to group work.

Others reflected on their classroom experiences. Hasan, for instance, admitted to ongoing skepticism about whether EBIPs measurably improved outcomes, but he still viewed student enjoyment and his own enjoyment as reasons to continue: "I always feel like I have to have [some] sort of skepticism – did it really make a difference? But I had enjoyed doing it, and I think the students enjoyed [it] too." For Hasan, these positive experiences with enjoying the classroom more became its own form of validation that EBIPs were worth using.

Noah also pointed to student reception as reinforcing his use of EBIPs. He looked for concrete signs of effectiveness – student engagement with the material, collaboration during class, and a willingness to study – as evidence that the practices were working: "...what makes it feel successful is that I see the students engaging with the material and talking to each other... and they're motivated to go back and relearn, actually learn things to pass the standards quizzes." This observable student response provided Noah with confirmation that his use of EBIPs was

achieving his desired outcomes. As he stated: “When I see those things, I feel like this is having the effect that I want it to have.”

Across these cases, it was positive feedback and experiences – whether in the form of appreciative comments, enjoyable classroom interactions, or students’ reception– that reinforced participants’ sense that EBIPs were worthwhile. These moments served as reminders of the value of their efforts and seemed to strengthen their commitment to persist using EBIPs despite the ongoing challenges they faced.

Leveraging Departmental and Colleague Support

Lastly, institutional support stemming from the department or colleagues emerged as a source of persistence for all participants. Across cases, there were references among participants to the role of the department in navigating the challenges they encountered. These ranged from examples of active incentives, a generally supportive environment for trying innovative teaching, or a department that simply did not actively impose barriers. For example, Joel described his practices as encouraged and aligned with the mission statement of University B, which he could include in his tenure packet. In contrast, Ian described the department as, at most, moderately supportive but really just not getting in the way, stating: “But overall, I would say the department is either unaware of things or moderately supportive. I’ve never had any sort of roadblocks from department, institutions, etc.” There was only one case where a department was described as actively impeding instructional choices. This occurred for Natalie, who received pushback on her use of test corrections due to department policies, leading her to stop using them until her dean intervened, illustrating how the department can actively support or impede EBIP use. As Natalie explained:

My department is, they say that they're supportive about some of these things, but then sometimes the feedback I get is not so supportive. Luckily, I have a dean, our dean is really, really amazing, and she's had my back in a lot of these things. I got

pushed back against doing test corrections or something, and my dean was basically just test corrections are a really valuable pedagogical tool.

Likewise, colleagues also provided resources, encouragement, and commiseration to persist through difficulty. For example, Natalie described relying on peers for help creating active learning materials in classes she hadn't prepared before, while Noah described his plan to teach linear algebra and reach out to a colleague who taught it using an inquiry-based textbook. Joel and Noah emphasized how commiserating with others helped them persist, normalizing that EBIP use is difficult and helping reframe challenges. As Joel stated:

Sometimes you get down [disappointed] that it's not working—in very simple terms. You get down, it's not working—and then saying, "It's okay, it doesn't always work." So that's why support, in that sense, is commiserating and just keep going. Those words of encouragement and normalizing the struggle, as well.

Overall, these cases suggest that a department that is supportive (or at least does not actively create barriers) together with collegial support, helped sustain participants' use of EBIPs in the face of challenges.

Chapter Summary: Persistence Using EBIPs

This chapter highlighted the ways participants persisted in using EBIPs despite ongoing challenges. Across cases, participants primarily navigated three constraints: content coverage pressures, logistical constraints, and student resistance. Rather than abandoning EBIPs in the face of these challenges, participants chose to adapt. Adaptation took many forms – refining practices, substituting one EBIP for another, or modifying implementation to fit a particular context – but it was the common outcome of persistence across cases. This adaptive persistence was supported by three mechanisms: reframing challenges, drawing on positive feedback and experiences as motivation, and utilizing departmental or collegial support when available. These mechanisms seem to have made adaptation a viable response, enabling participants to sustain

EBIP use despite dissatisfaction arising from implementation experiences. The relationship between constraints, experiences, and persistence is depicted in Figure 5.1.

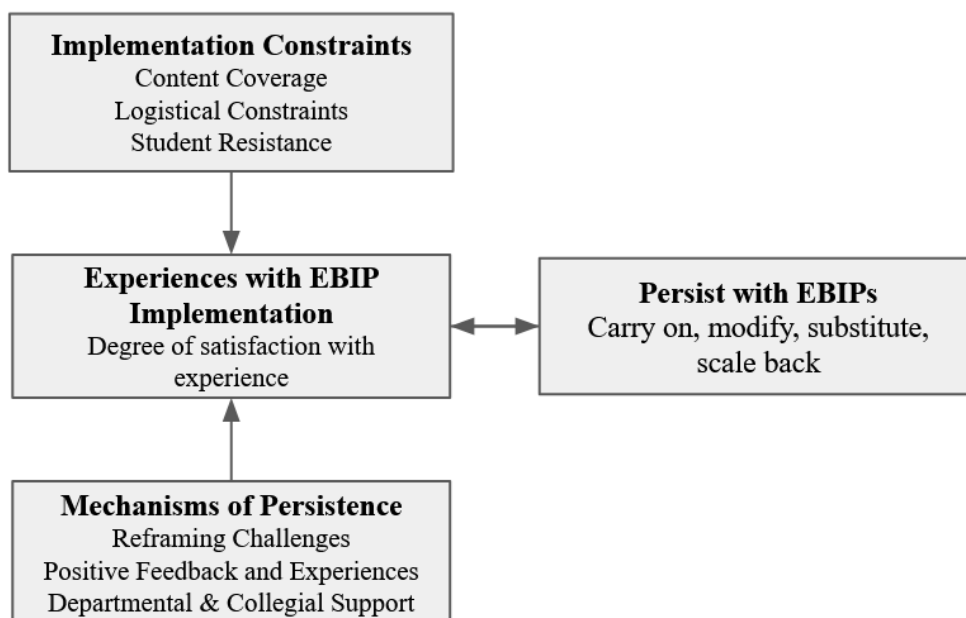


Figure 5.1: Model of Persistence in EBIP Use. Implementation constraints and persistence mechanisms shape participants' experiences with EBIP implementation, with constraints influencing their degree of satisfaction and mechanisms enabling persistence. The bidirectional arrows between experiences and persistence highlight the iterative process: implementation gives rise to dis/satisfaction with the experience, which informs EBIP adaptation, which in turn shapes subsequent implementation.

Together, these findings illustrate how participants' adaptation in response to implementation challenges was shaped by their ability to reframe challenges, see concrete success through student feedback and classroom experiences, and draw on institutional or collegial support. Importantly, the constraints participants described were not unique to any particular EBIP, but represented common challenges across mathematics instruction using such teaching approaches. These findings begin to paint a more detailed picture of how persistence may unfold as a process shaped by instructors' motivations and ongoing experiences (both positive and negative) using EBIPs in the classroom. In the next chapter, I explore how

participants enacted their motivations as they navigated everyday constraints by examining how they used EBIPs in practice.

Chapter 6 HOW AND WHY MATHEMATICIANS USE THE EBIPS THEY DO

In this chapter, I address my third research question: *What does mathematicians' use of EBIPs look like in ACM, and how is it shaped by their resources, orientations, goals, and other factors?* I present my findings in two sections. First, I describe what participants' use of EBIPs in ACM looked like and how their resources, orientations, goals (ROGs) and other factors shaped this use. Recall that *resources* refer to the knowledge (e.g., experiences as a student, student feedback) and tools (e.g., classroom spaces, materials) that instructors draw on when teaching; *orientations* include their underlying beliefs, values, and stances toward teaching and learning; while goals refer to the specific outcomes they aim to achieve in a given course (Schoenfeld, 2010). After describing participants' EBIP use and ROGs, I connect this analysis back to the categories developed in Chapters 4 and 5, illustrating how the reasons that led participants to adopt EBIPs also guided their day-to-day facilitation decisions in conjunction with the challenges they faced. In doing so, this chapter highlights both the alignments and the tensions between participants' reasons for using EBIPs and the ways they implemented them, painting a holistic picture of how and why mathematicians use EBIPs in the ways they do.

The Different Approaches Mathematicians Take to Using EBIPs

In my observations of the six mathematicians in this study, I noted two broad approaches to using EBIPs. The first approach (used by Noah, Hasan, and Joel) was lecture followed by small-group problem solving. These participants typically lectured on a topic and then devoted class time for students to work in small groups (e.g., two to six students) to complete worksheets on the topic they had previously lectured on. For some, this meant a lecture day followed by a

day devoted to the worksheet, whereas for others this looked like a single class session split between worksheet time and lecture. The second approach I observed (used by Ian and Shaun) involved interspersing activities within a lecture. Participants paused at key moments to have students engage in a mathematical task, such as making a conjecture about a theorem statement or working through part of a proof or computation. One participant (Natalie) was observed using slight variations of these two approaches. In this section, I examine these approaches in more detail and examine participants' ROGs to make sense of why they structured their classes in one of these two ways. I begin with the “lecture followed by small group problem solving” approach, then turn to “lecture interspersed with activities,” and conclude with the case in which Natalie used both approaches.

Lecture Followed by Small Group Problem Solving

Three participants (Hasan, Joel, and Noah) structured their classrooms by devoting specific class time to small group problem solving on worksheets after lecturing on the worksheet topic. Noah lectured on proof concepts until he had covered enough content and then devoted a class session to group work on the proof technique; Joel alternated between lecture days and small group problem-solving sessions focused on applying concepts from the prior lecture; while Hasan started each class session with small group problem solving on the previous lecture's material, typically spending the first quarter of class on this before lecturing new material for the remaining time. On the surface, all three adopted the same “lecture followed by small group problem solving” format, but their reasons for doing so, and the way they facilitated this, were shaped by their ROGs. In this section, I explore their cases together to show how a similar structural choice can reflect distinct ROGs.

The Choice to Lecture First

The key characteristic of this approach was lecturing first. All three participants preceded their group work time with a lecture. This was motivated by the need to cover enough mathematical content before students could work with it. For Noah, this was driven by his belief that students needed exposure to material before working productively with it:

They need to see how a proof is put together [...] Some of [the] proofs are more complicated than the ones I would ask them to do, but they can see how the rules get written in English and get organized, and so on. And then another day [they're] working in groups on exercises of that kind.

While he preferred active learning, he described lecture as a practical necessity. He had originally hoped to adopt a flipped classroom model, but lacking time to prepare video materials, he “ended up lecturing content in class and that’s almost not as effective really [...]. Also it takes up all the time in class that we could be using to do other things.” In other words, although he considered lecture less effective than active learning, he used it to ensure students were exposed to content when alternatives such as videos or assigned readings were unavailable. I observed this tension in action when Noah considered starting a group work day with a small lecture, as he hadn’t covered one proof he had wanted students to see, though he ultimately decided not to, stating “I don’t know that it’s gonna help them all that much with [the worksheet],” as the proof he wanted to show them (the division algorithm) was more complex.

Hasan, too, described lecturing to cover content, but also was willing to rush his lectures to make time for worksheets: “if I give a terrible lecture, but absolutely amazing worksheet time, that’s way better than having an amazing lecture and no worksheet time at all. So I accept the cost of having a not so great lecture.” Hence, he seemed to prioritize active engagement time over content exposure quality. Hasan also found that beginning class with a worksheet on the prior class’s lecture material gets students to “to think about the thing that they just learned a few

days ago” and “it’s a good way to get them warmed up” to be more engaged during his lecture. Indeed, in my two observations of Hasan, he spent 25 minutes on a worksheet in the first and 45 minutes in the second, saying he spent more time in the latter because he had gotten ahead of schedule covering content. This suggests that when content coverage was not a constraint, Hasan devoted more time to group work.

Like Noah and Hasan, Joel also described lecture as indispensable for covering content and examples, but unlike them, he expressed a personal preference for lecturing to cover content and go over examples. Joel described active learning as something that primarily occurs outside the classroom (e.g., via study groups) but that it had to be modeled within class. He chose the lecture followed by group work structure because it was similar to the lecture-recitation structure that he experienced as a teaching assistant, in which students were first exposed to the content in the main lecture and then got hands-on practice in recitation sections. Together, all three participants indicated their goals of covering content along with their own knowledge about how learning is best structured (e.g., exposure to content first, more time engaging with material), leading them to lecture prior to using active learning.

The Choice to use Small-Group Problem Solving

While Hasan, Joel, and Noah did lecture before engaging students in active learning, the active learning always took the form of small-group problem solving with a worksheet. This choice to use small-group problem solving, as opposed to other active learning strategies, was shaped by participants’ ROGs.

Noah. During the fall 2024 semester, Noah was teaching Discrete Mathematics, which served as an introductory proof class at University C. As such, his main goal was to teach students to read and write proofs. He viewed a proof as “a well-defined thing” governed by explicit logical rules, and he wanted students to leave his class knowing what they were

“allowed” to do in a proof. Without timely intervention, he worried students might develop a “grab bag” of strategies without understanding what they’re actually allowed to do. This concern was informed by his observation that students often could not self-evaluate the correctness of their work. Reflecting on his own success as a student, Noah believed his ability to judge correctness independently had been key; when he observed his students lacked this skill, he decided to have students work in class where he could see their work and provide feedback. For Discrete Mathematics, he hoped to provide feedback on what students were allowed to do and help them evaluate the logic of their proofs. Notably, this orientation toward feedback also shaped his instruction more broadly, as he incorporated frequent standard-based grading quizzes and feedback tools for proofreading, such the browser friendly interactive theorem prover *The Impossible Proof Machine* (Breitner, n.d.) and graphical proof writing methods.

However, Noah favored group work over one-on-one instructor feedback because he saw collaboration itself as conducive to learning. In his second stimulated recall interview, he explained this belief using the computer science idea of “rubber ducking” (Hayes, 2024):

The idea is you've got a little rubber duck that sits on your desk and when you're stuck on a problem, you explain your problem to the rubber duck and then the process of explaining it, often you will figure out the solution....

He extended the analogy to his own classroom:

...even if they were working individually and they all had me right next to them, they wouldn't get that experience of explaining it to somebody else who's a peer. And I think that process of explaining and that back and forth of figuring something out in two or three or four people is more than the sum of its parts....

Here, Noah emphasized that, to him, peer explanation was not just an alternative to instructor feedback but a fundamentally different learning process, one he considered more meaningful than “just getting direct feedback from [him] or from ChatGPT.” Hence, he was oriented toward student collaboration as he believed it offered more meaningful opportunities for learning.

Hasan. Like Noah, Hasan was also teaching an introductory proof class, and his central goal likewise focused on proof-writing. As he put it, “they have to know the importance of definitions...They have to understand the definition and know how to apply it in a proof. They have to be able to actually write proofs and understand how to read them.” Hasan believed that engaging with mathematics by doing problems was the only way to learn it, but that students did not recognize this themselves, leading him to use more active approaches. He described his rationale directly: “I wanted them to spend more time actually engaging with the abstraction” instead of passively listening and “being confused.” He contrasted lecture with active learning: “So like intro to proofs. So I tell them how to write a direct proof, what are [they] getting out of that? No, [they] should just be writing it and then have me look at it and give [them] feedback.”

Like Noah, Hasan wanted to provide feedback on students’ proofs so they could better learn how to construct them. However, Hasan was drawn to group work for a distinct reason. Whereas Noah framed group work as a way to surface proof thinking for feedback and learn from peers, Hasan discussed group work as a way to ensure students were actually engaged. He observed that when students worked individually, “you’ll have people who will just not do it” and instead just wait until he goes over the problem, which turned individual problem-solving into “a delayed lecture instead of actually doing the problem.” In contrast, Hasan found that when he used group work “[that] doesn’t happen nearly as often [...] it makes them actually work.” In other words, while group work did not guarantee engagement, he found that it helped facilitate it better than individual problem solving. Hasan also emphasized additional benefits of group work, including that working together made it easier for students to get unstuck (a view that resonates with Noah’s “rubber ducking” idea) and that students felt more comfortable

making mistakes in front of their peers than in front of him. Overall, he saw group work as creating a better “work environment” in which “it [is] much easier for [students] to learn.”

Joel. Where Noah and Hasan primarily emphasized proof writing as their central content goal, Joel was teaching Abstract Algebra, a course with a transition to proof course as a prerequisite. His main goal, therefore, was helping students apply Abstract Algebra concepts. As he explained, he wanted students to solve problems rather than reproduce memorized proofs or definitions. This included giving concrete examples and non-examples, identifying relevant theorems, and applying them to solve problems. Joel especially wanted students to unpack theorems that were “steeped in jargon” and make them “usable to problem-solve.” In short, his goal was for students to move beyond the rote memorization of definitions and proofs toward conceptual application – for example, using the first isomorphism theorem rather than just memorizing its proof.

Joel was drawn to group work for a reason distinct from Noah’s and Hasan’s. Whereas Noah emphasized collaboration for peer feedback and dialogue, and Hasan emphasized it as a mechanism for better engagement, Joel emphasized its role in fostering peer support outside of class. As Joel put it, “I’ve just found that students don’t work together out of class very well [...] I just didn’t succeed without it ... And I’ve seen students graduate here but never learned that skill and that’s just a shame.” He attributed his own success in lecture-heavy classes to peer interactions: “I had lots of success in lecture-based classes, but that was because I had really good classmates and social interactions with other math students.” Hence, Joel used group work to “set that expectation that they should be working together on problems.” Like Noah and Hasan, Joel also acknowledged that collaboration could aid problem solving in the moment, but his primary orientation was toward building collaboration that extended beyond class. To further

support this aim, he promoted office hours and created a class Discord server to facilitate study groups and homework discussion, effectively making “everything into group work.”

Implementing Small Group Problem Solving

While Noah, Hasan, and Joel all used a similar approach, I observed notable differences in how they implemented it. Classroom observations revealed how each participant’s ROGs influenced how they implemented the same overarching EBIP structure.

Noah. Noah’s orientation toward collaboration shaped how he structured his classroom. I observed that Noah’s Discrete Mathematics class had about 13 students and took place in a room with moveable individual desks and whiteboards on three walls. In my first observation, he encouraged students to break into groups, but they mostly worked quietly and independently at their desks, clustered in groups of two or three and facing one another, with only occasional chatter to compare answers. In our first stimulated recall interview, Noah expressed dissatisfaction with this limited collaboration. He hypothesized that his use of standards-based quizzes contributed to the problem, as he directed those who finished quizzes early to complete unfinished worksheet problems. This disrupted group work, as not all members finished their quizzes at the same time. Combined with the fact that he had not explicitly assigned groups, Noah believed these factors reduced collaboration, even on days he did not have quizzes. In response, he experimented with more intentional group structures. In my second observation, he assigned pairs to whiteboards with a single marker to ensure interdependence: “They can’t both be sort of doing independent things... I want them to be working together on a solution.” Using this group work structure, students were visibly more interactive, talking and working at the whiteboards. Noah later reported he was “pretty happy with it” and used it again before the semester’s end. This example illustrates how the availability of whiteboards as a resource

together with his orientation toward collaboration, shaped his use of group work to better promote student interaction.

Noah's orientations also shaped how he facilitated group interactions, particularly regarding the types of feedback he gave students. He encouraged students to pursue ideas as long as they remained mathematically productive, reserving corrections for moments that indicated errors in applying logic or major misconceptions. For instance, I observed him advise a pair of stuck students to "back up and try something else." When they interpreted this as Noah saying they were wrong, he clarified: "No, I'm not saying anything about [your solution]. In general, if you're stuck, then that means maybe you should back up and try something different." In contrast, when a group made major logical errors, he told them, "well there's a lot of things here that don't make sense," and directly corrected their proof. Taken together, these episodes illustrate his orientation was toward productive struggle when it advanced proof writing but toward correctness when core logical ideas were at risk of being derailed, aligning with his orientation toward feedback and proof-writing goals.

Hasan. In Hasan's Introduction to Proof class, I observed approximately 14 students and noted it took place in a classroom with fixed seating at shared tables arranged in rows, with multiple large whiteboards at the front of the room. In both observations, students immediately broke into small groups of about 3 to five, sitting across from one another at the tables and working from a shared worksheet, actively discussing the problems as Hasan circulated. In our stimulated recall interviews, Hasan emphasized his orientation toward student collaboration, describing how he carefully structured group work to ensure students worked together. For example, on one observation, I saw him ask a pair of students to join another group. When I later asked about this, he explained, "I think that four or five is the optimal number of people in a

group,” and he didn’t want them working as a pair because “it’s sort of like when you’re hanging out with friends – if it’s just you and the other person, it can be awkward unless you’re good friends.” Hasan also reflected on the dynamics within that pair’s original group: “[they had] one person who never showed up, one person who just never contributed, and another person who had a hard time contributing.” Because of this, he felt it was important to place them in a more functional group, noting that students would “frequently just be paralyzed” without peers at least willing to “talk things through.”

To further promote collaboration, Hasan used a designated group role called “the scribe,” responsible for recording the group’s solution. As he explained: “I like to say, ‘who’s your scribe’ to prompt them, ‘No, you’re actually a group and there should be one finished product.’” These strategies illustrate Hasan’s orientation toward collaboration and his attention to students’ social-emotional needs, which were informed by his experiential knowledge of how factors such as group size, regrouping, and role assignment shape students’ willingness to engage.

Like Noah, Hasan also had content goals for proof-writing that influenced his interactions with groups. He was primarily focused on correcting “bad habits” and monitored for misconceptions and errors to correct students or prompt them in a different direction. He emphasized, however, that group work can surface classwide issues he could then address for everyone. In one stimulated recall interview, Hasan shared that his use of standards-based quizzes had revealed that students were struggling to use proof-templates (a scaffold for proof-writing he used), so he designed a worksheet explicitly targeting this. During the worksheet time, he identified an underlying issue with the templates by talking with groups and then addressed it with the class. As Hasan explained:

This is the reason to me worksheet time is so valuable. If I'm lecturing, I don't know what they're having trouble with and I can't address it. So here [in-class] I

can see it, I can practice my responses within the group, and then I can give them a more polished answer to the whole class because presumably people who weren't in those groups also had those problems and didn't hear my answer at the time.

In short, Hasan's group work sessions functioned as a built-in feedback loop. They surfaced difficulties shared by multiple groups of students, which allowed him to fine-tune his responses before addressing the whole class. In this way, he could move beyond only discussing misconceptions with individual students or groups and instead give explanations to the whole class to support his proof-writing goals.

Joel. In Joel's Abstract Algebra class, I observed approximately 29 students. The classroom had blackboards on two walls and whiteboards on another, with moveable desks. During group work, students primarily stood together at the boards in groups of four to six, while some remained seated at desks facing the boards. Joel structured his group work by assigning students to work in groups at these boards (a resource key to his group work structure) as he circulated to monitor progress, provide feedback, and answer questions. Like Noah and Hasan, Joel facilitated group work with deliberate strategies to promote collaboration. For example, he described the importance of establishing expectations for group work early to accomplish this:

The most important thing about these problem sessions is setting the tone in the first weeks. And that requires shifting groups around so that they're not just...reinforcing bad behaviors... And even week one, not having a content related problem is kind of important and things like that. But there's writing. They understand that, okay, we want to write something down so that when we take it down to the homework and that there's enough interaction that if someone writes something down, the others hopefully are feeling comfortable to ask that person questions.

He also described strategies such as handing markers/chalk to disengaged students and rotating who was writing at the board within groups to ensure more participation, moves I observed him use multiple times. As Joel wanted students to work together outside of class, he also had strategies to help students view each other as resources. In two cases, I observed him explicitly

validating individual student contributions by redirecting group attention. For example, when he noticed a female student's approach was correct while her peers pursued a less efficient strategy, Joel drew attention to her solution: "And it's [Student Name], right? Okay. [Student Name]'s got a really nice start to this. She checked all the numbers." In another case, a student posed a question to Joel individually, and he redirected it to the whole group to validate the idea and spark discussion. He described these moves as ways to signal that "each of us has good ideas" and to "really value each other's questions" to promote better collaboration in and outside the classroom. Lastly, Joel also described being attuned to students' social-emotional needs in mathematics, intentionally trying to spark confidence and avoid phrases like "oh, just this" which could make students feel dismissed if a solution or fact was not obvious to them.

Joel's goals for conceptual understanding also shaped how he designed and facilitated his lectures and worksheets. He described using annotated slides to discourage students from simply transcribing definitions and theorem statements. Instead, he wanted them to focus on his annotations, which highlighted "actually understanding what the definition or theorem is saying and using it in practice" to help students "learn what should be written and shouldn't be written." Similarly, in one stimulated recall interview, Joel tied his worksheet design directly to lecture content: "like this problem [on the worksheet] required, it had two theorems attached to it. So there's a box, [a] little prompt of 'use this to answer the questions' and they're just a direct copy from what was in the lecture notes." During group work sessions, beyond his moves to ensure better collaboration, Joel described primarily looking for moments to reinforce his content takeaways, visiting each group to discuss the key takeaways for each problem and answer any questions.

Taken together, Noah, Hasan, and Joel illustrate how a shared “lecture followed by small-group problem solving” structure was enacted in distinct ways: Noah leveraged it to primarily generate opportunities for him to provide feedback on proof techniques and for students to brainstorm ideas with their peers, Hasan to promote student engagement through carefully structured worksheets and group dynamics, and Joel to promote conceptual application and foster collaboration as a durable practice outside the classroom. What appeared as a similar EBIP implementation on the surface reflected very different enactments of participants’ reasons for using EBIPs.

Lecture Interspersed with Activities

Two participants (Ian and Shaun) structured their use of EBIPs to balance lecturing on a topic and engaging students in active learning within the same class session. Participants who used this approach would pause their lecture at specific moments for students to engage with mathematics. Specifically, Ian interspersed think-pair-share activities in which students would first independently work on a task, then turn to their neighbor to discuss it, and finally would be asked to share their thoughts with the class; similarly, Shaun alternated between working through problems at the board and then pausing for students to try aspects of the problem (e.g., a specific step or computation) themselves before resuming his lecture at the board.

The Case of Ian: Think-Pair-Shares

Ian’s primary goal in his Discrete Mathematics class was to teach mathematical proof, with an emphasis on helping students recognize patterns and structure. Yet he found this work difficult because many students were not convinced the class was worthwhile. As a result, they often questioned why they had to “waste [their] time writing up a proof” of something they already knew, such as the fact that the sum of two even numbers is even. This skepticism led Ian to attend closely to students’ mathematical dispositions. He wanted them to view the class as

worthwhile so they would be less resistant to developing habits of seeking out underlying logic and structure. Alongside this, Ian wanted students to move beyond rote memorization toward conceptual understanding. He explained that he did not want students “to just memorize a bunch of little tips and tricks and tools” for writing proofs. Still, if students did rely on memorization, he hoped they would at least leave the course willing to try strategies even when uncertain: “I don’t understand this thing, but I have this tool I can try. Maybe using the tool will push me toward more understanding.” This perspective reflects Ian’s orientation toward productive struggle as central to learning mathematics. Indeed, he described wanting students to explore ideas and confront difficulty. As he put it, he wanted his students to “get comfortable with failing a lot... just do stuff they don’t understand.”

Ian’s motivation to use active learning stemmed directly from his belief in productive struggle (which required students to actively attempt problems) and his commitment to supporting it. He believed students would be better prepared for homework and exams if they first struggled with ideas in class, with him present to offer guidance: “If I give you problem A and I give you some thoughts on how to get started on it, you do it in my presence. And then a similar problem shows up in the homework. My sense is you’re going to be more prepared... You’ve already worked through that struggle, that hard part with me being there.” Ian described this struggle as where real mathematical learning occurred. At the same time, Ian noted that students often resisted active learning, expressing preferences for worked examples or videos. To balance students preferences with his ROGs, Ian assigned out of class readings and would recap these in class, typically demonstrating an example before giving students a related problem to attempt. He described this as a “call and response” approach: “I do a problem... I present

[another] problem... I give them a few minutes to think on their own... they talk with neighbors, then we come together.”

I observed Ian using this method in his Discrete Mathematics class. I observed that this class had about 20 students and took place in a classroom with moveable desks, where students worked at their seats and could turn to nearby peers during activities, with whiteboards and projector screens at the front of the classroom. Ian described timing his think-pair-shares to engage students with content they found difficult or to emphasize key ideas, particularly those that recurred or had broad applicability across the course. For example, in my first observation of Ian, students were preparing to work through their first proof by induction – something Ian described as “just such a weird thing” for those first learning the technique. This proof involved a sigma sum, and Ian had observed that students were often unfamiliar with or confused by the notation. Before starting the proof, he launched into a think-pair-share where he asked students to “take 30 seconds to write down what [the sigma notation] means in language [they’re] comfortable with.” When I asked what prompted this activity, he explained, “if they don’t know what that symbol means... what’s the point of doing the proof?” Similarly, when covering function correspondence, Ian gave students time to recall vocabulary (domain and codomain), noting his sense that students struggled with it. Though he worried that slowing down might sometimes “lose more students than [he] gained,” he felt it was worth devoting time to these stumbling points. At other times, he used think-pair-shares to emphasize important ideas more directly tied to his content goals, such as asking students to analyze a “bogus proof” to highlight the steps in induction.

However, not every situation associated with struggle led to a think-pair-share activity. At times, Ian opted for interactive lectures, posing questions to students instead. For instance,

when addressing a misconception about injectivity in multivariable functions, he asked students to reason about an output of $(2,2)$, posing the question to the class rather than doing a think-pair-share. Here, he felt the misconception was too specific to merit a think-pair-share, so he held this shorter discussion as a “middle ground” approach. As he explained:

I do not view this particular skill of recognizing the characteristics about this particular function as kind of the core what I want students to get out of [the lesson]....If there's something I think is a really, really core thing, either I feel like I need to explain it very clearly, or... this is something I want them to spend a while working on themselves, and then we'll come back and talk about it.

That is, for core ideas that he wanted students to practice, Ian would use think-pair-shares and for more subtle core ideas, Ian would lecture to ensure it was explained carefully, and for most other ideas, he would take a middle ground approach to ensure some level of engagement.

Each phase of think-pair-share enacted Ian's ROGs in different ways. In the Think phase, I observed Ian give students space to work individually, often just observing students instead of interacting with them. In the Pair phase, he circulated to check that students were engaged, caring less about correctness and more that they were talking through ideas. He sometimes redirected questions back to peers or prompted disengaged students: “Have you guys all compared an answer? Do we agree?” For him, this phase primarily fostered accountability: “If I'm not going to ask them to talk with each other, then... a lot [will] say, okay, this is my two-minute break from class.” However, he did acknowledge by talking they might also “reach some shared things or maybe hit upon a point that one of them didn't realize.” In this way, Ian viewed collaboration very similarly to Hasan. Finally, in the Share phase, Ian brought the class together, often soliciting a student to offer an idea or solution and then elaborating on it himself – balancing his desire for students to engage with attention to their comfort levels, as students might “have an answer that [they] could share, but maybe [they] don't always feel comfortable sharing.”

Overall, Ian integrated active learning into his lectures in a way that reflected his ROGs. Lecture provided structure and clarity for students, while think-pair-shares created space for students to wrestle with ideas with peer and instructor support. He worried that if students only confronted difficulty in homework, they would make little progress. Active learning, then, became a way to ensure they engaged with the “hard stuff” – typically content he had noted they struggled with – while support was readily available. As Ian summarized: “My general philosophy on why I do any sort of active learning at all is just simply I want them to do more of the stuff that is hard for them when I’m right there to provide support.”

The Case of Shaun: Pausing at Specific Moments

Because Shaun withdrew from the study partway through, my data on his instruction are more limited, but they still suggest how his ROGs shaped how he interspersed activities into his lectures. Unlike other participants, Shaun was not teaching a proof-based course but a 500-level ordinary differential equations class. His goal was for students to develop fluency with abstract linear algebra methods for solving high-dimensional differential equations. Like Joel, he framed this as applying concepts to solve problems and developing comfort with abstraction: “they should...develop comfort with, and facility with working with that abstraction, casting problems in more abstract forms, leveraging various theorems that at first blush may not be immediately useful.” To this end, Shaun was oriented toward in-class engagement so that students – who he observed rarely engaged critically with mathematics outside of class – would have opportunities in class to “spend time with their confusion [and] address their own issues.” In this way, he also valued productive struggle as part of the learning process. However, like Noah, he paired this with an emphasis on providing constructive feedback that helped students diagnose what they know, describing this as “shining a light” to help them target their efforts.

To enact these orientations, Shaun structured his lectures with moments for students to problem-solve. He would work through a problem at the board, pausing at what he called “low hanging fruit moments or critical moments,” and then prompting students to attempt a step themselves: “‘...you do this’ or ‘see if you can go further from here.’” He believed students were more receptive to this than to group work, which he found many had resisted in the past. He likened this to setting up a “zipper” that students just needed to pull, giving them enough structure to move forward while still requiring some effort.

My observation of Shaun’s class illustrated this approach. His class had about 14 students seated at movable desks, where they took notes and worked on problems individually. There was a large whiteboard at the front of the room where Shaun lectured and a large blackboard on an adjacent wall. He described his plan as “a long, slow walk through one central computation,” anticipating that students would need repeated nudges to make progress. His pacing decisions were tightly linked to monitoring students’ engagement and affective states. After an extended setup of the computation, he paused to let students attempt a step, then returned to the board when many seemed stuck, explaining that this was both the most efficient way to move the class forward and less intimidating than approaching individual students directly. This rationale revealed his concern for both efficiency and students’ social-emotional needs, working to ensure students did not feel overwhelmed. Although Shaun reported not assigning formal groups, I observed him encourage an isolated student to join a nearby pair of students. He framed this as an in-the-moment decision to ease the isolated students’ frustration: “if nothing else, the lecture will be more memorable because they’ll have an experience that wasn’t just staring at their page.”

He also distinguished between “unproductive” mistakes that derailed progress and “strange but potentially productive” approaches, intervening only after watching long enough to

judge their trajectory. He characterized this stance as improvisational, doing “whatever I feel will help them move forward at the time.” At times, he shifted from light-touch nudges to more direct guidance when he worried a student was overly frustrated. For example, I observed him telling one student explicitly what to write. In the stimulated recall interview, Shaun told me he did it to “not make this worse than it is and we’ll just lay it out” having observed the student had “no recognition” of what was going on. Indeed, Shaun often adjusted his facilitation when he perceived students were frustrated, reflecting an orientation toward students’ affective needs.

Overall, Shaun’s use of active learning reflected his orientation toward both productive struggle and student’s social-emotional needs. Like Ian, he saw lecture as a way to provide structure and clarity, particularly to help students avoid feeling lost or frustrated, while short in-class tasks created opportunities to engage with challenging mathematics. Yet, whereas Ian relied on structured activities like think-pair-share to systematically support productive struggle, Shaun’s pacing, interventions, and occasional promotion of collaboration were more improvisational, guided by his awareness of students’ progress and their affective states. Hence, his approach to interspersing activities was guided primarily by his concern for students’ comfort with struggle, primarily lecturing to avoid difficulty from turning into discouragement.

The Case of Natalie: Two Different Uses of EBIPs

Natalie provided an interesting case because I observed her using variations of both the approaches described in the previous section on different occasions. At the beginning of the term, she described a structure similar to that used by Noah, Hasan, and Joel, explaining that she often drew on textbook exercises as in-class activities: “if there’s a section that I feel like the students can kind of have the tools to be able to work through themselves, I’ll be like, okay, we’re going to spend the first 20 or so minutes of class with you guys in group, and I want you guys to work yourself through section 1.5 or whatever.” In my first observation, she gave students a

worksheet at the end of class on material she had not yet lectured on but believed they could complete using prior knowledge. In my second observation, she took a different approach, using activities interspersed with lecture in a manner more similar to Ian and Shaun. In this section, I explore how and why Natalie used these two approaches.

Natalie's Resources, Orientations, and Goals

Natalie's main goal for her Mathematical Structures course was to help students learn to read and write proofs, as this was only their second course at University A's sequence that required formal proof-writing. As she put it, she wanted students to know "what does a good rigorous proof look like? What are some of the things that we should prove versus things we can just state? How do I rigorously justify everything?" Natalie believed this kind of learning happened through direct experience reading and writing proofs, where students developed an intuitive feel for the "language" of mathematics. "When you are writing proofs, I think that there's some stuff that can't really be taught – at least not specifically. It's kind of like learning to speak a different language." As discussed in Chapter 4, this belief motivated her use of active learning, since she saw learning as requiring active sense-making, with her own student experiences reinforcing this orientation.

In addition to developing students' proof skills, Natalie was oriented toward creating a safe and supportive classroom climate focused on addressing students' social-emotional needs. She wanted to counter what she called mathematics' "[public relations] problem." As she explained:

I don't think people hate math. They hate the way that someone made them feel about math. And it's really frustrating to be just told, 'oh, you're wrong.' And to feel like you don't understand why versus having a conversation about the thinking process.

Hence, Natalie strove to create a classroom in which students felt free to ask questions, be curious, and share ideas to help students have more positive mathematical experiences. She viewed the interactive nature of her class – which helped her develop better working relationships and foster a better classroom community among her students – as central to this.

Lastly, Natalie’s use of her colleague’s textbook was a major teaching resource. The textbook itself supported active engagement as it embedded exercises directly in the text, rather than placing them all at the end of chapters. Her colleagues had expressed a desire for the book to have “more interactive student content,” and Natalie saw this as an opportunity. She described planning to use those exercises in class whenever she felt students had the tools to engage with the content, reflecting her orientation toward building active engagement into the class.

Natalie’s Choice to Use a Worksheet to Cover a Chapter

Prior to my first observation of Natalie, she described being “incredibly behind on the material,” which motivated her to lecture: “So we’re finishing up [a] section...so that part is just lectures, because we got to get through it.” At the same time, this time pressure also motivated her to use a worksheet instead of lecturing on the next chapter. She explained that there were “a couple of sections that [she] was just going to not do fully by using a worksheet that focused on “just some of the highlights of the next section.” Natalie felt comfortable doing this because the material included properties of absolute value, divisibility, greatest common divisors, and least common multiple, which she believed her students should already be familiar with. She viewed doing the proofs on the worksheet as mostly “an interesting exercise” rather than as working through new content. Thus, condensing the chapter into a worksheet felt like a good way to catch up, drawing on textbook exercises to “just [hit] the highlights of each of these topics and [prove] one or two things about them... in lieu of spending a ton of time on this section.”

In class, I observed Natalie enact this plan. Her class had approximately 19 students and took place in a classroom with fixed tables in rows, like Hasan's classroom, with multiple large whiteboards at the front of the room. She lectured for the first 34 minutes to finish the prior section, then transitioned students into the worksheet activity. During her lecture, she used techniques often employed by lecture-based instructors to make lectures more engaging, such as frequent questioning. When asked about these choices, she explained that she wanted to avoid "just tell[ing] them things all the time," so she paused to let students think and "fill in the blanks." She was careful not to ask questions she thought students could not answer, since she saw in-class questioning as stressful: "if I ask them something they maybe could answer if they were given more time, they might feel bad," so instead she asked questions she knew they could "hit out of the park." This reflected her orientation toward students' affective needs. Also aligned with this orientation, I observed her explicitly assign ownership of mathematical ideas to students by name. Natalie described feeling empowered by this teaching move as a student: "when it happened to me... it kind of gave me a certain ownership over that idea ... And it made me feel proud that I'd had an insight that hadn't had to be spoonfed to me."

During the worksheet portion of class, students naturally formed groups and engaged in conversation. Natalie allowed groups to self-select, noting that students already knew each other from prior classes and that assigned groups had not worked well for her in the past. To promote participation, she collected work without grading it. While circulating, she made herself available to students who might otherwise be hesitant to approach her. In these interactions, she emphasized sense-making, letting students' own need for understanding drive the focus during the worksheet time. For instance, when asked about her decision to allow a student to not write a fully realized formal proof for the worksheet, she explained:

I'm not giving these worksheets as assessment necessarily. It's supposed to be an activity for them to engage in that helps with their understanding. So when a student is like, 'do you want a formal proof with this?' I'm like, I don't know. That's not really what I care about in this moment. Right? Yeah. It's always good to practice your formal proof writing techniques, but honestly, if you can read through a problem and explain it to yourself in a way that makes you understand it, that's more the thing [that I'm going for].

Overall, Natalie's implementation of her worksheet demonstrated her commitment to engaging students directly in mathematics and fostering a sense of ownership rather than passively exposing them to ideas, even when time constraints led her to lecture. Her lecture facilitation showed her concern for reducing student anxiety, and her interactions during group work emphasized sensemaking, aligned with her beliefs about learning.

In her end-of-term interview, Natalie reflected on the approach she took. She described it as a departure from her usual practice and appeared unsure of its effectiveness:

...[F]or the sake of time, and there was one day when you were there where there was a chapter that I was like, here's a worksheet to work through the main ideas of the chapter. So that's interesting because it then basically, I didn't talk about the chapter at all basically at all, and just had them work through the main ideas. And that's a little bit different than I usually do. Usually we teach some stuff and then they go and play with it, versus this time it was like they read, I wrote up some things and they'd read it instead of me talking about it and then they would do it. So I don't know, that was a little bit different. I have no, I don't really have a good concept of how successful that was, just because it was like the point of it was like I was playing catch up and I didn't put things on homework or whatever. But I think that they got it and they enjoyed it.

This suggests that using a worksheet in place of a lecture was somewhat at odds with Natalie's typical approach of introducing material before asking students to engage with it. She considered the activity appropriate in this case because the content was somewhat familiar to students, though she still avoided assigning it as homework. The worksheet nevertheless gave students an opportunity to practice justifying why properties are true, aligning with her broader goals of developing students' proof-writing. Still, Natalie expressed uncertainty about whether this structure would be effective more generally. Overall, Natalie's choices illustrate how she sought

to balance content pressures with her orientation toward active engagement focused on sense-making and proof-writing and her orientation toward students' affective needs.

Natalie's Choice to Intersperse Activities in a Lecture

Prior to my second observation of Natalie, she again described being limited by time and feeling pressure to cover more content than she thought could reasonably fit into the remainder of the term. As she stated in our pre-observation interview: “I woke up in anxiety in the middle of the night when I realized how little of the semester is left.” This anxiety was heightened by the importance of the upcoming topic – convergent sequences. She explained, “I need to spend a lot of time [on convergence sequences] because I know when I teach real analysis, I am assuming that they have a lot of background...” Here, Natalie connected her immediate content coverage goals to the longer-term responsibility of preparing students for future courses, which, as discussed in Chapter 5, intensified the pressure she felt. She planned to intersperse activities with lecture to engage students, though she anticipated collaboration might be limited as “sometimes it takes them a full 10 minutes to start talking to each other,” and her interspersed activities would not be that long.

In class, I observed Natalie using a format similar to Ian's think-pair-shares. She would introduce a definition or theorem, sketching or presenting a proof, and then pose a related statement for students to consider. For instance, after presenting a proof sketch about the limit of a particular type of sequence, she wrote a similar statement on the board (which was altered so it was false) and asked whether it still held and why. After posing a problem, she would instruct students to talk to their neighbor – though, as Natalie anticipated, most worked independently.

When asked about the timing of these activities, Natalie explained that she chose them based on what she thought would be engaging and aligned with her specific content goals, such as helping students work with convergence proofs. For example, regarding one activity, she

justified posing it to the class because “I’m trying to build this idea that... the thing that I want in the end is Epsilon, what ingredients do I need to get there?” At the same time, she saw these activities as supporting her broader proof-writing goals. For instance, regarding the false theorem statement activity, she explained that she wanted students to see the importance of not simply assuming a statement is true, but instead checking it and developing their own intuition. As she put it: “So anything where they can come up with an example of something, I think that that helps with their understanding.”

The timing of these activities also revealed additional orientations. In one instance, just as Natalie was setting up an activity, a student publicly offered a conjecture before Natalie had formally instructed the class to begin. Natalie responded, “So I’ll let you think about it. I’ll give you a few minutes,” and encouraged the class to work on the problem she had posed. Reflecting on this, Natalie described an orientation toward productive struggle, emphasizing the importance of giving students space to persist with uncertainty:

It’s good practice...because I also see my students will just give up on things right away if they don’t know how to do it....I think one of the best lessons that we can learn is if we don’t know how to do something right away, how can we still keep at it and persevere rather than just try to find the answer elsewhere immediately?

Although not the explicit reason she gave for using these activities, Natalie described productive struggle as an affordance they provided, one she intentionally fostered by not immediately providing answers.

After students worked, Natalie would bring the class together – sometimes asking them to share solutions and other times working through the solution herself while soliciting student feedback. When she did ask for student input, she prioritized their examples over the ones in her lecture notes. For example, she used a student-provided counterexample for the false theorem statement on convergence sequences rather than one she told me she had planned.

Her interactions with students in this observation were similar to those in my first, but her content goals played a stronger role. Whereas the worksheet activity centered on familiar ideas, this lesson focused more directly on advancing proof techniques she expected students to master, such as fluency with convergence proofs. To this end, she checked in with individual students she worried might not have a solid grasp of the concepts, engaging in extended one-on-one conversations around these key takeaways.

When she ran out of time for a planned activity on supremum and infimum, Natalie shifted to an interactive lecture. She still tried to maintain participation by posing questions:

...There can only be one thing that's going to be the least or the greatest, right? So that's a theorem... I was going to have you do this, but we're running low on time. So what do you suppose the argument would be? Let's suppose we had two different suprema...

She continued to walk the class through the reasoning with intermittent prompts. In our stimulated recall interview afterward, she reflected on this instructional choice:

I was a little bit short on time, and I was like, I would give you time to work on this on your own, but we don't really necessarily have the time, so let's just have a discussion about it as a group... If there's something I feel they can add to and contribute to, and we can have a participatory discussion rather than just me preaching and telling them this thing is true, then I try to do that. This is an example of something they can figure out on their own—like, 'if I have a max, it must be the supremum'—and I want them to notice that rather than me just stating it...

This episode illustrates how Natalie actively negotiated between competing instructional priorities. Even when she compressed an activity, she preserved her commitment to student engagement by framing it as a participatory discussion.

What Led to Natalie's Two Approaches

Across these two approaches, Natalie's approaches illustrate a tension she navigated: she believed students learn best by doing mathematics, but time and content pressures often led her to provide direct instruction. However, rather than abandoning in-class engagement, she

modified her strategies in ways that reflected her ROGs. In both observations, she created opportunities for students to engage during lecture portions through carefully chosen questions that students could confidently answer, avoiding the stress of unanswerable questions while still creating opportunities for active engagement. At the same time, content coverage shaped her decisions differently across the two observations. In the first, she used a worksheet to cover familiar material, saving class time while still providing opportunities for students to practice proof-based reasoning. In the second, her strong need to prepare students for real analysis led her to lecture more extensively while strategically inserting activities to advance her content goals and, when pressed for time, she adapted by shifting to interactive lecture. Yet, in both cases, Natalie's approach was still guided by her desire for students to engage with ideas on their own and develop a sense of ownership over their thinking over passive listening.

How Reasons for Use and Challenges Manifest in Practice: Cross-Case Synthesis

Across these six cases, I observed that mathematicians taught in ways that aligned closely with their ROGs. Two broad approaches were prevalent: lecture followed by small-group problem solving, and lecture interspersed with activities, with Natalie using elements of both. At this structural level, participants' approaches were fairly similar. Lecture was commonly motivated by the need to cover content, prepare students, or address student resistance to active learning. Goals about covering content, combined with orientations toward collaboration, seemed to motivate lecturing prior to small group work (as with Joel, Hasan, and Noah), while concerns about student resistance or affective needs primarily motivated interspersing activities into lecture (as with Ian, Shaun, and Natalie). Time constraints also led Natalie to adopt either approach depending on the content she was teaching.

However, examining each participant through their ROGs revealed how these shared structures took on different meanings. This analysis highlights how participants' overarching

motivations were enacted in practice alongside the challenges they faced in ways specific to each instructor. Participants' ROGs reveal how the core motivation to bring learning into the classroom (see Chapter 4) was enacted by giving meaning to how participants defined "learning" through their orientations and goals. For example, Noah used group work to surface proof thinking so he could provide feedback on correctness – something he viewed as integral to learning – while Joel used the same structure to model the collaboration he hoped students would carry beyond the classroom. Table 6.1 details how participants viewed learning in terms of their ROGS, summarizing how the motivational category Ensuring Learning Happens in the Classroom was enacted differently depending on their ROGs.

Table 6.1: How Participants' ROGs Shaped What Ensuring Learning Meant.

Participant	Resources	Orientations	Goals	What “Learning” Meant in Practice
Joel	Experiences as a student Experiences as a teacher	Active engagement Students' social-emotional needs Collaboration	Applying concepts	Learning required collaboration outside of class; group work modeled the practices he wanted students to develop. Informed by his own success as a student and by observing that students do not do this on their own.
Hasan	Experiences as a teacher	Active engagement Students' social-emotional needs Collaboration Feedback	Reading and writing proofs	Learning required active engagement in a supportive environment with opportunities for feedback; group work fostered this. Informed by his own learning via active engagement and by noticing that students tend to avoid it.

Table 6.1: How Participants' ROGs Shaped What Ensuring Learning Meant, Continued.

Participant	Resources	Orientations	Goals	What “Learning” Meant in Practice
Ian	Experiences as a student Experiences as a teacher Student feedback	Productive struggle Students' social-emotional needs	Reading and writing proofs Developing conceptual understandings	Learning required active engagement and becoming comfortable with failure; think-pair-share provided structured practice. Informed by his experiences with productive struggle and his observations that students resist it.
Natalie	Experiences as a student Experiences as a teacher	Active engagement Students' social-emotional needs	Reading and writing proofs Developing conceptual understandings	Learning required active engagement without overwhelming students; EBIPs supported this balance. Informed by her own experiences feeling both empowered and overwhelmed as a learner and by noticing similar patterns among her students.
Noah	Experiences as a student Experiences as a teacher Student feedback	Self-evaluation Collaboration Feedback	Reading and writing proofs	Learning required evaluating the correctness of one's work; group work created opportunities for peer dialogue and feedback. Informed by the importance of self-evaluation in his own learning and by observing that students often lack this skill.
Shaun	Experiences as a teacher Student feedback	Self-evaluation Productive struggle Students' social-emotional needs	Applying concepts Developing conceptual understandings	Learning required productive struggle and self-evaluation without discouragement; short problem steps maintained engagement. Informed by his teaching experience seeing students improve through active effort but struggle with frustration and resistance.

The ROGs analysis also highlights how the rationale categories from Chapter 4 were enacted in participants' day-to-day teaching. For example, Joel avoided dismissive language like "trivial" or "obvious" and redirected attention to student ideas to promote social support that could extend beyond class, while Hasan carefully composed groups so students felt supported to participate, and Natalie assigned ownership of ideas and made herself available to students to provide support. Each of these demonstrate how they implemented the category of *Creating Supportive Conditions for Engagement*.

Likewise, *Seeing and Responding to Student Thinking* was enacted differently across participants. For example, Noah and Hasan monitored group work for opportunities to intervene, correcting incorrect ideas or nudging students toward productive paths, while Shaun primarily used information from student engagement to adjust pacing, seeking to mitigate frustration when students seemed stuck. Additionally, Hasan used standards-based grading information to design a worksheet for group work to elicit a prevalent sticking point about proof-writing. These cases show how ROGs gave concrete shape to the affordances of EBIPs by revealing what participants noticed and how they acted on it.

At the same time, the constraints discussed in Chapter 5 shaped not only which EBIPs were used (e.g., via start-up burdens) but how they were enacted alongside participants' ROGs. That is, while orientations and goals often framed why participants used EBIPs in particular ways, resources and local context shaped how they were realized in practice. Affordances such as whiteboards or worksheets, as well as instructors' own experiences, mediated participants' implementation of EBIPs. For example, student feedback influenced both Shaun and Ian's choice to use interspersed activities, while their content goals guided the timing of those activities. Time constraints led Natalie to alternate between different approaches depending on her content goals,

and – while logistical barriers prevented Noah and Hasan from flipping their classrooms – they utilized worksheets as an alternative resource. In each case, the available resources – whether time, technology, or materials – shaped how participants could enact their orientations and goals undergirding their use of EBIPs. These examples underscore that implementation involved balancing participants' ROGs with the practical realities of teaching. The reasons for using EBIPs described in Chapter 4 were continually negotiated with the constraints described in Chapter 5, directly shaping how these practices played out in the classroom.

Figure 6.1 synthesizes these findings, showing how the three major reasons for using EBIPs identified in Chapter 4 – *Ensuring Learning Happens in the Classroom*, *Creating Supportive Conditions for Engagement*, and *Seeing and Responding to Student Thinking* – took on participant-specific meaning in practice. While Chapter 4 established these as broad categories, participants' ROGs gave them concrete meaning in context, shaping their implementation of EBIPs in tandem with the constraints from Chapter 5. The figure thus elaborates the 'implementation of EBIPs' phase of my conceptual framework (see Chapter 2).

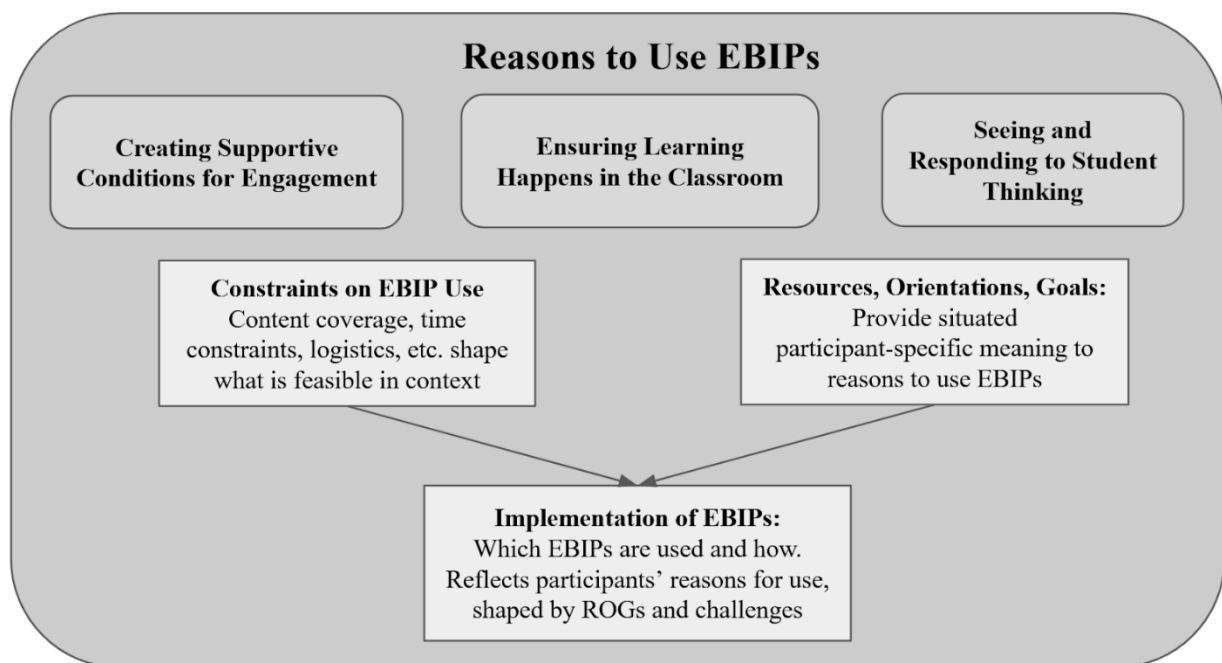


Figure 6.1: Relationship between Participants' Reasons for Using EBIPs, the Challenges They Face, and Their Implementation of EBIPs. Participants' reasons for using EBIPs manifest in situated participant-specific ways, as seen through their ROGs, which shapes their use of EBIPs, which is also shaped by challenges they encounter during real-life use, resulting in the varied EBIP use seen among participants.

Overall, this analysis shows that while participants gravitated toward similar structural approaches to using EBIPs at a broad level – shaped by shared reasons for using EBIPs and their experiences navigating similar challenges – their enactments of EBIPs and the ways they saw EBIPs as supporting their orientations and goals were distinctive. Orientations and goals gave meaning to what it meant to 'ensure learning' in their classrooms and revealed how participants enacted the affordances of EBIPs identified in Chapter 4. Constraints, in turn, shaped how their reasons for using EBIPs were carried out in practice with the resources participants had at hand in their local contexts.

Chapter 7 DISCUSSION AND CONCLUSION

The aim of this study was to understand how and why mathematicians use evidence-based instructional practices (EBIPs) in advanced collegiate mathematics (ACM) from their perspective. I was motivated to pursue this work because, despite decades of research advocating for student-centered approaches, lecture remains the dominant mode of instruction in collegiate mathematics (e.g., Johnson et al., 2018; Stains et al., 2018). This disconnect between research and practice raises important questions about how mathematicians themselves perceive and use EBIPs – questions that have received limited attention in the literature. I was also motivated by my own identity as a mathematician, mathematics education researcher, and mathematics educator. I have both studied and used EBIPs and want to improve their uptake in the field, yet I am also keenly aware of the tensions surrounding them and the persistent preference for traditional teaching methods in mathematics. Hence, I wanted to better understand EBIPs from a mathematician’s perspective because mathematicians play a key cultural role in defining what it means to do and teach mathematics, and their uptake of EBIPs has the potential to impact collegiate mathematics instruction at large.

To this end, I investigated why mathematicians use EBIPs, what supports their continued use of EBIPs, and how their reasons for using EBIPs inform what implementation looks like in practice. In this final chapter, I begin by reviewing my findings and synthesizing across the results to provide a more holistic view of mathematicians’ reasons for and experiences using EBIPs in their ACM instruction. I then discuss the implications and limitations of this study before concluding with its contributions and directions for future research.

Summary of Findings

In this section, I provide a summary of the key findings from each of my three research questions to address why mathematics use EBIPs, how and why they persist in using them, and what their use of EBIPs looks like in practice and why.

Research Question 1: Why Do Mathematicians Use EBIPs?

Mathematicians' reasons for using EBIPs centered on one core motivation and two ongoing rationales. The core motivation was the desire to ensure that meaningful learning occurred during class time, grounded in the belief that students learn mathematics by doing mathematics. Participants described becoming motivated to use EBIPs when they observed that students were not engaging productively outside of class, leading them to conclude that learning opportunities needed to happen during instruction. The ongoing rationales for continuing to use EBIPs involved (a) creating supportive conditions for engagement and (b) improving instruction through access to student thinking. Participants emphasized that EBIPs fostered classroom climates where students felt comfortable participating, supported one another, and viewed mistakes as part of learning. Experienced faculty also valued EBIPs for making students' reasoning visible, which allowed them to provide feedback, identify misconceptions, and adjust pacing or emphasis during class. Prior exposure to EBIPs and departmental or collegial support made these practices feel viable, though such experiences were typically enabling rather than motivating factors. In sum, instructors' decisions to adopt EBIPs were rooted in a desire to ensure learning in class and supported by experiences and contexts that made such approaches feel feasible.

Research Question 2: How and Why Do Mathematicians Persist in Using EBIPs?

Participants faced common challenges when using EBIPs – especially pressures to cover content, logistical demands, and student resistance – but persisted by adapting their practices.

Content coverage pressures were most frequently cited. Many participants felt responsible for exposing students to foundational material, particularly in proof-based courses, and believed that students required initial exposure before meaningful engagement. Logistical barriers such as preparation time and implementation complexity further constrained how fully they could employ EBIPs. In response, participants modified their approaches rather than abandoning them. Adaptations included refining or simplifying activities, alternating between lecture and group work, and integrating EBIPs when they felt most feasible (e.g., after lecturing on a central topic). Persistence was supported by several mechanisms: reframing challenges as part of the learning process, drawing motivation from positive feedback or experiences, and leveraging departmental or collegial support. Across cases, persistence reflected flexibility and problem-solving rather than strict adherence to any prescribed method.

Research Question 3: What Does Mathematicians' Use of EBIPs Look Like and Why?

Across cases, participants' instruction took two broad forms: (a) lecture followed by structured group work or (b) lecture interspersed with short activities. Despite these shared structures, implementation varied considerably based on instructors' orientations, goals, and resources. Those who used lecture followed by group work viewed lecture as necessary for initial exposure and group work as the space for deeper engagement, but their goals for that engagement differed, ranging from encouraging collaboration to providing feedback or supporting proof-writing. Those who interspersed activities during lecture sought to balance active engagement with student comfort, often using short think-pair-share prompts to scaffold productive struggle. One participant alternated between these approaches depending on time and topic familiarity, illustrating how constraints shaped instructional decisions. Mathematicians' use of EBIPs reflected shared motivations but individualized implementations. Each instructor's

orientations and goals gave distinct meaning for how their reasons for using EBIPs translated into practice, which were further shaped by their available resources and constraints.

Implications

In this section, I discuss the implications of these findings. These implications stem from results that highlight how orientations influence EBIP uptake and shape their use, how adaptation supports persistence, the role of assessment in using active learning, and how departmental and collegial contexts can sustain the use of EBIPs over time.

Beliefs About Learning as a Starting Point for Change

This study indicates that direct dissatisfaction with lecture frequently served as a catalyst for mathematicians to adopt EBIPs. Although participants consistently believed that mathematics is best learned through active engagement, their shift toward EBIP use was typically prompted by recognizing lecture's inability to engage students, especially after observing students' lack of engagement outside of class. This dissatisfaction adds nuance to portrayals of mathematicians as assuming that learning occurs after lecture through independent work outside of class (Sfard, 2014). While participants often echoed this belief, describing homework as the site of "real" learning, they also recognized that students were not engaging with homework in this way and adapted their instruction accordingly. The participants in this study were primarily motivated to use EBIPs by observations of how students engaged with mathematics and each other, often comparing this to their own experiences as students and acknowledging the differences.

Prior research has shown that mathematics faculty value student behaviors such as exploration and mistake-making (Vishnubhotla et al., 2022) and those who primarily lecture often believe lecture is not the best way to teach (Johnson et al., 2018). This study adds to such work by demonstrating that beliefs consistent with EBIP use (e.g., valuing learning by doing) are not always sufficient to prompt their adoption; instead, this motivation often depends on a clear

recognition of lecture's limitations in achieving instructors' own orientations and goals. Because many mathematicians can readily see lecture as aligned with their instructional orientations and goals for teaching ACM (e.g., Woods & Weber, 2020), understanding what aspects of lecture they find unsatisfactory enough to change their teaching offers important insight into what can facilitate the adoption of EBIPs.

These findings suggest that encouraging EBIP adoption may depend less on promoting their effectiveness and more on helping mathematicians notice when their current methods fall short of their own goals and values. Professional development and departmental discussions could focus on reflecting on how lecture aligns with or constrains their desired forms of student engagement and learning. This may be especially salient in the modern age, in which students engage with higher education differently than faculty likely did as students themselves, shaped by increases in extracurricular commitments (Irwin et al., 2023) and technologies like generative-artificial intelligence (Digital Education Council, 2024; Ketsman et al., 2026). Framing EBIPs as tools that enable learning to happen in the classroom, where reasoning and collaboration can be actively supported and modeled for students to carry into their independent work outside of class, may better resonate with mathematicians who already value learning by doing.

Additionally, a second belief about learning shaped which EBIPs participants adopted. What participants often described as “content pressure” appeared less tied to departmental mandates and more rooted in their own views about when learning can productively occur. While all participants endorsed “learning by doing,” many situated that “doing” after initial content exposure, viewing EBIPs as useful only once students had something to work with. They expressed concern that students could not productively struggle with material they had not yet

had explained to them. Hence, lecture was viewed as something that must happen prior to using EBIPs in their ACM instruction. This mirrors findings by Vishnubhotla et al. (2022), in which some self-reported IBL users' teaching practices, namely lecture, resembled non-IBL users, which was associated with their belief that students best grapple ideas on their own after direct instruction. Similarly, Johnson et al. (2019) found that non-EBIP users often believed they should directly explain material to students before letting them engage with it themselves.

While such beliefs about prior content exposure (e.g., explaining content directly, doing examples) can diverge from more inquiry-oriented approaches, they are not inherently incompatible with active learning itself and, importantly, do not reflect a resistance to active learning; rather, they shape instructors' sense of what feels pedagogically responsible. For example, the sense of content pressure was intensified by worries that insufficient coverage would leave students underprepared for future courses. Notably, these concerns did not reflect departmental expectations – multiple participants stated that they could likely teach whatever they wanted; rather, they reflected an obligation to ensure students' readiness for subsequent ACM courses. Thus, the barrier of content coverage pressure may be less a structural constraint than a manifestation of beliefs about how learning occurs and what responsible teaching entails. Together, these findings illustrate that mathematicians' reasons for using EBIPs may be primarily influenced by how different teaching methods align with their orientations.

Understanding mathematicians' perspectives this way has implications for institutional change efforts that seek to improve the uptake of EBIPs in ACM. The participants in this study already used EBIPs in their instruction, and this study highlighted their reasons for doing so, which can inform how EBIPs are framed to those who do not currently use them. For instance, change efforts may be more effective in helping mathematics faculty see how EBIPs can address

their goals for content coverage, student preparation, and promoting learning by doing if they begin by engaging with instructors' existing beliefs. While participants believed it necessary to explain material before having students do mathematics themselves – a position that may differ from some strands of mathematics education research, such as inquiry-oriented instruction – this belief does not preclude their use of EBIPs, as my study has demonstrated.

Understanding which EBIPs mathematicians find helpful can facilitate dialogue about how EBIPs can support student learning more effectively among those who might not yet use them. Instructional conversations might be more productive if framed around how active learning strategies can serve instructors' current needs. For example, mathematics education researchers might highlight strategies that preserve the sequencing of first lecturing on content to expose students to ideas while still deepening student learning through active engagement. Such strategies might include the two approaches that participants in this study favored (i.e., interspersed activities and lecture followed by small-group problem solving), as well as flipped classroom models that some participants reported using. Flipped models may be particularly appealing to instructors concerned about content exposure, as they explicitly preserve initial exposure (through pre-class videos or readings) while dedicating class time to active engagement. However, these models present high start-up costs associated with developing or curating materials such as readings or videos, while also requiring instructors to learn how to facilitate active learning during class. Indeed, some participants cited these barriers as reasons for not flipping their classes. In contrast, "minimally invasive" strategies like interspersed activities (Alcock, 2010; Rasmussen & Johnson, 2019; Weber & Dawkins, 2018) offer a lower-barrier entry point that may better support initial adoption and persistence. If mathematicians can see how to sustainably integrate EBIPs in ways that honor their beliefs while better promoting

student learning by doing, they may be more willing to adopt EBIPs in their instruction.

Adaptations in EBIP Use and EBIP Integrity

The prior findings about content-coverage pressure illustrate how challenges can reveal underlying orientations toward teaching and learning. More broadly, this study suggests that mathematicians' beliefs about the purpose of EBIPs are most visible in how they adapt these practices to fit their contexts. While some of these adaptations were framed as trade-offs or compromises by participants, they may also have been productive adaptations in that they allowed participants to persist in using these practices. In many cases, these adaptations reflected a thoughtful balancing of priorities that enabled instructors to persist with EBIPs over time despite struggling with student resistance, logistical constraints, or concerns about content coverage. This echoes broader critiques of fidelity-oriented models of implementation, which emphasize adherence to prescribed strategies, often at the expense of context, viewing EBIPs as one size fits all. Scholars such as LeMahieu (2011) advocate for shifting from a model of fidelity to one of integrity; that is, supporting instructors to adapt practices in ways that preserve their purpose while responding to local needs and goals.

Indeed, this study contributes to improving and advocating for integrity in EBIP use by providing insight into how mathematicians conceptualize the purpose of EBIPs. While all six participants' use of EBIPs broadly looked similar, falling into one of two approaches (lecture followed by small group problem solving and interspersing activities into lecture), their individual implementation of these practices reflected their unique resources, orientations, and goals as instructors, as well as the specific challenges they encountered in practice. This finding highlights the diverse array of reasons mathematicians utilize EBIPs and the affordances they believe these practices offer. For example, participants used similar strategies for different purposes: some used lecture to cover content or prepare students, while others gravitated toward

lecture primarily to address student resistance or affective needs. Additionally, the case studies of each instructor provided in this study reveal how the shared motivation to ensure learning in class was enacted differently. For instance, Noah viewed feedback on correctness as vital for learning mathematics, and so used group work to facilitate providing feedback, whereas Joel used group work to model collaboration, as he viewed problem solving with others as central to what it meant to succeed in learning mathematics.

These different conceptions of how EBIPs promote learning, along with the other affordances participants identified (i.e., creating supportive conditions for engagement by cultivating a safe learning environment, and seeing and responding to student thinking to improve instruction) provide insight into the purpose of EBIPs from a mathematicians' perspective. Understanding mathematicians' purposes and goals for EBIP use can facilitate more productive dialogue between mathematicians and mathematics education researchers about how and why EBIPs should be used, moving beyond questions of whether specific strategies are implemented "correctly" to focus on whether or not they are effectively achieving a meaningful pedagogical purpose in practice.

Active Learning and Assessment

This study also indicates how important the role of assessment can be when using active learning. Multiple participants in this study viewed active learning (especially group work) as creating supportive conditions in which students felt safe and able to participate meaningfully and engage in productive struggle. Four of the six participants discussed the role of assessment in promoting productive struggle, often through providing additional opportunities to demonstrate growth, reducing anxiety, or promoting more productive learning behaviors by disincentivizing cheating. Participants' use of two alternative assessment practices (test corrections and standards-based grading) echoes broader movements that conceptualize how assessment fits into

active learning. This movement emphasizes the use of alternative assessments that promote the approaches to learning participants like those in this study and the broader mathematical community value (Katz, 2022; Sisneros-Thiry, 2024). Hence, this study emphasizes further how assessment practices fit into active learning and adds to knowledge of instructors' perceptions of how alternative assessments may help reap the full potential of the benefits that active learning provide by creating a safer learning environment that promotes learning – benefits which research indicates students may also perceive (e.g., Belomy et al., 2025).

In addition, the perceived affordance that EBIPs offer among more experienced instructors – namely, more opportunities to see and respond to student thinking – emphasizes how some instructors are learning to use active learning itself as a form of formative assessment. The instructors in this study found that group work in particular could elicit evidence of student understanding, which they used to adjust their instruction to better target specific learning needs. They also described how group work enabled them to provide feedback that promoted improvement toward learning goals (such as writing correct proofs) and to engage students as resources for one another's learning, such as providing this feedback to one another. Together, these affordances – eliciting evidence, providing feedback, and fostering peer support – reflect key strategies of formative assessment (Black & Wiliam, 2009). This suggests that professional development could emphasize the role of active learning as a type of formative assessment to help instructors monitor and support student learning in real time.

Collegial and Departmental Support as Enabling Adoption and Persistence

Across cases, collegial and departmental support also played a key role in both motivation and persistence. Colleagues often served as more trusted and influential sources than research literature. Hasan, for instance, described remaining skeptical of EBIPs until hearing a colleague from another institution share success stories, while Noah and Joel credited peer

support with helping them persist through difficulties. Prior research emphasizes the role of communication networks in spreading EBIPs (Andrews & Lemons, 2015; Lund & Stains, 2015; Salazar et al., 2010; Shadle et al., 2017). This study extends those findings by highlighting how informal collegial interactions – often outside formal departmental initiatives, or even interactions across institutions – can shape decisions about which teaching practices to adopt or avoid. These results suggest that professional networks, disciplinary workshops, and conference connections may be particularly effective in fostering EBIP uptake and persistence, especially where departmental cultures are less supportive.

Early experiences with EBIPs, whether as students or novice instructors, appeared to orient participants to view these practices as viable. While previous studies show that instructors' past experiences shape their teaching (Lortie, 1975; Oleson & Hora, 2014), my findings provide qualitative insight into how such experiences operate. They did not directly motivate adoption, but they made EBIPs seem legitimate and feasible. Similarly, positive experiences using EBIPs, such as receiving appreciative student comments or observing improved engagement, reinforced instructors' persistence. Because teaching experiences are highly salient in shaping practice (Oleson & Hora, 2014), ensuring that novice instructors encounter early, positive outcomes may be critical for long-term use. Supporting those early successes – through mentoring, feedback, and collegial encouragement – can help mathematicians experience EBIPs not as a risk but as a viable and rewarding form of teaching.

Lastly, participants' ability to reframe challenges as opportunities to learn rather than as failures contributed significantly to their persistence with EBIPs. Participants in this study often reported viewing difficulty and setbacks with EBIPs as a disappointing but expected part of teaching, choosing to reflect on how to improve and learn from challenges rather than viewing

them as signs to abandon a practice. Literature has suggested that faculty discontinue using EBIPs because they lack the time, support, or confidence to implement them properly, leading to modifications that may not produce desired student outcomes and ultimately creating dissatisfaction with EBIPs (Andrews & Lemons, 2015; Hayward et al., 2016). My findings extend literature (e.g., Andrews & Lemons, 2015) by suggesting that faculty who can anticipate failures and identify problems are more likely to persist in using EBIPs. Indeed, participants in this study focused on identifying problems and adapting their use of EBIPs in the face of dissatisfaction. For instance, Noah changed his group work structures midway through the semester I observed him. Given the role of colleagues in providing encouragement and support, and the fact that some participants explicitly cited the value of commiserating and normalizing struggle when talking about teaching with colleagues, this finding also suggests that community-based support may be a vital component of EBIP persistence. Such communities may help instructors maintain their sense of self-efficacy and provide problem-solving resources for addressing challenges that arise when using EBIPs, ultimately supporting the kind of productive adaptation and persistence observed in this study.

Limitations

This study has several important limitations. The sample of six mathematicians from three universities in the Western United States is small and geographically localized, reflecting the perspectives of participants within their specific contexts rather than a broad representation across all mathematicians. While I intentionally recruited across varied demographics (age, race, gender) and institutional contexts (two public, one private; different research emphases), the findings presented here ultimately reflect the perspectives of these six individuals.

My recruitment approach may also have shaped the range of perspectives represented in this study. Because I relied primarily on snowball sampling, participants may have shared similar

viewpoints or experiences with EBIPs due to their professional connections. Additionally, my intentional focus on mathematicians who viewed EBIPs favorably, while appropriate for my research questions, centers the perspectives of those engaged with EBIPs and does not capture the views of those who do not use EBIPs or who hold less favorable opinions of these practices. Moreover, participants' willingness to engage in extended interviews about teaching and to be observed may also indicate a level of reflection or enthusiasm for pedagogy that is not representative of all mathematicians, even among those who use EBIPs. Additionally, the representation of mathematicians teaching proof-based courses, particularly introduction-to-proof courses, means these findings are most applicable to that instructional context and may not fully reflect the perspectives or priorities of those who teach other courses, such as applied mathematics.

However, in-depth understanding of specific cases offers valuable theoretical and practical insights that can inform and extend existing research (e.g., Johnson et al., 2019; Woods & Weber, 2020). Hence, while these results are not intended to be broadly generalizable, they contribute meaningfully to understanding how and why mathematicians engage with EBIPs.

Lastly, as with all qualitative research, my interpretations were inevitably shaped by my positionality, particularly my own experiences with and beliefs about mathematics instruction. While I sought to mitigate this through reflexive memos, my positionality may have influenced both data collection and analysis.

Future Directions

I see new directions in which to continue this research. This study highlighted several reasons mathematicians use EBIPs, including goals related to shaping how students engage with mathematics. A natural next question, then, is how students experience and interpret these practices. For example, when students collaborate in class, do they view this collaboration as

productive mathematical work, and do they see it as something that should continue outside of class? Next, as proof-based courses were overrepresented in this study, this opens up two additional directions: first, one area of research could focus more specifically on the introduction-to-proof context, as these courses represent a major turning point in mathematics students' educational experiences. My dissertation revealed several goals mathematicians hold for supporting proof-writing and the distinct instructional strategies they developed for doing so, including the use of graphical approaches to proof-writing. Building on this work, I could examine the various strategies mathematicians use to support students' proof-writing in more depth, investigate the perceived role of EBIPs in facilitating this process, and study the impact of these instructional approaches on student learning outcomes. Second, I could expand this work to understand the different orientations and goals that influence those teaching other ACM courses, such as those in applied mathematics. For instance, do mathematicians using EBIPs in applied mathematics share the same motivations for using EBIPs as those teaching proof-based courses? What EBIPs do these mathematicians gravitate toward, and why? What orientations and goals specific to applied mathematics might influence their choice to use similar or different approaches to EBIPs than those teaching proof-based courses?

Additionally, this study provides a foundation for researching how best to support mathematicians in using EBIPs to improve advanced mathematics instruction in ways my dissertation suggests are valuable. For example, if a mathematician is open to incorporating active learning through interspersed activities, what types of activities best promote that mathematician's goals (e.g., developing proof-writing skills), and what kinds of support are needed for them to feel confident implementing those activities with integrity? How can mathematicians be supported in navigating the content trade-off? How might departments

cultivate mindsets that encourage reframing challenges as opportunities for growth, or foster connections among colleagues who can help one another navigate difficulties with EBIP use? These directions for future research are particularly valuable for informing efforts to directly support mathematics faculty and to transform the landscape of collegiate mathematics instruction by improving the uptake and sustainability of EBIPs.

Concluding Remarks

This study has extended previous research and contributed to the literature by providing a first-hand account of how multiple factors influence mathematicians' use of EBIPs in ACM instruction. It offers insight into why mathematicians are drawn to use EBIPs given their beliefs about learning and perceived needs arising from student behaviors, as well as how their instructional motivations guide them toward certain practices over others. It has also illuminated the varied ways mathematicians experience and interpret common barriers to EBIP use (e.g., content coverage pressures), how they navigate these challenges to persist in their use of EBIPs, and the forms of support that enable them to do so. By understanding not only what motivates mathematicians to adopt EBIPs but also what shapes and sustains their continued use, the field of mathematics education can develop more effective, discipline-specific support systems that enhance mathematics learning for all students. Through this work, I have sought to contribute meaningfully to that ongoing effort.

APPENDIX A: PRE-SCREENING INTERVIEW PROTOCOL

- **Background Information**
 - Can you briefly describe your academic and professional background?
 - What is your position at your current institution?
 - What is your typical teaching load?
 - What classes do you typically teach?
- **Use of Evidence-Based Instructional Practices (EBIPs)**
 - Can you describe your typical instructional approach? That is, what methods or strategies do you usually use?
 - What classes do you typically use these practices in?
 - How long have you been using these approaches?
 - What have been your experiences with these practices thus far?
 - Will you be teaching an upper-division math course in which you plan to use these practices or others in the upcoming Fall or Spring semester?
- **Colleague Recommendations**
 - Do you know any colleagues who are also using lecture alternatives or otherwise incorporating activities into their upper-division mathematics classes and might be interested in participating in my dissertation research?
- **Follow-Up**
 - What is the best contact information for me to reach out to you again in the future about my dissertation research?

APPENDIX B: BEGINNING OF TERM INTERVIEW PROTOCOL

Beginning of Term Interview Protocol (1 Hour)

Introduction (5 minutes)

- As a reminder, I am a PhD student in mathematics education studying why mathematicians use student-centered instructional practices in advanced mathematics classes. I use the term instructional practices as a catch-all for the way someone teaches and student-centered to describe ways of teaching that are more beneficial for students, like active learning or group work.
- This interview should take approximately 60 minutes of your time. Everything you share will be confidential, and any identifiable information will be anonymized in my dissertation, so please answer as candidly as you're comfortable doing. If any of the questions make you feel uncomfortable, please feel free to skip the question, and you have the right to stop the interview at any time.
- Do you have any questions, comments or concerns before we start the interview?
- Do I have your permission to start recording the interview?

B. Rationale for Using Instructional Practices (10 minutes)

1. Can you share what student-centered instructional practices you tend to use?
 - **Note:** Make note of what practices they describe to follow up on each one.
2. Can you share your rationale for using these instructional practices?
 - **Prompt:** How do you believe these practices benefit students?
 - **Prompt:** How do these practices reflect your approach to teaching or responsibilities as an educator?

C. Early Experiences Using Instructional Practices (10 minutes)

1. How did you first experience these types of instructional practices (as a student, teacher, workshop participant, etc.)? Can you share that experience?
2. What motivated you to first start using these practices in your own teaching?
 - **Note:** Motivations may arise in the prior question. Follow up accordingly.
3. What were some of the challenges you faced when you first started using these practices?
 - **Prompt:** How receptive were students? How supportive was your department or institution at the time?

D. Changes in Instructional Practices (5 minutes)

1. How have you changed the ways you use these practices since you first started using them and why?
 - **Note:** Looking for contextual and individual factors. Follow up on the other if one does not arise. Example: "You shared about [individual factors], were there any experiences with [contextual factors] you would like to share?"
 - **Prompt:** Are there any student-centered instructional practices you tried before but stopped using?
2. What would you say has supported or encouraged you to keep using the practices you still use up to today?

E. Goals and Instructional Practices for Advanced Mathematics Classes (20 minutes)

1. What are your main non-content goals for teaching Math [xx] this term?
 - **Prompt:** What skills or experiences do you want your students to gain beyond specific content knowledge?

2. How do these compare to your non-content goals in other advanced mathematics classes you teach?
3. Can you describe your planned instructional practices for Math [xx] this term?
4. How do you decide what instructional practices to use? For example, does your choice of instructional practice depend on the content of the class? Does it depend on if you've taught the course before?
5. How do you see the instructional practices you use as helping you achieve your goals?

F. Closing (5 minutes)

1. Is there anything else you would like to share about your experiences with EBIPs or your plans for teaching advanced mathematics classes this term?

APPENDIX C: PRE-OBSERVATION INTERVIEW PROTOCOL

Introduction

1. As a reminder, I am a PhD student in mathematics education studying how and why mathematicians use evidence-based instructional practices in advanced mathematics classes. This interview should take about 10 minutes. Your responses will be confidential, and any identifiable information will be anonymized. You can skip any questions or stop the interview at any time.
2. Do I have your permission to start recording the interview?

Interview Questions

1. Can you share what concepts you are teaching today?
2. Would you mind sharing what types of learning activities you have planned to teach those concepts?
 1. Can you elaborate on why you chose these specific activities?
 2. Can you say more about your plans to ensure every student has learned what you're teaching today?
3. Is there anything else you'd like to share?

APPENDIX D: STIMULATED RECALL INTERVIEW PROTOCOL

Stimulated Recall Protocol

I observed your class on [date] and recorded the lesson. During this interview, we will watch some video clips from your class together. Whenever you recall why you made an instructional decision or want to share something about what you did or said while teaching, please hit the pause button. You can share any thoughts or feelings you remember that you think are important or interesting.

I might pause the video myself a few times if I have a question, but I'm primarily interested in what you remember and think about your use of [instructional practice] in your class. So, whenever you remember anything significant about your teaching decisions, please feel free to pause and share.

This interview should take approximately 60 minutes of your time. Everything you share will be confidential, and any identifiable information will be anonymized in my dissertation, so please share as candidly as you're comfortable. If at any point you feel uncomfortable, please feel free to skip any part or question, and you have the right to stop the interview at any time. Do I have your permission to start recording the interview?

Interview Questions

- A. Before we dive into the clips today, I just wanted to ask, how do you feel the class went?
- B. [clips/questions]
 1. [Clip 1]...
- C. That was all the clips I had prepared. Were there any moments from class you remember and would like to watch?
- D. Is there anything else you'd like to discuss about this class session or your use of student-centered teaching?

Sample questions to ask at targeted instances (will be prepared per interview):

- Can you share what you were thinking here?
- What were you thinking when you decided to do this?
- What were your thoughts on doing this activity?
- What prompted you to [ask that question, use that activity, etc.]?
- Is this something you've done before?

Stimulated Recall Interview Guidelines for Interviewer

1. Participant will primarily control pausing the video
 1. Participant will share salient thoughts and feelings about their teaching decisions.
 2. Researcher may ask follow-up or probing questions
2. Researcher may pause the video at points they pre-selected and ask pre-prepared open-ended questions.
 1. Researcher may ask follow-up questions based on participant responses.
3. If more than 2 minutes go by without a comment from the participant, the researcher will pause the video and ask questions from the sample questions.
 1. Example: Can you tell me what you were thinking about here?

APPENDIX E: END OF TERM INTERVIEW PROTOCOL

End of Term Interview Protocol (1 hour)

Introduction (5 minutes)

- As a reminder, I am a PhD student in mathematics education studying how and why mathematicians use student-centered instructional practices in advanced mathematics classes; that is, classes typically taught after calculus sequences, like discrete mathematics and abstract algebra. I use the term instructional practices as a catch-all for the way someone teaches.
- I observed and chatted with you about your teaching this past term. This interview is going to focus on your experiences this term using student-centered instructional practices in Math [xx].
- This interview should take approximately 60 minutes of your time. Everything you share will be confidential, and any identifiable information will be anonymized in my dissertation, so please answer as candidly as you're comfortable doing. If any of the questions make you feel uncomfortable, please feel free to skip the question, and you have the right to stop the interview at any time if you wish.
- Do you have any questions, comments or concerns before we start the interview?
- Do I have your permission to start recording the interview?

Main Interview Questions (50 minutes)

A. Reflection on Student-Centered Practices (10 minutes)

- How do you feel using student-centered instructional practices in Math [xx] went this term?
 - **Prompt:** What challenges did you encounter using these instructional practices?
 - **Prompt:** What successes did you experience using these instructional practices?

B. Goals (10 minutes)

1. At the beginning of the term, you told me you hoped to achieve certain goals. [list]. How do you feel that went?
2. How do you think your instructional practices influenced how or whether you achieved your goals?
3. What else, if anything, do you think influenced how or whether you achieved these goals?

C. Impact on Instructional Practices (15 minutes)

1. How would you describe your use of student-centered instructional practices this term compared to previous years?
 - **Prompt:** Can you describe any changes to your teaching you made this term and why you made these changes?
 - **Prompt:** How did this term's experiences compare to your initial expectations? What shaped these alignments or differences?
 - **Prompt:** What unexpected factors emerged this term that influenced your teaching, and how did you respond?
2. Reflecting on our conversation, what would you say had the greatest impact on your instructional practices this term?

- **Prompt:** Can you give any examples of how this impact manifested in your teaching? Were there any particular moments or feedback that highlighted this impact for you?
 - **Note:** probe for what contextual factors (e.g., departmental policies, institutional culture) and individual factors (e.g., teaching philosophy, prior experiences) had this impact
3. Based on your experiences, what would you say is shaping your perspective on continuing to use student-centered instructional practices?
 - **Prompt:** Did any factors this term change your approach or perspective on student-centered instruction?

D. Future Considerations (15 minutes)

1. What do you think are the greatest benefits and greatest drawbacks to using active learning and other student-centered instructional practices in advanced mathematics classes?
2. What new instructional practices might you consider using in the future and why?
 - **Prompt:** Are there any challenges or obstacles you anticipate might arise if you tried these instructional practices?
 - **Prompt:** What support or resources would you need to implement these instructional practices?
3. What types of instructional practices would you not consider using and why?

E. Closing (5 minutes)

1. Is there anything else you would like to share about your experiences teaching Math [xx] or using student-centered instructional practices when teaching advanced mathematics classes?

APPENDIX F: FIRST CYCLE CODES

First Cycle Codes

Goals: Goals are what a participant wants to achieve. An outcome was coded as a goal when (a) a participant stated they wanted to achieve a specific outcome in a class/lesson or an important idea they wanted to convey to students or (b) when they evaluated an instructional practice positively or negatively due to its ability to help or hinder a specific outcome.

- **Fostering Mathematical Exploration:** Encouraging students to engage in creative or open-ended mathematical thinking, such as making conjectures or recognizing patterns. Includes: Goals related to discovery, creativity; activities that emphasize exploration over correctness Excludes: references to mathematical exploration as part of activities without inferring the skill or experience itself is a goal.
- **Teaching Mathematical Proof:** Teaching students to read, write, and evaluate proofs and including their associated heuristics and conventions. Includes: Emphasis on proof as a skill to be learned (e.g., proof templates, structure, correctness); references to understanding “what counts” as a valid proof; use of tools or representations to this end (e.g., graphical proofs). Excludes: Vague or general references to writing proofs without focus on structure or the mathematical practice; conceptual understandings of concepts involved in proof.
- **Helping Students Develop Conceptual Understandings:** Developing students’ intuitive feel for concepts and ideas. Focus on conceptual understanding and informal intuition. Includes: References to students gaining “intuition,” a “feel” for what’s correct, conceptual understandings, or valuing their use of informal or “handy-wavy” explanations.
- **Teaching Application of Concepts:** Having students use mathematical definitions, theorems, or ideas, especially in new contexts, to demonstrate understanding. Includes: References to applying or operationalizing abstract ideas (e.g., through examples or problem-solving); emphasis on knowing when and how to apply formal concepts
- **Preparing Students:** Preparing students for their future classes or careers.
- **Covering content:** Covering content includes references to progressing through mathematical topics, theorems, or concepts as an outcome of a class or lesson. Includes: Discussing a list or progression of ideas or concepts that they want students to learn as an outcome of a class session, course, or activity. Excludes: general discussion of relevant mathematical concepts

Orientations: orientations include beliefs, values, and preferences that undergird teaching, which were coded when stated or by inference when participants described features of classroom environments or instructional practices they believe are conducive/detrimental to learning, desirable/appropriate, or personally pleasant/unpleasant.

- **Social/Emotional Needs:** Valuing a classroom environment in which students feel safe, comfortable and included, particularly as it is conducive to the classroom climate necessary for students to do mathematics.
 - **Reduce Anxiety:** Valuing practices that make students less anxious, particularly assessment practices.
 - **Out of class disposition:** valuing how social/emotional needs extend outside of class. The participant expresses valuing how their classroom climate extends to shaping student behavior out of class, such as via office hours or study groups.

- **Beliefs about Learning:** classified as knowledge/belief as it gets at how and why EBIPs should be used.
 - **Learning Math by Doing Math:** The participant expresses a belief that mathematics is best learned through active problem-solving. They emphasize students doing math for themselves, rather than passively watching or listening. May involve constructing knowledge but usually focuses on practice and experience.
 - **Exposure to Material Before Engagement:** participant expresses a belief that students should be exposed to material before they engage with it. Explicit or inferred.
- **Student Collaboration:** Valuing peer interaction during class to support both mathematical understanding and social connection. Instructors value collaboration for both learning and social support (sometimes co-occurs with Social/Emotional Needs).
- **Student Engagement:** A preference for or belief in students' being actively engaged and doing mathematics in class as beneficial for learning or teaching, particularly a preference for mental presence and participation in doing and talking about math. Includes: references to wanting or preferring students to be active participants and engaged during class, or for students to be actively involved in doing mathematics. Excludes: vague references about students talking or working without implying the talking or doing math is what is beneficial to teaching or learning
 - **Productive Struggle:** A belief that students should engage in productive struggle to learn mathematics or a preference that students engage in productive struggle. Includes: wanting students to engage in struggle or discussing the value of struggling with mathematical ideas, particularly as part of the learning process or improving learning. Excludes: general references to students struggling with the class or a topic.
 - **Self-Evaluation:** A belief that students should engage in self-evaluation (e.g., reflecting on and regulating their own learning processes) to develop mathematical proficiency. Includes: references to wanting students to identify when their work or ideas are incorrect, when they don't know something, what they need to know, or preferring instructional approaches that help students do this. Excludes: references to correcting student work or misconceptions without inferring that this is to help them learn to self-evaluate.
 - **Fostering Mathematical Communication:** A preference that students to communicate mathematics in class, whether by explaining their reasoning, describing their thought process, or expressing mathematical ideas in plain or intuitive language as a mathematical practice.
- **Feedback/Adapt:** Participants expressed an appreciation for classroom environments in which student thinking is made accessible as it allows them to adapt instruction to meet student needs (e.g., provide timely feedback or slow down pace).
- **Mathematical Rigor/Correctness:** An instructional orientation that emphasizes the importance of mathematical rigor and correctness as disciplinary standards. Includes: Justifying teaching decisions based on incorrect or imprecise student math; valuing correction of errors or misconceptions; viewing EBIPs as tools that can support these disciplinary standards. Note: often drives feedback or interventions during problem-solving

- **Personal Fit:** References to their personal alignment with the EBIP. This includes references to not using an EBIP due to epistemological misalignment as well as finding an EBIP a poor fit for their personality.
- **Personal Enjoyment:** References to their personal enjoyment using an EBIP.
- **Supported by Research:** Preferring EBIPs that are proven conducive to student learning. References to an EBIP being supported by research or having actual merit/benefits for learning rather than just being innovative, novel, or trendy. A strong desire to use instructional practices that are actually beneficial.

Knowledge: any information a teacher can bring to bear in the moment. This includes understanding of how to use EBIPs and prior experiences.

- **Experiences:** The influence of prior experiences on motivation or persistence.
 - **Experiences as a student/learner:** experiences as a student that influence the use of EBIPs (positive/negative, memorable events, etc.)
 - **Personal Learning Experiences:** Prior experiences with learning that inform a participant's understanding of what is beneficial for learning. Typical examples include discussing what they found helpful as a student or what is personally beneficial for them for learning.
 - **Experiences as a teacher:** experiences as a teacher that influence the use of EBIPs (inspiring, initial exposure, memorable use, etc.)
 - **Observations of Student Behavior:** Observed behaviors for how students engage with and thus benefit from past instructional approaches they used that inform the adoption of their approaches. May be informed by personal learning experiences.
 - **Exposure to EBIPs:** Early teaching experiences (often as a GTA, postdoc, or early-career instructor) that introduced the participant to EBIPs and influenced their buy-in. May involve observing, receiving training, or beginning to use EBIPs
 - **Student Reception and Feedback:** discusses how students' reception or feedback (e.g., student preferences, reactions, comments, evaluations, resistance) to their teaching contributes to their motivation or facilitates their use of EBIPs
- **How to use EBIPs:** references to knowing how an EBIP is used, particularly difficulties knowing how an EBIP is used or learning how to use it properly.

Contextual factors/resources: external, institutional, and departmental influences

- **Institutional Factors:** these are contextual factors related to their institution that the participants described as influential in their use of EBIPs. These factors affect motivation mainly by increasing/decreasing an instructional practice's utility and perceived cost.
 - **Talking with colleagues:** participant discusses how colleagues or peers facilitates their use of EBIPs by sharing ideas, experiences, and materials. Includes references to commiserating over shared experiences.
 - **Departmental Culture**
 - **Departmental support/incentive:** participant discusses how their department facilitates their use of EBIPs, such as through providing support, feedback, or active incentives.

- **Permissive environment:** participant discusses how a generally supportive or neutral environment facilitates their use of EBIPs by not imposing barriers.
 - **Policies/culture that constrain implementation:** participant discusses how the department constrains their use of EBIPs, negatively impacting motivation.
- **Course Specific Factors:** disciplinary contextual factors that influence mathematicians use of EBIPs via considerations of the mathematics involved in a course
 - **Course Content:** A disciplinary contextual factor reflecting that certain mathematical content better suits particular teaching approaches, including the design or selection of course materials and the fit of EBIPs like active learning. Coded when a participant discusses how and why they select or design specific materials or teaching approaches based on course content considerations.
 - **Course Level:** References to how the course level (lower-division, upper-division, graduate) or position in curriculum (e.g., intro to proof as a transitional course) influences instructional decisions, such as viewing intro to proof students as needing more structure
- **Student Backgrounds:** More diverse student backgrounds (e.g., non-traditional, varied prerequisites, etc.) influencing their use of or perception of an instructional practices' utility, such as lecture not serving student needs or group work helping classes with a wide range of ability levels.
- **Time in Class:** References to how classroom time constraints or availability influences the use of EBIPs, reflecting perceived trade-offs between content coverage and instructional methods. Includes: explicit mentions of how time availability/limitations in class affects EBIP use; references to time-based trade-offs between covering content and using EBIPs or that EBIPs cover less material by slowing down instruction. Excludes general references to covering material without mentioning time constraints; comments about preparation time outside class (covered under "time/effort").
- **Time/Effort:** references to how time consuming or logistically difficult an EBIP is to prepare or implement. Constraints on time, energy, or resources. Includes: references to how much time an EBIP takes to prepare or learn to implement as influencing the motive to use them, including logistical considerations, time outside of class, or other resource considerations. May overlap with knowledge about EBIP use.
 - **Start-up prep/burden:** Barriers related to the initial time, effort, or planning required to implement an EBIP (especially for new courses or practices). Includes building materials, creating assessments, or structuring activities from scratch. Focus is on work outside of class.
 - **Logistical complexity:** Challenges arising from coordinating or managing an EBIP during implementation (e.g., timing, group dynamics, classroom layout, or activity pacing). Applies when logistical challenges contribute to hesitation, reduced extent of use, or complete non-use of EBIPs. Includes "messiness" of execution and overwhelm from EBIPs' demands on time and effort.
- **Classroom factors:** participants discuss the role of a classroom specific resource in their teaching, such as how a room without whiteboards or class size influences their use of active learning or the central role of a physical resource (chalk, whiteboard) in their facilitation of active learning.

- **Materials:** references to needing materials involved in using an EBIP, such as designing materials or finding materials, including materials such as worksheets, manipulatives, and textbooks.

Inductive Codes - responses to degree of satisfaction

- **Modify Practice:** a participant discusses the modifications they made to an EBIP, including implementation changes or swapping one EBIP for another, to better suit their needs or otherwise improve their satisfaction.
- **Quit Using EBIP:** A participant discusses why they ceased to use an EBIP altogether or in a certain context (e.g., a specific course or course size/level, quit temporarily, etc.)
- **Considering changes:** an instructor discusses changes they plan to make to their teaching in the future, such as quitting or modifying their use of EBIPs. Reflective.
- **Managing Expectations:** a participant discusses how they manage their expectations for how successful an EBIP will be, anticipating or normalizing failures as part of the process.

APPENDIX G: SECOND CYCLE CODES

Second Cycle Codes

Axial Codes

Early Exposure to EBIPs: Participants discussed early exposure to EBIPs through experiences as a student or novice instructor, which often shaped their baseline assumptions about what teaching practices are viable or appropriate to teach mathematics.

- **Properties:**
 - *Experiences:* Exposure to EBIPs via experiences as a student or novice instructor that participants discuss as influential to their use of EBIPs.
- **Dimensions:**
 - *Source of experience:* The stage in which the participant first was exposed to EBIPs (e.g., as an undergraduate student, a graduate student, a teaching assistant, a postdoc).
 - *Form of experience:* Experience with EBIPs ranged from formal/informal experiences as a teacher (e.g., GTA training, talking with colleagues) to personal learning experiences with EBIPs as a student.

Culture and Colleagues in EBIP Adoption: Participants discussed the role of their colleagues and institutions in shaping their adoption of EBIPs, particularly through the support or constraints these factors provided.

- **Properties:**
 - *Talking with Colleagues:* Colleagues' success/failure stories that serve as informal heuristics for practice evaluation.
 - *Departmental Culture:* Institutional norms that signal whether experimentation is encouraged, tolerated, or discouraged.
- **Dimensions:**
 - *Talking with Colleagues:* Ranged from validating/encouraging to cautionary/constraining
 - *Departmental Culture:* Spectrum ranged from supportive culture, permissive environment (no barriers but not supportive per se), to constraining culture/policies.

Ensuring Learning Happens in the Classroom: Mathematicians use EBIPs to engage students in mathematical work (e.g., problem solving, reasoning, and feedback) during class time rather than relying on out-of-class activities as students' main source of doing mathematics.

- **Properties:**
 - *Learning Math by Doing Math:* The belief that mathematics is best learned through active problem-solving rather than passively watching or listening.
 - *Student Engagement:* orientation toward student engagement in class.
- **Dimensions:**
 - *Types of Student Engagement:* The specific forms of engagement participants aim to foster during class time (e.g., collaborative, productive struggle). Often shaped by formative experiences. Range from primarily individual (e.g., productive struggle) to primarily collaborative (e.g., peer feedback, group problem solving)
 - *Catalyst for Bringing Engagement into Class:* The catalyst prompting a shift from expecting mathematical work to happen outside of class to designing for it in-

class. Ranged from none mentioned beyond belief in doing math by learning math to observations of student behavior outside of class.

Seeing and Responding to Student Thinking: Participants used EBIPs to gain real-time insight into student understanding and struggles. They found this enabled them to adapt instruction in ways that were otherwise unavailable, such as clarifying misconceptions, guiding student reasoning, adjusting pacing, or offering timely feedback.

- **Properties**

- *Student Engagement:* EBIPs are valued for actively engaging students, which surfaces student ideas, misconceptions, and reasoning during class.
- *Feedback/Adapt:* EBIPs enable participants to respond to student needs in the moment rather than after the fact, enabling instructional adaptations.

- **Dimensions:**

- *Feedback/Adapt:* ranged from corrective (e.g., fixing errors) to constructive (e.g., probing, guiding); and from momentary (e.g., adjusting pace, clarifying) to structural (e.g., task redesign).

Creating Supportive Conditions for Engagement: Participants valued EBIPs for creating the supportive conditions that made engagement with mathematics in class possible by reducing anxiety or fostering a positive classroom climate and community.

- **Properties:**

- *Social/Emotional Needs:* Valuing meeting students social/emotional needs to create a supportive environment in which students can thrive.

- **Dimensions:**

- *Source of Support:* who participants believe should provide support (instructor, peers) within class via feedback/instructional adaptations or student collaboration. Ranged from instructor driven support to peer support via collaboration
- *Scope of Support:* how participants conceptualize support as extending within or beyond the classroom or extending to assessment practices. Ranged from in-class only to beyond class

Managing the Content Trade-Off: Mathematicians manage their use of lecture and EBIPs to balance EBIPs' perceived instructional value with the practical need to cover course content, especially in courses seen as foundational for future mathematical study.

- **Properties**

- *Content Coverage:* How participants viewed covering course content as a primary goal shaping their use of EBIPs
- *Time in Class:* How participants perceive the time demands of EBIPs relative to lecture and how that influences their use of lecture
- *Beliefs About Learning:* How participants belief in learning by doing makes them value using EBIPs.

- **Dimensions:**

- *Course Level:* Course level ranged from terminal/elective to prerequisite/gateway courses. The course's role in a sequence shapes participants' perceived flexibility in balancing coverage and pedagogy
- *Beliefs About Learning:* Content pressure was influenced by beliefs about learning, particularly regarding the role of content exposure.

Navigating Logistical Constraints on EBIP Use: Mathematicians make cost–benefit evaluations about whether and how to use EBIPs, based on the ease of use (e.g., preparation effort, logistical complexity, and sustainability) of the practice in their context.

- **Properties:**
 - *Time/Effort (Burden):* the type of logistical time/effort burden they encounter.
- **Dimensions:**
 - *Burden Type:* the type of logistical burden they encounter. Ranged from start-up (e.g., initial prep) to ongoing complexity (e.g., learning to use, facilitate)
 - *Response to Burden:* The approaches participants use when practices become too burdensome ranged from modifying practices to dropping specific practices
 - *Practice Alignment:* whether participants feel a practice fits their teaching context, values, and constraints (personal fit).

Responding to Student Feedback: Mathematicians adjust how they use EBIPs based on how students respond, with responses filtered through their underlying instructional goals and orientations.

- **Properties**
 - *Student Feedback:* Participants describe receiving and responding to student feedback on their use of EBIPs, which influences their persistence with EBIPs
- **Dimensions:**
 - *Response to Student Feedback:* Modify EBIPs. Variation in how participants act on student feedback, ranging along a spectrum: Scale Back $\longleftrightarrow$ Refine Implementation $\longleftrightarrow$ Maintain.
 - *Type of Feedback:* Variation in what feedback participants responded to including student behaviors (e.g., engaging, resistance), student comments (e.g., praise, complaining), and student evaluations (formal, informal)

Persistence Themes

- **Adapting Practice:** Mathematicians persist in using EBIPs by adapting their practice in response to challenges they encounter.
 - **Contributing Codes:**
 - Modify Practice
 - Considering Changes
- **Reframing Challenges:** Persistence involved instructors' ability to normalize imperfection, frame difficulty as a natural part of instructional growth
 - **Contributing codes:**
 - Managing Expectations
 - Confidence Through Experience
- **Drawing on Positive Feedback and Experiences:** Positive affective and experiential feedback reinforced participants' commitment to EBIPs, offsetting frustrations and confirming their perceived value. Persistence was supported by visible evidence of success, enjoyment, and student appreciation.
 - **Contributing codes:**
 - Student Reception and Feedback
 - Personal Enjoyment
- **Leveraging Departmental and Collegial Support:** Persistence was strengthened by departmental climates that normalized innovative teaching and by colleagues who

provided encouragement, materials, or emotional support. These environments reduced the perceived costs of EBIP use and validated continued effort.

- **Contributing codes:**

- Institutional Factors → Departmental Culture (Departmental support/incentive, Permissive environment, Policies/culture that constrain implementation)
- Institutional Factors → Talking with colleagues

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