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Understanding How and When Graduate Student Instructors Break Through Challenges with Active Learning

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Abstract

Across recommendations for teaching undergraduate mathematics and statistics courses, instructors, including graduate student instructors (GSIs), are encouraged to implement techniques that actively engage students in the material. Despite these recommendations, GSIs' adoption of active learning techniques remains limited. Research suggests that instructors' knowledge about and emotions towards using active learning can promote or inhibit their use of active learning in the classroom. However, little is known about how GSIs' knowledge about and emotions towards using active learning evolve over time. We present findings from a longitudinal case study following two GSIs within a department of mathematical sciences across four semesters and discuss observed breakthroughs regarding their knowledge of, emotions towards, and use of active learning techniques. Data from surveys, interviews, and classroom observations revealed that GSIs' breakthroughs in their use of active learning only occurred after their increased knowledge about active learning aligned with their emotions towards it. This study further revealed that the GSIs needed to feel confident in and be challenged by their course structure, such as teaching in classrooms more suitable for active learning, before implementing such techniques. From these findings, we provide suggestions for professional development programs and discuss future research practice when investigating GSIs' longitudinal development as instructors who use active learning techniques in the classroom.

Keywords Active learning · Graduate student instructor · Longitudinal case study · Professional development

Introduction

In recent years, the distribution of university instructors in the United States has shifted to include more graduate student instructors (GSIs), many of whom are teaching for the first time. The American Association of University Professors

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(AAUP, 2018), synthesized data collected in 2016 from the Integrated Postsecondary Education Data System, revealing that among instructors at Research I universities, GSIs make up the largest percentage. In Ph.D. statistics departments, it's reported that GSIs teach roughly 25% of introductory courses in the United States (Blair et al., 2013). Ellis (2014) discussed that universities' instructional needs are being met in-part by an increasing number of GSIs. Thus, GSIs have a prominent role in teaching undergraduate mathematics and statistics courses (Speer et al., 2005).

Along with the shift in who is teaching undergraduate-level mathematics and statistics courses, there has been a shift in the recommended instructional practices for these courses. For example, the Conference Board of the Mathematical Sciences (CBMS) and the American Statistical Association (ASA) promote the use of *active learning*, which Abell et al. (2018) define as any classroom practice that enables students to be actively engaged in their own learning (we elaborate on characterizations of active learning in the following section). Research has shown that the use of active learning techniques (e.g., think-pair-share, wait time, and group work) positions the instructor to elicit students' prior knowledge, create cognitive dissonance, have students think, investigate, and create new knowledge, as well as provide the opportunity for students to reflect on their learning (Baviskar et al., 2009). The CBMS (2016) states that a "wealth of research has provided clear evidence that active learning results in better student performance and retention than more traditional, passive forms of instruction alone" (p. 1). Further, the American Association for the Advancement of Science suggests that the use of active learning can increase students' learning of and persistence with STEM courses, including mathematics and statistics (Laursen, 2019). These recommendations can help students learn in a variety of ways, including inquiry-based learning and problem-based learning. Inquiry-based learning is the process of learning through making real-world connections and high level questioning (Pedaste et al., 2015). Problem based learning utilizes the complexity of real-world problems to drive student understanding (Hmelo-Silver, 2004). These types of learning are forms of active learning where instructors provide questions, problems, or situations that immerse students in their own learning, allowing for the opportunity for students to make sense of the topic (Ernst et al., 2017). This type of teaching largely contrasts with more traditional types of learning, where students are passively taking in the material lectured to them by the instructor.

Despite these recommendations and research, many instructors, including GSIs, adhere to traditional lecture-based teaching approaches that they themselves experienced as students, where students passively receive information from instructors (Deshler et al., 2015; Harmin & Melanie, 2006). Further research suggests novice instructors (like GSIs) may not be ready to use active learning when they teach for the first time because they are likely in survival mode, trying to make it through the semester any way they can (Beisiegel, 2019). Other research suggests that, even when novice instructors attempt to use active learning, it is implemented differently than intended, mitigating potential learning benefits to students (Auerbach et al., 2018).

There exist many challenges that impede an instructor's effective use of active learning in the classroom. Specifically, research has shown that these challenges relate to instructors' knowledge about and emotions towards active learning. For example, instructors with less knowledge about, or more negative emotions towards using active learning may be more hesitant to use, and less effective when using active learning in the classroom (Finelli et al., 2014; Henderson et al., 2012). Better support may help instructors, such as GSIs, break through challenges related to their knowledge about and emotions towards active learning to start using active learning earlier and more effectively in their instruction. However, little research has explored when and how these breakthroughs occur.

Our research was designed longitudinally to allow for natural investigation into how and when GSIs break through challenges related to active learning. In this study, we focus on breakthroughs in the context of a GSI's knowledge about, emotions towards, and use of active learning. We follow two mathematics GSIs across four consecutive semesters and investigate the following research question: When and how do breakthroughs occur for GSIs in their knowledge about, emotions towards, and uses of active learning techniques across multiple semesters of instruction?

By investigating GSIs' breakthroughs with, and the relationships between their knowledge about, emotions towards, and uses of active learning, our research will help promote more encompassing information on how to best support GSIs in their use of active learning while teaching. This research can lead to more informed and differentiated professional development for GSIs, helping to promote, enhance, and accelerate their use of active learning in classroom instruction and thereby enhance their students' learning.

Relevant Literature and Conceptual and Theoretical Framing

Active learning can look different for each instructor and, as displayed in Fig. 1, may include a spectrum of "simple" to "complex" activities such as group work, hands-on technology, and interactive lectures (O'Neal & Pinder-Grove, n.d.). Across these different active learning techniques, common aspects include student involvement, shared learning responsibility, and not being passive in learning (Bonwell & Eison, 1991). Armbruster et al. (2009) reinforce this conjecture, sharing that active learning "involves a cycle of activity and feedback where students are given consistent opportunities to apply their learning" (p. 203).

A large body of research supports the use of active learning techniques (Knypstra, 2009), offering evidence that indicates the adoption, integration, and implementation of active learning techniques can help promote student learning, achievement, and confidence in mathematics (e.g., Freeman et al., 2014). The CBMS (2016) calls on "institutions of higher education, mathematics departments, and the mathematics faculty, public policy-makers, and funding agencies to invest time and resources to ensure that effective active learning is incorporated into post-secondary mathematics classrooms" (p. 1). The Guidelines for Assessment and Instruction in Statistics Education College Report further stresses the importance of active learning in the mathematical sciences,

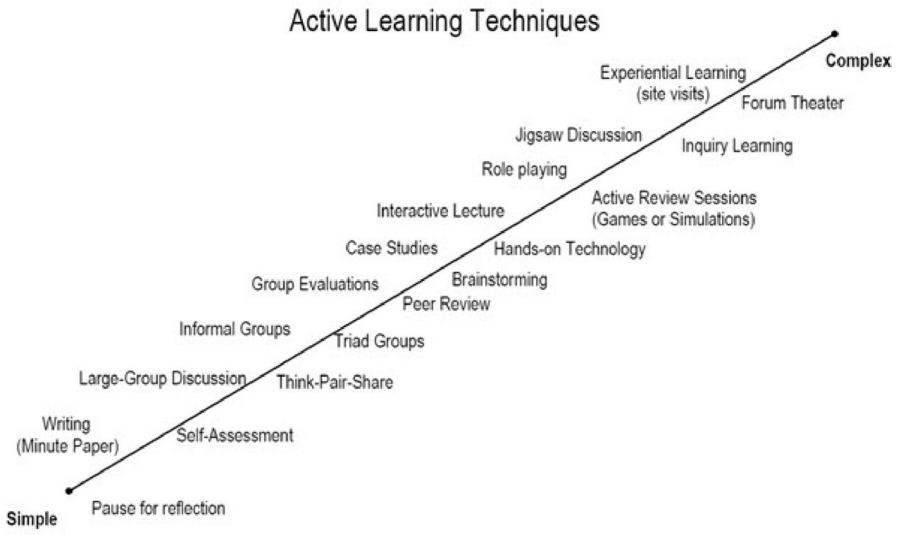

Fig. 1 Active learning continuum (O'Neal & Pinder-Grove, n.d.) that shares a variety of techniques that can be used for active learning, ordered by complexity and classroom time commitment

encouraging instructors to use active learning to foster and enhance students' understanding and communication of statistics (Carver et al., 2016).

Despite this research and calls for instructors to adopt active learning techniques in their classroom, the use of such techniques in classrooms remains sparse (Apkarian et al., 2021). Many challenges exist that may hinder instructors' use of active learning techniques and they are often grounded in instructors' knowledge about active learning (e.g., the benefits of active learning and the techniques to use) and emotions towards using active learning (Justice, 2020; Tyng et al., 2017).

Knowledge

For this study, we define and understand *knowledge* as facts, information, and skills obtained through experiences or education (Pritchard, 2013)**.** Thus, we define *knowledge about active learning* as articulated information, such as stated definitions and types of active learning teaching techniques, that aligns with current literature on how such teaching techniques are best understood. Knowledge about active learning is an important factor to study in relation to the use of active learning in the classroom because while teaching experience is crucial, it does not solely manifest into teaching knowledge for active learning (Andrews et al., 2019).

Emotions

Emotions also play a key part in facilitating change in teaching behavior (Zhu & Thagard, 2002). For example, experiencing negative emotions toward the use of

active learning may inhibit GSIs' use of active learning techniques in their instruction (Tyng et al., 2017). For this study, we define *emotions towards active learning* as states of feeling experienced consciously or unconsciously towards using active learning. A state of feeling is a conscious mental reaction (Debellis & Goldin, 2006), and this is highly confounded with, but a different construct than beliefs. Beliefs involve the attribution of some sort of projected external truth. Beliefs often develop from emotions and can be changed or strengthened by the emotional responses one holds towards a specific context (Frijda et al., 2000). For example, emotions towards active learning may include anger and boredom. These are descriptors of how active learning makes you feel and can manifest your external truth about active learning as a teaching tool (e.g., a belief that active learning does not help students learn mathematics). Yet, despite emotions being a driving force of developing beliefs and critical to several change of behavior theories (Davis et al., 2015), instructors' emotions toward instructional practices are not often studied. Currently, research on instructors' emotions has primarily focused on the relationship between emotions and instructors' work, development, and livelihood, uncovering that when an instructor is experiencing negative emotions, they may experience higher levels of burnout and job dissatisfaction (Hargreaves, 2005; Keller et al., 2014; Zembylas, 2005).

A characteristic of emotions that influences an individual's behavioral change is level of intensity. Emotions influencing behavior that are more negative, with higher intensity levels, are associated with maladaptive strategies such as avoidance or distraction (Kozubal et al., 2023). Positive emotions function to promote the optimal well-being of an individual, while negative emotions detract from such a state. To situate this study to better understand both type and intensity of emotions towards active learning, we incorporate Plutchik's (2001) wheel of emotion model (Fig. 2). Plutchik's wheel of emotion contains eight primary emotions: joy, trust, fear, surprise, sadness, disgust, anger, and anticipation. On the wheel, emotions closer to the center of the wheel within a petal are characterized as more intense, while emotions closer to the outside of a petal are considered less intense.

While there are roughly 34,000 different distinct emotions in total (Plutchik, 2001), we leverage this model because of its utility for emotion identification by synthesizing the complex construct of emotion into eight primary emotions, their intensities, and their relationships with each other. This model provides practical implications for approaching and understanding how to characterize, compare, and contrast GSIs' emotions towards active learning within and across time.

Categorizing GSIs' emotions as positive or negative helps provide practical characterizations of change in emotions across time and better connects with change behavior theories that suggest more positive emotions relate more closely with adopted change in behavior (Fredrickson, 1998). Although Plutchik (2001) doesn't categorize his wheel of emotion model into positive and negative emotions, we used existing literature around emotions to categorize each emotion as positive or negative within the context of active learning. For example, we categorized *joy* as a positive emotion because recent literature suggests that joy can promote well-being (Fredrickson, 2013). Table 1 provides the list of the categorization of our a-priori themes used to investigate GSIs' emotions towards active learning across timepoints. We note that the emotion of surprise could not be uniquely categorized into a positive or

Fig. 2 Wheel of emotion model (Plutchik, 2001) that uses a color wheel to highlight different types of emotions and position to highlight different levels of emotional intensity

Table 1 Categorization of the eight primary emotions on Plutchik's (2001) wheel of emotions model

Primary Emotion	Categorization
Anger	Negative
Sadness	Negative
Fear	Negative
Joy	Positive
Trust	Positive
Surprise	Positive / Negative
Disgust	Negative
Anticipation	Positive

negative emotion. This is because, as the emotion of surprise intensifies, it is characterized as amazement, aligning with a positive state of feeling towards active learning. However, when the emotion is less intense, it is characterized as a distraction, aligning with a more negative state of feeling towards active learning.

Use

GSIs typically approach teaching based on their prior experiences in school as a student (Justice, 2020). Further, when using active learning, new instructors often implement less complex techniques that take less time to implement (e.g., minute papers), often adapting rather than adopting practices and unknowingly compromising their effectiveness (Vickrey et al., 2017). The two challenges discussed above (knowledge about and emotions towards active learning) may play a role in limiting new instructors' use of active learning and its effectiveness in student learning.

Transformative Learning Theory

GSIs' current understandings and habitual ways of thinking and feeling are called their frames of reference. As shown in Fig. 3, these frames of reference help influence the way that GSIs understand and interpret different experiences. Frames of reference are complex and can include traits such as knowledge or emotions. As practicing teachers, their knowledge about and emotions towards active learning

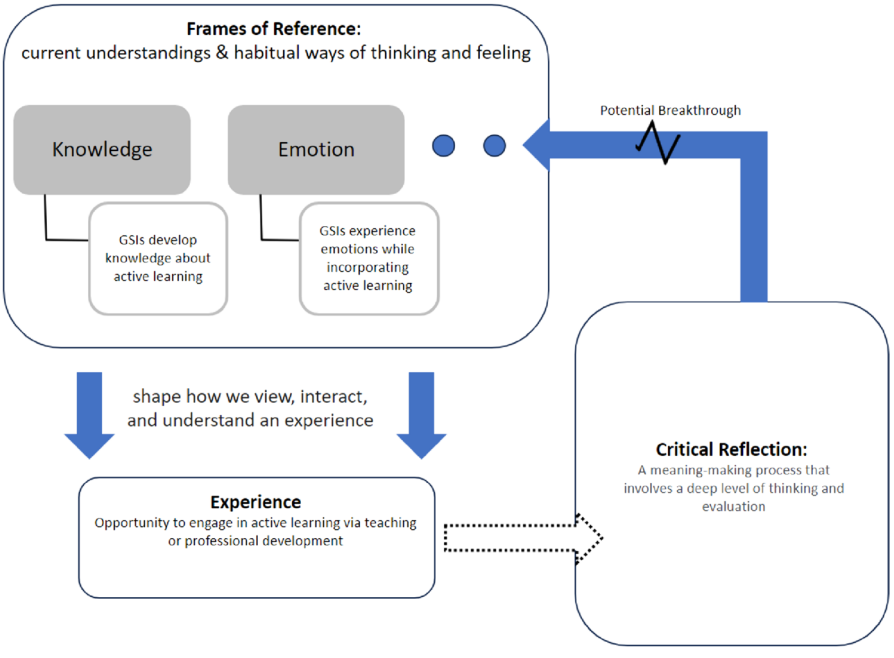

Fig. 3 Framework describing how GSIs experience active learning over time

may change and grow through experience and professional development opportunities. As described above, knowledge is often coupled with emotions experienced while teaching, providing feedback on the perceived utility and success of active learning in classrooms. For example, if a GSI has limited knowledge about active learning and has negative emotions toward implementing a lesson in this way, they might believe active learning is not as effective in helping students learn a concept.

Critical reflection is the driver for change in one's frames of reference. As GSIs grow in their understanding of active learning and have experiences, either through teaching or targeted professional development, and can share and reflect on these experiences, their frames of reference can shift. When this change is positive (i.e., a teacher gains knowledge about active learning or expresses more positive emotions towards active learning), we recognize and observe this as a breakthrough. We equally identify a breakthrough in the use of active learning if this reflective process lends itself to more frequent or complex uses in the classroom (Fig. 1).

To understand how these frames of reference change, we employ the lens of transformative learning theory (Mezirow, 1991). Mezirow (2003) defines transformative learning as a process of critical reflection that transforms frames of reference. These frames of reference can continuously change if there is critical reflection on the experience that either reinforces or challenges the GSI's frames of reference. Critical reflection speaks to an in depth meaning-making process of analyzing, reconsidering, and questioning your experiences (Rodgers, 2002). This is different than more general reflection, which refers to simply thinking intentionally about your experiences in more of a descriptive manner. We position this research to highlight and uncover details around when frames of reference on knowledge about and emotions towards active learning change over time and how this may cultivate into the use of GSIs implementing active learning techniques in their classroom.

Methods

In this study, we used a collective case study approach (Crowe et al., 2011), where each case is defined to be each GSI. This approach encompasses both a within-case and a cross-case analysis. A within-case analysis helps describe and explain a GSI's longitudinal progression of their knowledge about, emotions towards, and uses of active learning. Because GSIs' knowledge about, emotions towards, and uses of active learning can differ across individuals, we also employed a cross-case analysis to explore processes and outcomes across each case. The cross-case analysis helps develop more sophisticated and powerful descriptions of GSIs' knowledge about, emotions towards, and uses of active learning within the contextual boundary of a mathematical sciences department at a land-grant research university in the Rocky Mountain region. At this university, a GSI is typically the lead instructor of one section of a freshman- or sophomore-level mathematics or statistics course each semester. These courses often include College Algebra, Pre-Calculus, Calculus I, and Introductory Statistics, which have approximately 30–40 students per section.

Department Support for GSIs

All new GSIs in the mathematical sciences department attended a week-long orientation prior to the start of the academic year. At the beginning of this research study in Fall 2017, the orientation included workshops and activities focused on building community, preparing GSIs for their first week of teaching, and encouraging the use of active learning techniques during instruction. This orientation offered GSIs multiple opportunities to interact with their peers and experienced instructors while learning about their upcoming roles and responsibilities as GSIs.

During the academic year, the new GSIs continued to meet weekly in Fall 2017 and monthly in Spring 2018, attending interactive one-hour workshops that exposed them to innovative teaching methods, techniques, and tools. Each workshop was structured so that GSIs could observe, explore, and reflect upon a pre-determined topic. We note that the first three authors co-developed and co-led the GSI professional development (PD) program.

In addition to the development program for new GSIs, all GSIs had weekly meetings with their Student Success Coordinator (SSC). Each SSC was responsible for coordinating the instruction and assessment of all sections of an undergraduate course. During weekly course meetings, the SSCs discussed the material GSIs would teach for the week, and they also encouraged GSIs to use active learning techniques in their classrooms.

Participants

At the beginning and the end of the first semester of the GSI PD in Fall 2017, we surveyed all new GSIs ($n=20$) about their perceived roles as educators and their definitions of active learning. Because an instructor's perceived role can help shape their experiences with active learning (Grasha, 1994), we chose to group GSIs based on how they perceived their roles as instructors at the beginning and the end of their first semester of teaching. Based on the GSIs' written responses, we identified two different roles: *facilitator* and *lecturer*. GSIs identified as a facilitator wrote about the personal nature of instructor-student interactions, and the value of students making informed choices and self-discovering the value in the mathematical or statistical content. We identified only one GSI as a facilitator among the 20. GSIs in the lecturer group noted a one-directional flow of knowledge, stating they were responsible for passing information onto their students. We purposefully selected two GSIs (Table 2) who were representative of the GSIs we identified as either a lecturer or facilitator because these two roles capture two different belief systems about the role of the teacher in the mathematics classroom and how content is learned.

Max (pseudonym) is a self-identified female from the United States who consistently described herself as a *lecturer*: "My role as a teacher is to assist students in learning through lectures, worksheets, homework, and doing my best to answer questions that arise." Andy (pseudonym) is a self-identified male and international student who consistently described himself as a *facilitator*: "I function majorly as

Table 2 Descriptions of the study's participants

	Max	**Andy**
Degree Program	M.S., Mathematics	Ph.D., Mathematics Education
Perceived Role as Instructor (Fall 2017)	Lecturer	Facilitator
Demographics	Female, United States	Male, International
Prior Teaching Experience	None	Completed a different teacher development program; Lead instructor of mathematics classes
Initial Understanding of Active Learning (Fall 2017)	"I had never heard of active learning before."	"Engage our students in the learning process."
Courses Taught (Fall 2017-Fall 2019)	Survey and Applications Course in Calculus (4 sections) College Algebra (2 sections) Introductory Statistics (1 section)	Survey and Applications Course in Calculus (2 sections) Calculus I (4 sections)

a facilitator of learning. I am also a learner in my own class." Max had no prior teaching experience and had never heard of the term active learning before. During the week-long orientation, Max wrote that she planned to use "group work, smaller lectures before group work, [and] different colored pens to emphasize stuff." In contrast, Andy had experience in a K-12 setting from 2012 to 2017 and had completed a PD program for instructors at another institution in 2016. At the start of the semester, he noted that he planned to use "grouping, worksheets, pair and group teaching, differentiated learning, [and] formative assessment" in his classroom to actively engage students. Even though both Max and Andy planned to use active learning techniques, to different extents, when starting the semester, their differing perceptions of their role as an instructor allow investigation into when breakthroughs with active learning occur for each type of instructor.

Max was the instructor of record for sections of coordinated courses each semester she participated in the study. Her primary responsibilities were teaching and grading; she was not responsible for creating assessments or syllabi for any course. Andy was also the instructor of record for sections of coordinated courses for all semesters except Fall 2019, when he both co-taught a course with a tenure-track faculty member and led a lab section. Lab sections mimicked a typical class, accompanied by a lab assignment. Like Max, Andy was responsible for teaching and grading, but not creating assessments or syllabi.

Data Collection

Our primary sources of data were interviews and survey responses which provided a description of GSIs' self-reported knowledge about, emotions towards, and use of active learning during each semester of the study. We used classroom observations (through self-recorded classroom videos) to help triangulate the data

from the interviews and survey responses. In particular, we were able to observe whether GSIs were using active learning techniques as they described using them in their survey responses and interviews. For this research study, we used similar data collection techniques during each semester, as shown in Table 3.

Throughout this study, each GSI completed four semi-structured, audio-recorded interviews (Appendix). GSIs answered questions about their knowledge about, emotions towards, and uses of active learning in their classroom. Existing literature suggests that forms of structured interviews are appropriate for measuring one's knowledge and emotions for a given topic (Agarwal & Tanniru, 1990; Oplatka, 2018). For this study, we found that individual interviews allowed for GSIs to openly share their experiences during the semester—both challenges and triumphs.

We wrote interview questions about their knowledge about active learning around our working definition of knowledge about active learning to best ensure we were measuring this knowledge as intended. Some of these questions include: *What is your definition of active learning? How has the definition changed since last semester? Why has your definition changed? What strategies do you consider to be active learning and why?* To further provide evidence of validity towards our measurement of knowledge, we considered Pritchard's (2013) two basic requirements for knowledge: truth and belief. We assessed truth by explicitly comparing what each participant claimed as factual about active learning with current literature. While answering questions, careful consideration was taken during the interview to ensure that GSIs believed their responses, instead of guessing correctly or trying to give the "correct response." This was done in a multi-faceted process. We articulated before the interview to give only truthful and honest answers as they understood the question. We ensured that each GSI understood that answers would not be shared with anyone outside of the research team and had no impact on their employment as a GSI. During the interviews, we took notes regarding the tone of responses, and critically reviewed all data that we categorized as knowledge with our working definition of knowledge to help ensure evidence of validity.

We similarly created interview questions tailored to our working definition of emotions towards active learning. Some of these questions include: *How do you feel about using active learning techniques when teaching? How have these feelings changed?* When answering these questions, it was common for each GSI to express answers related to emotions and other constructs, such as beliefs. This was noted, coded, and categorized during data analysis to ensure we were measuring what was intended.

Table 3 Four timepoints of the data collection process

	Fall 2017	Spring 2018	Fall 2018	Fall 2019
Data Collected	Pre- and post-semester surveys	Classroom observation Pre- and post-observation interviews	Classroom observation Post-observation interview Survey	Interview Survey

Each GSI also completed four free-response surveys. At the beginning and the end of Fall 2017, the surveys asked about their perceived roles as educators and their definitions of active learning. The other two surveys prompted each GSI to describe how they defined active learning, how they felt about active learning as an instructional practice, how they used active learning techniques in their classrooms, and how (if at all) their knowledge about, emotions towards, and use of active learning changed from previous semesters. We found it critical that, at each data collection timepoint, each GSI had the opportunity to reflect on current and past teaching experiences to help us more holistically understand and code any detailing of a breakthrough (if at all) in their knowledge about, emotions towards, and use of active learning.

To triangulate our data, we also collected two video-recordings of each GSI teaching during the study, once during Spring 2018 and once during Fall 2018. Max was recorded instructing Survey and Applications in Calculus both semesters, and Andy was first recorded instructing Survey and Applications in Calculus and then Calculus I. To capture how the participants used active learning, the video recordings occurred on days when each GSI self-reported that they planned to use active learning techniques; each GSI was given multiple weeks to select a date. The researchers were not present during the filming of the class to ensure each GSI didn't feel undue pressure when teaching.

Data Analysis

The first author wrote memos of important ideas and responses for each survey transcribed and during each interview to initially explore these data. For the interview questions, memos included descriptions of the GSIs' tone, body language, and other verbal and non-verbal cues when answering questions. This information was used to help authenticate the data being collected during the interview and help attend to any potential unconscious emotions that the GSI may not have articulated. Additional memos were created when transcribing each interview to build upon and provide evidence of validity in the researcher's memos. We used field notes from classroom observations to identify how and when GSIs were using active learning during instruction. The following sections detail the analysis of these data regarding each GSI's knowledge about, emotions towards, and uses of active learning.

Knowledge About Active Learning

To investigate GSIs' knowledge about active learning, we utilized interview transcripts, survey data, and memos as our primary data sources. We used an iterative coding process by repeating the data analysis process to provide evidence of reliability towards the formation of the codes. Through this iterative process, the lead author used a provisional coding approach, beginning with a list of researcher-generated codes found in the literature on graduate students, active learning, and teaching experiences (Miles et al., 2013); for example, *student involvement* is a term used

Table 4 Descriptive codes from literature

Code	Definition
Cognitive engagement	Psychological effort students devote to interacting with others and the material (Bonwell & Eison, 1991)
Student involvement	Students' willingness to take on the learning task (Freeman et al., 2014)
Learning process	Process of acquiring new understanding, knowledge, behaviors, or skills for oneself (Freeman et al., 2014)
Pause for reflection, Think-Pair-Share, Large-group discussion, etc.…	List of active learning techniques (O'Neal & Pinder-Grove, n.d.)
Engage, Explore, Explain, Elaborate, Evaluate	5 E Instructional Model: Five phase sequence that instructors facilitate to put students at the center of learning (Kudryashova & Rybushkina, 2016)

when defining active learning (Bonwell & Eison, 1991). Table 4 identifies examples of our initial codebook, including the generated codes and their working definitions. Other codes emerged throughout the analysis based on the GSIs' responses to the interview and survey questions.

At each of the four timepoints during the study, we combined similar codes within a single case to create initial themes, which we then discussed and refined as a research team. For example, Table 5 provides codes and their descriptions that were generated based on Max's responses to an interview question asked in Spring 2018. The codes—*detail*, *student involvement*, and *student attitudes*—share the commonality of students being cognitively positive and sharing effort in their learning. This description is best defined as *positive engagement,* the emergent theme from these data.

Emotions Towards Active Learning

To investigate emotions towards active learning, we used interview transcripts, survey data, and memos as our primary data sources. For each interview and survey, we generated codes from the data using a similar iterative approach that was used in analyzing knowledge about active learning. Once we created initial codes from iterative evidence across the data, we implemented a deductive approach to group similar codes together. Our deductive approach used pre-determined a-priori themes from Plutchik's (2001) wheel of emotion model (Fig. 2) as descriptive themes of the data-generated codes. If we created codes that didn't cultivate into a theme on the wheel of emotion model, we critically assessed whether we should categorize that piece of data as emotions towards active learning or as a different construct.

For example, during an interview, Andy reflected on his initial experiences with active learning that occurred before this study. He shared that when he was first introduced to the idea, he believed active learning did not work. He said that the use of active learning was "bullshit", which was coded as a belief of the effectiveness of such techniques during the timepoint referenced (i.e., before the study). Data categorized as beliefs were not included in our assessment of or identification of

Table 5 Coding example for one interview question Max answered in Spring 2018

Participant: Max – Spring 2018	Code	Code Description/Evidence	Theme
Question: How do you define active learning?	Detail	Max talks about how active learning lets students provide more detail to an answer, instead of just a one-word answer	Positive Engagement – students showing a willingness to remain cognitively positive and make an effort to be immersed with others in the content
	Student Involvement	Max discusses how she understands active learning is when students are not just sitting and watching the teacher do problems. They are willing to be involved in the lesson	
	Student Attitudes	Max relates active learning to the idea that students should not put themselves down when doing mathematics	

breakthroughs with emotions towards active learning. Later in the interview, Andy shared that when he started using active learning in the classroom, he had the revelation that "it wasn't like … there was a grand teacher in the front just giving the students everything. Ever since, I've been in love … you know with this strategy." This response was classified as a state of feeling towards active learning and was coded and categorized as emotions of joy and admiration.

Use of Active Learning

To learn about GSIs' use of active learning in their classrooms, we first analyzed their self-reported responses to survey questions such as *what types of active learning teaching techniques do you use in your class* to identify a list of active learning techniques they reportedly use during instruction. Then, we used classroom teaching observations to triangulate their survey responses and note whether their self-identified list of techniques aligned with what they used in their classroom. The classroom observations also served as an opportunity for the research team to identify follow-up questions to ask each GSI in their post-observation interviews. For example, we followed up by asking each GSI why they implemented a particular active learning technique (if any) and asked them to reflect on how their implementation of that technique went.

Two of the authors, who were co-facilitators of the GSI PD and familiar with the literature on active learning and the different active learning techniques, independently watched these videos and wrote field notes. While we took inspiration from existing observation protocols (e.g., Teaching Dimensions Observation Protocol, Hora & Ferrare, 2010) to structure our field notes, we purposely tailored the field notes to capture their uses of active learning in a way that aligned with our research question. These field notes were an opportunity to document and describe the GSIs' instructional actions and use of active learning techniques and to reflect on what we observed. Within these notes, we identified (1) what active learning techniques GSIs used during instruction, including how often and when they were implemented during the lesson, (2) how the GSIs implemented each technique (e.g., what role did the GSI have when implementing each technique), and (3) how students visually responded to these techniques. By identifying these items during the classroom observations, we captured GSIs' *uses of active learning* in their classrooms. Further, prior to watching the videos, we first created a list of active learning techniques that included (1) techniques identified in the literature (e.g., O'Neal & Pinder-Grove, n.d.) (2) techniques we emphasized in the GSI PD, and (3) techniques GSIs self-reported as using in their classrooms. This list allowed us to quickly identify which active learning techniques each GSI used during their instruction.

After independently watching the classroom teaching video recordings, the same two authors met and corroborated all identified instances of each GSI using an active learning technique. For example, one author wrote, "Max first reviewed a u-substitution integral problem on the board with the entire class. She asked students questions as she worked through the problem on the board (~4-min mark)." In this example, each author identified the use of "posing questions" as an active

learning technique. These identifications and descriptions of each GSI's use of active learning techniques across timepoints were compared among the two authors to reach consensus. Together our field notes captured the different active learning techniques each GSI implemented, along with how and when they occurred during their instruction. Simply identifying the technique (e.g., group work) without some attempt to involve students in their learning was documented but not identified as a use of active learning, per its definition.

Breakthroughs with Active Learning

When and how breakthroughs with active learning occurred for each GSI are discussed below through an interpretivist thematic comparison of themes across each timepoint. Breakthroughs within knowledge about, emotions towards, and use of active learning can occur when GSIs participate in critical reflection around their experiences with active learning that can challenge and update their frames of reference. We defined a breakthrough as a positive shift or increase in each construct measured. When investigating breakthroughs in knowledge about active learning, we compared themes across each timepoint and assessed whether the comparison of themes reflects evidence that knowledge about active learning has increased and is more aligned with the current definitions and literature around such techniques. A GSI is identified as having a breakthrough in emotions towards active learning if the thematic comparison across timepoints suggests that the emotions become more positive, or more intense within a positive emotion. We identified a breakthrough in a GSI's use of active learning if an active learning technique was observed in one timepoint that had not been observed previously, and the intent to use that technique was corroborated with the GSI in the interview process. Further, we referenced the active learning continuum (Fig. 1) by O'Neal and Pinder-Grove (n.d.) that lists a series of active learning techniques ranked on a scale from simple to complex. We characterized the attempt to use more complex active learning techniques from more simple ones as a breakthrough in using active learning.

Results About Max

Coming into this study Max had no prior teaching experience, nor had she "heard of active learning". Below, we outline Max's breakthroughs with active learning in the context of her knowledge about, emotions towards, and uses of active learning in her teaching (Table 6).

Spring 2018 Breakthrough in Knowledge About Active Learning (1)

Max's knowledge about active learning evolved throughout Spring 2018. At the beginning of Spring 2018, Max described active learning, during an interview, as students doing something more than just sitting and listening to the instructor: "[active learning is] getting your students involved in class, and not just…sitting

Table 6 Max's evolution and breakthroughs (blue arrows) with active learning

Time	Knowledge	Emotion	Use
Beginning Spring 2018	Understood as getting your students *involved*	Communicated emotions of *apprehension*	*Passive* usage of active learning
End Spring 2018	Better articulated her knowledge of active learning by understanding it as *positive engagement*	Communicated emotions of *apprehension* and *fear* stemming from how students would respond	Despite wanting to use active learning, usage remained *limited*
Fall 2018	Description remained consistent, centered around *engagement*	Described emotions of *trust* and *acceptance*	Started at the beginning of the semester, primarily using *group work*
Fall 2019	Description remained consistent, centered around *engagement*	*Apprehensive* of techniques that required students to work outside of class but showed *trust* in in-class techniques.	Continued to use active learning by *asking questions* and *letting students work together*

there watching you lecture to them." Max explained, "I think it's [active learning] the difference between a one-word answer and more of an extensive answer, and it's about involvement of your students." She thought that active learning techniques were helpful to get students to talk to each other and found learning about these techniques rewarding for her overall growth as an instructor.

At the end of Spring 2018, between her second and third semester teaching, Max showed more advanced knowledge about active learning by elaborating on what she meant when she described active learning as students "not just sitting." For Max, not sitting meant that students were not passively learning the material but instead learning through "some form of active engagement." She articulated a more advanced understanding of active learning by discussing it further through the lens of engagement. When explaining engagement, she detailed students being cognitively engaged by "really paying attention" and understanding the transitional steps when learning proofs. She thought active learning techniques were helpful for "get[ting] these students involved with one another… [and to] keep students awake." Max largely attributed her more advanced knowledge of active learning (i.e., breakthrough) to conversations with other instructors and the GSI PD she attended in Fall 2017. Specifically, Max cited a workshop about active learning, where groups of GSIs had discussions on what active learning is and what instructional strategies promote student engagement and thinking. Within our theoretical framework, it is understood that conversations with others was one experience that she critically reflected on, updating her frames of reference around her knowledge about active learning.

We did not observe Max experience a breakthrough in her emotions towards and her use of active learning during Spring 2018. Max's emotions towards active learning were strongly and consistently influenced by her own experiences as a student. She had positive experiences learning in lecture-based classes stating, "As far as [my] classroom experience, for the most part, it has been very, very positive. My math classes in undergrad were very much a lecture-based thing." When reflecting on her experiences with non-lecture-based learning, she said, "I know for me when I was a student and forced into those situations I didn't prefer having to work in groups." In fact, as a student, Max "fully avoided having one [flipped (non-lecture-based) class] because I didn't think that was how I learned." Thus, as an instructor, Max relayed emotions of apprehension and fear of using active learning. This related to concerns about how students may interpret her use of active learning. Max explained that using different active learning techniques may result in students becoming adversarial towards each other or make her students feel like "children."

During this time, Max was also hesitant to use active learning in her classroom and questioned how it could work in a mathematics class, stating, "That's awesome, but how in the heck do you do that [active learning] for math?" Max was unsure about how to use active learning, wrestling with conflicting views about its usage against her own learning preferences as a student. She reflected: "I was a student that hated group work so I kind of battle between what I like and what I don't." Video data depicted Max predominantly lecturing to her students and then assigning a worksheet midway through the class that students primarily completed individually. Despite a breakthrough in knowledge about active learning, Max's emotions

towards active learning remained primarily negative and her use of active learning was limited.

Fall 2018 Breakthroughs in Emotion Towards and Use of Active Learning (2 & 3)

During her third semester teaching in Fall 2018, Max experienced a breakthrough in both her emotions towards and her use of active learning, shifting to align with her breakthrough in her knowledge about active learning. We coded some of her interview and survey responses as the emotional theme, trust, and her responses also showed evidence of the less intense emotion, acceptance. During interviews, we derived codes of optimism and excitement when she discussed how active learning can help improve student understanding. She felt excited about using active learning, stating that she was "really enjoying it" and found it "fun to see your class interacting with one another." As her emotions towards active learning evolved positively, Max's use of active learning was more apparent. In the video data, we observed Max ask more questions during class and facilitate conversation between students, frequently encouraging students to discuss with their group members. For example, Max asked the following questions which engaged multiple students in conversation: "Did you guys converse about this?" and "Do you understand their explanation?".

Max shared insight into how this breakthrough may have occurred. Max explained that she "never wanted to be a stale teacher" and wanted her students to talk to one another. When Max talked about "not want[ing] to be stale…", she gave insight into a critical reflection on past lecture-based teaching experiences where she "has put kids to sleep." This critical reflection appears to stem from this negative experience, and a desire to avoid these types of unwanted situations in her classroom. When Max started to develop more negative emotions towards lecture, her emotional frames of reference were challenged and then updated after she reflected on how active learning may be a way to help avoid "being stale." This reflection helped change her emotions towards active learning, which then influenced the change in her use of active learning techniques in her class. This was also the semester that Max expressed a desire and willingness to seize the opportunity to use active learning at the beginning of the semester, noting that previously, she had not known how to start using active learning in the middle of a semester.

Max's breakthrough in use of active learning was observed at the same time she was both knowledgeable about active learning and experienced a breakthrough in emotions towards active learning. Max explained that this alignment between her knowledge about, emotions towards, and use of active learning led her to being "a lot more open to doing [active leaning] as much as possible instead of being like, no, I like to lecture and don't really want to let go of this."

Fall 2019

In Fall 2019, we observed Max initially re-express some negative emotions towards active learning. During this semester, her frames of reference were challenged by the experience of teaching in a flipped classroom where students completed course

content readings outside of class time and spent class time working through problems. Teaching within this different classroom structure, Max expressed low intensities of the primary emotions anger and fear, categorized by the wheel of emotions model as annoyance and apprehension towards active learning techniques. This was largely due to teaching in an unfamiliar classroom setup that she avoided as a student. She substantiated her annoyance and apprehension, explaining that she's a "control freak." She did not want to use active learning strategies that relied on students' preparation before class, because she could never be sure they were prepared. Over time, she started to become more comfortable:

> You kind of take yourself and your personal feelings about it [active learning] out of the equation as much as you can so that you can do your job as a teacher as it is stipulated by your boss. Which can be frustrating, and I think initially it was frustrating and hard for me. And now it's going much better.

Despite conveying annoyance and apprehension towards the structure of active learning in a flipped classroom, she eventually articulated the emotion, trust, in using active learning to help students learn. She suggested that using active learning was easier after gaining teaching experience in a flipped classroom because she did not have to figure out how to implement group work. When asked if she would want to try new active learning techniques, Max again expressed apprehension, saying she felt uncomfortable implementing new techniques because she was not sure how those would fit in with the structure of her class.

Throughout the study, when Max critically reflected on new information about active learning, she compared it to what she experienced as a student and her own classroom practice. This suggests that her initial frames of reference were grounded in her experiences as a student and influenced the trajectory of her breakthroughs throughout the study. These more traditional experiences that made up Max's initial frames of reference were reinforced by the teaching techniques she used in subsequent semesters, suggesting that simply increasing knowledge about active learning may not be enough to manifest its use in the classroom. Max was using "what worked" for her as a student when teaching until she subsequently experienced breakthroughs in her emotions towards and her use of active learning in Fall 2018.

Later, when Max became apprehensive about using active learning in a flipped classroom, her new, more positive frames of reference about active learning may have helped her to not revert to only traditional means of teaching: "There has to be a middle ground of these two [techniques]." Unlike previous semesters teaching, Max showed no fear in how active learning would be perceived by students: "They don't necessarily enjoy that I [use active learning], but I think it really gets them to have to think about it and synthesize some knowledge."

Results About Andy

Andy, who came into the study with prior teaching experience and an understanding of active learning, showed evidence of experiencing breakthroughs in emotions towards and use of active learning, both in similar and different manners than

Table 7 Andy's evolution and breakthroughs (blue arrows) with active learning

Time	Knowledge	Emotion	Use
Before Study	Attended professional development which taught active learning as *engagement*	Communicated emotions of *apprehension* and *anger* when introduced to active learning	*Forced* to use active learning; predominantly used *group work*
Beginning Spring 2018	Described active learning, at its core, as *engaging* students	Shared emotions of *trust* and *acceptance*	*Facilitated discussions* and *activities* with students
End Spring 2018	Continued to describe active learning as *engaging students*	Emotions, remained consistent sharing his *trust* and *acceptance*	*Flexible* in using different types of active learning; Took on more of an *interest* and became curious on how research and recommendations would play out
Fall 2018	Continued to describe active learning as *engaging students*	Expressed *joy* and *admiration*	Remained *committed* to a *flexible* active learning approach
Fall 2019	Described active learning as students taking *active roles* in their learning	Expressed *joy* and *admiration*	Remained *committed* to a *flexible* active learning approach

Max. Below, we outline when and how Andy's breakthroughs with active learning occurred (Table 7).

Before the Study

Unlike Max, Andy had prior teaching experience, so we establish his baseline knowledge about, emotions towards, and uses of active learning in this section. Andy explained that when he first started to teach in 2012, his knowledge about active learning increased through the PD he took at his previous institution, but he initially thought "[active learning] would never work" and was apprehensive and angry towards using active learning. During his initial PD experience, Andy "was exposed to this collaboration and active learning so…[he] had the definition of active learning, of what active learning should be."

Andy met active learning with frames of reference built on more traditional experiences as a student and instructor. Andy had never experienced active learning as an undergraduate student; his undergraduate education was primarily traditional, fueling his apprehension and anger toward the idea of using active learning: "When [active learning] was [first] presented I was like this is bullshit. I never had the experience. I was like this would never work. How would you have students sit in groups? They will be making noise." He explained that before the PD, he used to be a dictator in his class:

> I used to be the almighty teacher. The one with the almighty knowledge. You have to pour everything out to the students. And you would see me sweating profusely because you know right from the outset, I wanted my students to learn mathematics.

However, while still learning about active learning, Andy was required to teach in a flipped classroom that required the use of active learning: "The school has the students sit in groups, so as the teacher you can't say, 'I want a traditional way.'" At that time, he questioned the idea: "Students would be allowed to talk in a math class? No, that never happens." By the end of his initial PD experience, he thought, "Oh! This is cool."

Spring 2018 Breakthrough in Use of Active Learning (1)

Andy, entering our study with an advanced knowledge about, positive emotions towards, and a consistent use of active learning, experienced a breakthrough in how he used active learning by the end of Spring 2018. At the beginning of Spring 2018, Andy described active learning as a tool to engage his students in learning the material, where learners are learning from each other. He detailed how using active learning (using group work and group discussions) helps students better learn, portraying trust and acceptance of active learning because its use "makes students to be proactive in their reasoning."

By the end of Spring 2018, Andy demonstrated a more flexible approach to using active learning by implementing a variety of more complex active learning

techniques. When using active learning in his class, Andy started by sharing the day's learning objectives, emphasizing the process of problem solving by telling students to "exercise their minds." When facilitating classroom discussions, he questioned students' logic and reasoning and focused on interpretations over correct answers. When administering a warm-up worksheet of five true or false questions, he asked students to work together and "think and be sure you know why this is true or false." When his students asked him if the worksheet would be graded, Andy stated, "No. We just want to see what is happening!" When a student tried to confirm a true or false answer, Andy asked, "If it is true, what makes it true?" In short, Andy used a variety of active learning techniques to engage students with the material throughout the entire class; he asked groups to share and compare answers, held class discussion on the true–false warm-up questions, asked students to raise their hands if they agreed with an answer, and had a student show and explain their answer to the class. These methods together cultivated into an interactive lecture, a more complex categorization of active learning than the previous semester. Andy also talked to students at eye level, seemingly making them feel more comfortable to communicate with him as he checked in with groups.

Andy provided insight into how this breakthrough may have occurred. Andy, being interested in education research, shared an openness to trying new techniques in order to "see what worked" and wanted to "gather his own personal data." During this time, Andy shared he was curious to try many active learning techniques because every class is different, and you need to try different techniques to find out what works. He also explained why he enjoys doing this:

> As a Ph.D. student I think I do more of thinking like, 'Okay if I want to do research, what can I actually find out?' So sometimes I think of all these things and say, 'Okay let me use this thing in the class. Will it make sense? Will it work?

Similar to Max, having a sophisticated knowledge about active learning and emotions towards active learning that aligned with his knowledge may have helped Andy better manifest a targeted, consistent, and flexible approach to using active learning in the classroom.

Fall 2018 Breakthrough in Emotion Towards Active Learning (2)

In Fall 2018, Andy articulated a breakthrough with his emotions towards active learning. Remaining consistent in his knowledge about active learning, Andy now saw instruction as synonymous with active learning, and displayed a higher intensity of the emotion trust, admiration. He stated:

> I can say now that I feel uncomfortable seeing my students sitting individually. If they are not working in groups, it seems like I'm doing something wrong. You know at a point in time you come to this realization that this thing is now part of me.

In continuing the conversation, he also expressed joy in using such techniques. He discussed some of the hesitations students might have about engaging in active learning, but asserted, "People might not think this, but I love that it's all about the knowledge." This observed breakthrough may be attributed to Andy's experiences co-teaching with the course coordinator that semester. During the interview, he frequently mentioned learning from the other instructor. Being able to learn from and see an experienced instructor use active learning may have heightened his infatuation with such techniques. Also, this breakthrough was observed despite Andy being challenged with a larger class size and a classroom that was more conducive to a more traditional lecture style of teaching. These challenges may have incited critical reflection, further reaffirming and strengthening more positive emotions around active learning techniques.

Fall 2019

In Fall 2019, Andy's knowledge about, emotions towards, and use of active learning remained unchanged as he continued to show an advanced knowledge about, positive emotions towards, and flexible uses of active learning in his classroom. During this time, he reiterated his role as a facilitator when defining active learning: "There is one thing I know about active learning for me… placing myself as a facilitator in the classroom whereby my strategies allow my students to…take active roles in the classroom." He emphasized that the active roles students take include discussing with each other and solving problems.

Although initially resisting active learning based on what his initial frames of reference were about teaching, Andy's critical reflection on his experiences using active learning in his classroom facilitated updates in his knowledge and emotional frames of reference. During our study, as Andy gained more experience with active learning, his frames of reference surrounding his knowledge and emotions were reinforced, setting the stage for a committed and flexible approach to using active learning.

Cross-Case Comparisons

We noted similarities and differences about how and when Andy and Max experienced breakthroughs during our study. First, both expressed initial frames of reference largely grounded in their student experiences, which were predominantly traditional. We observed Max experience a breakthrough with knowledge, as she started to describe in detail how she could get her students engaged in the material and with others. Andy shared a similar understanding of active learning upon entering our study. The timing of this in our study is to be attributed to his prior teaching experience and training. Both attributed their knowledge about active learning, in part, to their initial experiences in PD programs. Once understanding active learning through the lens of engagement, each GSI remained consistent in how they articulated their knowledge of active learning for the study. Further, each GSI experienced

a breakthrough in having more positive emotions towards active learning. Once experiencing a breakthrough in emotions, we observed an increased willingness (in each GSI) to use active learning techniques in their classrooms, and both GSIs shared how they trusted the use of active learning to heighten student learning.

Overall, Andy shared more consistent and extremely positive emotions than Max during the duration of the study. Max showed evidence of reservation towards active learning after her breakthrough, largely attributing this to the new flipped classroom structure and additional responsibility the curricula was putting on her students. Andy, initially introduced to active learning through a flipped classroom, shared that the class structure helped him understand how he could interact with students and not be the "grand teacher" in front of his students.

Discussion

Even though national recommendations suggest the use of active learning techniques in undergraduate statistics and mathematics instruction, many instructors rely on lecture-based instruction, believing that their students learn best in that environment (Johnson, 2019). We observed this reliance on lecture-based instruction with Max and Andy, particularly as they detailed their first-time teaching. Literature on novice instructors suggests that the first year of teaching is a survival year (Beisiegel, 2019). During this stage, the instructor's main concern is whether they can survive, reflecting on questions such as, '"Can I get through the day in one piece;' 'Can I really do this kind of workday after day?'" (Katz, 1972, p. 3). While in survival mode, instructors are first learning about teaching and are not necessarily ready to enact more demanding instructional approaches, such as active learning (Beisiegel, 2019; Katz, 1972). However, the different trajectories in breakthroughs between Max and Andy provide insight into how to promote early, consistent, and persistent use of active learning.

GSIs need to feel confident in and be challenged by their course structure before implementing active learning techniques. Andy's and Max's use of active learning were heavily influenced by the structure of their courses. Andy's breakthroughs with active learning were kickstarted during his first semester teaching when he got to experience active learning in a flipped classroom that required its use. These experiences allowed him to critically reflect and update his existing frames of references around emotions towards active learning that he developed as a student. Having a curriculum and classroom environment that supported active learning through the required use of group work allowed Andy to expand his knowledge about, and update his emotions towards, active learning. Initially resisting active learning, curricula that supported his use of active learning allowed him to conclude, "Oh! This is cool." The early timing in which he had experiences to reflect and update his emotions towards active learning helped fortify persistence and consistent use. Persistence and consistency are staples of behavioral change, relating to observing breakthroughs with using active learning in the classroom (Duckworth & Gross, 2020). If this critical reflection came later, eliciting this critical reflection process may have been more difficult.

Max, whose first teaching experiences were in more traditional lecture-style classrooms, didn't experience a breakthrough in her emotions towards or use of active learning until the very beginning of her third semester teaching. This finding may support research suggesting that instructors have an easier time using active learning when the curriculum is inquiry-based and necessitates the use of active learning for instruction from the beginning (e.g., Haack, 2008). Inquiry-based learning revolves around students obtaining knowledge through doing and discovery. Often structured in problem-based learning, this type of curricula is not conducive to teaching through passive lecture and aligns more with the core fundamentals of active learning techniques and student engagement (Ernst et al., 2017).

This finding also suggests that Max's early experiences with active learning (such as through the GSI PD) may have been productive in helping elicit a breakthrough in knowledge but was not eliciting critical reflection to transform her emotional frames of reference. Starting in Fall 2018, Max wanted to challenge herself to use more than just lecture techniques because of the negative experiences she had with lecture in prior semesters. Critically reflecting on these negative experiences at the beginning of the semester helped positively shift Max's emotions, cultivating her use of such techniques. This suggests that the alignment of breakthroughs, as well as the timing in which they occur, may be key to helping GSIs use active learning in their classroom. Max, despite understanding active learning through the lens of engagement, did not start using active learning in her classroom until she subsequently experienced a breakthrough in her emotions towards active learning before going into the Fall 2018 semester. PD alone may not be enough to facilitate breakthroughs for newer instructors who have limited experiences with active learning. Our results suggest that frustration around how to start implementing active learning into a class that is currently being taught by lecture may inhibit a breakthrough in emotions towards such techniques. Further, PD targeted only on increasing GSIs' knowledge about active learning may not result in their use of it. Like Andy's initial experiences with active learning, when in a flipped classroom during Fall 2019, Max articulated that using group work was easier than before. This is further evidence to suggest that providing experiences early that show GSIs that active learning can be successful in a mathematics or statistics course is critical, and designing courses within classrooms or curricula that help enable such techniques can make the experiences less complicated for GSIs, and easier to garner positive emotions towards active learning.

The timing of and descriptions around breakthroughs in using active learning provides evidence that the roles of knowledge about and emotions towards active learning may drive a feedback loop that promotes or inhibits GSIs' breakthroughs in using active learning. Before the Fall 2018 semester, Max made minimal attempts to use active learning, so her knowledge about and emotions towards active learning arose from what she learned during the GSI PD and her experiences with group work as a student. Despite showing a breakthrough in knowledge, Max continuously taught "using what works," which limited her opportunities to critically reflect and update her frames of reference around emotions towards active learning. Because traditional teaching experiences as a GSI in her initial semesters of teaching "were working," any critical reflection reinforced negative emotions towards active

learning, strengthening her existing frames of reference. Traditional lecture techniques ensured the students were getting all the information they needed from her and did not create a learning environment where the students could become adversarial or feel like children—all deterrents for Max to use active learning.

Facilitating a breakthrough in a GSI's emotions towards active learning is key to consistent use of such techniques. Research suggests that positive and negative emotions greatly influence individuals' knowledge, creation, learning, and memory while acting as a motivator for action and behavior (Kremer et al., 2019; Tyng et al., 2017). When Max started to raise hesitations with active learning again in Fall 2019, she did not resort to using traditional ways of teaching. A previous breakthrough in her emotions towards active learning updated her frames of reference, allowing her to reflect on newfound hesitations with trust and acceptance. Using these frames of reference to reflect on her current emotions, Max suggested, "There has to be a middle ground of these two [techniques]." Andy, with extremely positive frames of reference towards active learning, explained that, despite receiving some student resistance, he would always commit to a flexible active learning approach.

This evidence suggests that careful consideration into how PD can best support GSIs' emotions towards active learning may be necessary to support GSIs' use of active learning in the classroom. This may include designing PD to better facilitate emotional responses and critical reflection around active learning. We suggest interventions designed with emotional intelligence in mind. Emotional intelligence is commonly defined as the ability to perceive, use, understand, and manage emotions. Research has shown that emotional intelligence can be improved through training (Gilar et al., 2019), and group-based training can help cultivate more positive emotions. This includes creating opportunities for GSIs to openly communicate about teaching inside and outside PD, thereby providing a better sense of community and support. Tangible practices to improve emotional intelligence include incorporating small group activities where GSIs feel they are in a safe space to share ideas and experiences, discuss current literature, and admit challenges in teaching to further discuss. Based on our evidence, we suggest this be taken further by adapting a co-teaching model for new GSIs so they can be situated in an experience with active learning to facilitate critical reflection. This may also be accomplished with required in-person observations of an instructor who teaches using active learning techniques. However, we acknowledge that these are suggestions and recommend further investigation into emotional intelligence's role in PD for GSIs.

Limitations

In this study, we narrowed the complexity of a GSI's frames of reference to their knowledge about and their emotions towards active learning. The frames of reference a GSI holds towards active learning are more complex and can be thought of as a set of criteria or stated values in relation to which GSIs use to make judgments. Expanding, or investigating different constructs, such as teaching beliefs and values, would lead to a better overall understanding of the complexity of GSIs using active learning in their classrooms. Further, investigating other influential factors related to knowledge about

and emotions towards active learning, and how these factors can be leveraged to challenge GSIs' initial frames of reference around such techniques could lead to a deeper understanding of how to help break feedback loops that may influence more traditional styles of teaching.

Future research should collect data at more frequent timepoints within and across semesters to obtain higher resolution data for investigating when breakthroughs occur with active learning. It may be particularly useful to collect data at times within a semester when GSIs critically reflect and update their frames of references, such as after they solicit feedback from students about their teaching or observe another instructor use active learning. It also may be useful to let GSIs determine when they themselves experienced a breakthrough and collect self-reported data both within and across semesters. These data may provide a finer reflective representation of GSIs' frames of reference and experiences and offer insight into any critical reflection processes that may have promoted breakthroughs with active learning.

We also acknowledge a potential limitation in our data collection methods. We designed these methods for GSIs to articulate and discuss their current knowledge about, emotions towards, and uses of active learning across timepoints. For more complete data, we also asked questions that had GSIs reflect on previous semesters. Although unlikely, this could have unauthentically induced critical reflection, and should be noted.

Conclusions

The evidence from this research strengthens the argument that GSIs can use active learning early in their teaching experiences with proper support and offers information about how to support GSIs in the future. Sufficient knowledge about active learning is foundational but not sufficient for its use in a GSI's classroom. Emotions towards active learning play a key role in how a GSI implements active learning, if at all, and experience with active learning should be leveraged to elicit positive reinforcement. Thus, support structures including PD, classroom environments, and curricula supporting inquiry-based learning need to be in place to foster active learning. Further, PD programs need to offer ongoing support for GSIs' evolving needs as their knowledge about and emotions towards using active learning change over time. Although knowledge about active learning consistently grew for each GSI, emotions towards active learning were more volatile for Max. Longitudinal studies, such as this one, are imperative to understand how PD can support the refinement of GSIs' instructional practices and foster positive emotions towards active learning techniques.

Appendix

Common Questions

The interviews were semi-structured in nature, allowing for more natural conversations to be had around each construct. Below is a list of common questions that were

asked to participants to incite initial conversations around each graduate student instructors' knowledge about, emotions towards, and use of active learning. Each interview lasted roughly two hours.

Knowledge Questions

1. What is your definition of active learning?
   (a) If they use the term engagement: ask to define engagement.
2. How did you form this definition?
3. Has your definition changed since last semester? Last year?
4. What different types of teaching techniques would you consider active learning?

Emotion Questions

1. What is your reaction when asked to implement a different active learning technique?
2. How do the different types of active learning techniques planned for the class alter your feelings on that day's lecture? During lecture?
3. So, you are (insert emotion) about active learning? (Reaffirmation question within natural conversation)

Use Questions

1. What current active learning strategies have you been using in your classroom?
2. What (if any) other types of active learning techniques do you plan on using this semester?
3. Show video data: Would you define this clip as using active learning? Why or why not? What type of active learning technique are you using here?

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Data Availability Data are not publicly shared with this submission. It proved increasingly difficult to anonymize transcripts while keeping the integrity of the data intact.

Declarations

There are no financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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