Enacting Active Learning in Calculus: How One Graduate Teaching Assistant's Instruction Shifted with an Experienced Learning Assistant's Support

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This study explores the changes in a graduate student teaching assistant (GTA)'s teaching actions over two semesters in an active learning Calculus I course. Cole, a GTA with little teaching experience and no prior experience with active learning, was paired with an experienced undergraduate learning assistant (LA) in his second semester teaching in a purposefully designed active learning-based Calculus I course. Cole's teaching actions varied more when paired with the experienced LA, including short periods of lecture and classroom discussion with the facilitation of group work. This case study provides insight into how an experienced undergraduate LA can be an agent of change in an active learning-oriented classroom.

Keywords: Active Learning, Calculus, Teaching Practices, Graduate Teaching Assistants, Undergraduate Learning Assistants

At the undergraduate level, introductory Calculus is typically a core requirement for degree programs across science, technology, engineering, and mathematics (STEM) disciplines. However, Calculus can act as a barrier to students' continuation in such programs, with many students who fail calculus ultimately leaving STEM majors (Smith & Funk, 2021). Because of this relationship, many are concerned with the currently high rates of student drop, withdrawal, or failure from calculus courses (Bressoud & Rasmussen, 2015).

Previous research suggests that active learning is an effective means of lowering DWF rates (students who receive a D, F or withdraw from the course) in Calculus courses (Bressoud & Rasmussen, 2015; Freeman et al., 2014) and cultivating more positive attitudes toward STEM subjects (Tutal & Yazar, 2022).While active learning is conceptualized in many ways (Ting et al., 2023), we offer the following literature-based definition to guide our work: active learning is marked by a learning environment which provides meaningful opportunities for all students to learn mathematics, by incorporating engagement with cognitively demanding mathematical tasks, and instructor facilitation of collaborative learning opportunities, including the promotion of both small and whole-group discussions (CBMS, 2016).

Due to its documented success in cultivating positive content-related and affective outcomes for students, university administrators and faculty within mathematics departments are interested in transforming large-lecture introductory Calculus courses to include active learning practices. Practically, the transformation of such courses requires "buy-in" from a number of individuals, including course instructors and graduate teaching assistants (GTAs) who are responsible for the teaching of the course. For instructors, the implementation of active learning can require construction of high-level tasks to engage students, moderation of classroom discussions, and facilitation of group work, which are distinct from the skills required to teach traditional, lecture-based courses. At larger universities, many Calculus courses rely on the teaching of graduate students, either as instructor of record or as a recitation section instructor. These GTAs often have scant teaching experience, speaking generally. They also typically have little experience with active learning as a student, meaning that they have few examples to emulate when asked to teach in active ways. Consequently, recent efforts have been made to create and provide

professional development to GTAs regarding the implementation of active learning and other evidence-based strategies (Deshler et al., 2015), but still little is understood about GTAs' teaching practices and their development.

Motivated by this under-researched topic, we conducted a previous study (Sager et al., 2023), in which we examined the conceptions and teaching actions of a group of Calculus GTAs with varying levels of background in teaching and experience with active learning. We found that more experienced GTAs tended to scaffold their small-group work time with short bursts of class discussion and content review, while less experienced GTAs tended not to incorporate such scaffolding. One GTA from this study, Cole, had had little previous teaching experience and no experience with active learning, and showed little scaffolding of his group-work time during his first semester implementing active learning. However, our research team noticed significant qualitative differences in his classroom environment during his second semester as a GTA when he was paired with an undergraduate Learning Assistant (LA) who had ample experience teaching and learning in the active learning environment at the university. In this current study, we specify these noticed differences, asking: how do Cole's teaching actions and perspectives on active learning shift as he gains experience with different LAs in an active learning Calculus I course, and how are these shifts related to the actions and perspectives of the LAs? Cole's case contributes to our understanding of GTA professional development in the active learning context by showing how GTAs development and the broader classroom environment can be impacted by LAs.

Literature Review

The important role of GTAs in the introductory STEM experiences of university students has led to increased interest in professional development (PD) programs for GTAs (Braley, et al., 2023). PD programs allow GTAs to interact with student-centered and evidence-based practices, such as active learning (Archie et al., 2022, Deshler et al., 2015). Many GTAs have little to no teaching experience, and have not experienced student-centered teaching in a classroom, which leads to limited confidence in implementing these strategies in their own classrooms (Deshler et al., 2015). Additionally, while GTAs may believe students learn best through active learning or other student-centered strategies, they often do not act on this belief, instead teaching how they were taught (Patrick, et al., 2021). GTAs also need a way to gain the pedagogical content knowledge and knowledge of student thinking central to effective teaching (Kung & Speer, 2009). The research on graduate students' background and their implementation of student-centered learning strategies is sparse.

While GTAs can act as facilitators of active learning in large-lecture courses, an additional approach to facilitation is through the incorporation of undergraduate LAs into the course structure. An LA is an undergraduate student who has successfully passed the course previously and returns to aid in the teaching of that course, typically by facilitating discussion amongst small groups of students. In addition to their time in the classroom, LAs also typically participate in a pedagogy course and meet weekly with instructors to discuss course content. While much of the research around the LA model of instruction has focused on ascertaining the benefits to both students and LAs involved in this instructional model (Barrasso et al., 2021), recent efforts have centered on aspects of departmental change, since this was an original goal guiding the design of this model (Otero et al., 2010). In particular, the nature of LA-faculty partnerships in the instruction of LA-supported courses has been of interest. Faculty members working with LAs have reported improvements to their course designs, including increased emphasis on active learning classroom activities, and that LAs present them with new pedagogical perspectives (Hill

et al., 2024; McHenry et al., 2010). Others have begun to conceptualize how these faculty-LA relationships impact course design and particular instantiations of the LA instructional model (Davenport et al., 2017; Karch et al., 2024). While the literature suggests that these faculty-LA relationships influence both instructors' professional development and the design of the course, the impacts of LAs' relations to other members of the instructional team remain largely unexplored. Our study contributes to this area by exploring the relationship between a GTA and LA, detailing the impacts of this relationship on classroom instruction and this instructor's conceptions of teaching and learning.

Data and Analytic Frameworks

This case study takes place within a larger project focused on improving introductory STEM courses at a large research university in the Northeastern US. One component of the project was the introduction of active learning into the Calculus I course. The course follows a lecture-recitation structure, where the students meet with a faculty member for a lecture section (of approximately 120 students) three days a week, and with a GTA in recitation section (of approximately 20 students) the other two days. Undergraduate LAs were introduced within the recitation sections to support group learning, an integral part of the active learning incorporated into Calculus I recitations.

To promote active learning, a new recitation structure was suggested to GTAs: a short introduction, followed by small group work, and whole class discussion. GTAs were given autonomy to adapt the suggested structure to fit their classroom. At the beginning of each semester, the course team (faculty instructors, GTAs and LAs) met with project team members to discuss the active learning and recitation structure, ask questions, and give and receive advice about best practices. In addition, all first-year TAs in the mathematics and statistics department are required to take a full year course discussing pedagogy and other topics pertaining to GTAs' teaching, including active learning. Similarly, the LAs are required to take a pedagogy course designed for peer coaches. Both LAs and TAs also meet with their peers and course instructors weekly to discuss upcoming course topics, but also to share feedback and suggestions related to course activities.

This case study focuses on one GTA: Cole. Cole was a beginning Ph.D. student in statistics and served as a GTA in this active-learning recitation during the Spring 2023 and Fall 2023 semesters. During his first semester as a GTA in the active learning context, Cole taught with an LA named Ann, a second-year mechanical engineering major who was a novice LA. However, during the Fall 2023 semester, Cole worked with an LA named Fran, a junior environmental engineering major who had been a mathematics LA for the three previous semesters.

In this study, we focus on the case of Cole because the research team noticed significant qualitative differences in Cole's classroom between these two semesters, with many of these differences seeming to be initiated or introduced by the LA, Fran, in the second semester. While Cole's Spring 2023 classroom practices and conceptions of teaching were analyzed in a previous study (Sager et al., 2023), here we examine how Cole's actions and conceptions change over time, connecting these changes to his relationship with Fran. The data for this case study includes 360-degree video recordings of Cole's recitation sections across the Spring 2023 and Fall 2023 semesters and as well as two interviews with Cole (one from the end of each semester) and one end-of-semester interview with each LA. Video recordings were conducted during six recitation sections each semester consisting of class sessions in which students worked on researcher-designed, conceptually-oriented activities. The semi-structured interviews with Cole focused on his perception of, experience with, and use of active learning. The LAs' interviews

we also semi-structured, but included stimulated recall, with each LA reflecting on video clips of their interactions with small groups and discussing their general thoughts on mathematics teaching in this context.

In order to capture the actions of Cole, Ann, Fran, and the students in the classroom, the Classroom Observation Protocol for Undergraduate STEM (COPUS) (Lund et al., 2015) was used to code the recitation video recordings. COPUS is an observation framework which applies codes for instructor and student actions to every 2-minute interval of the recording. Traditionally, COPUS is used to categorize an instructor's teaching (e.g., lecture-based or active), specifically for the purposes of professional development. However, we leverage COPUS as an analytic tool to provide a snapshot of recitations across the semester. For more information about COPUS and codes in the framework, see Lund et al. (2015). Two recitation recordings were chosen for each semester – one from the first third of the semester, and one from the last third, based upon the availability within the data set. The content of the early semester activities was the same for both semesters (continuity), while the content of late semester activity was different for the two semesters (antiderivatives and logarithmic differentiation, respectively). Nevertheless, each recording took place during the implementation of researcher-designed, conceptually oriented activities. Each classroom recording was coded by two members of the research team resulting in an interrater reliability of 92% and disagreements were discussed until a consensus was reached. The codes for Cole, the LAs, (Figure 1) and students (Figure 2) were aggregated over the two recordings for each semester in order to provide a profile of the classroom over the entire semester.

The GTA and TA interviews provided context and background to the GTA and LA relationship and Cole's actions in the classroom. Interviews were coded using open and thematic coding to capture the changes in Cole's definition of active learning and the GTA and LA relationship in the classroom (Miles et al., 2018; Strauss & Corbin, 1998).

Results

In this section, we compare the classroom actions of Cole, the LAs, and the students during Cole's first and second semesters as GTA in Calculus I. While Cole's actions and perceptions during the Spring 2023 semester are more extensively detailed in Sager et al. (2023), we provide an overview here to contextualize our new analysis of his LAs' actions, their perceptions, as well as his evolving conceptions and practices in the Fall 2023 semester. We illuminate the changes that occurred when Cole worked with an experienced learning assistant.

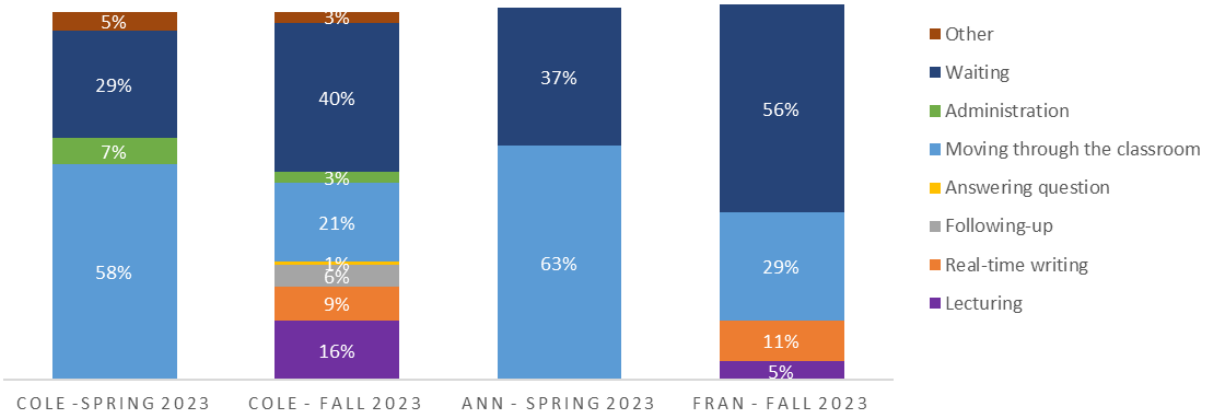

Figure 1. Instructional actions of Cole and his learning assistants.

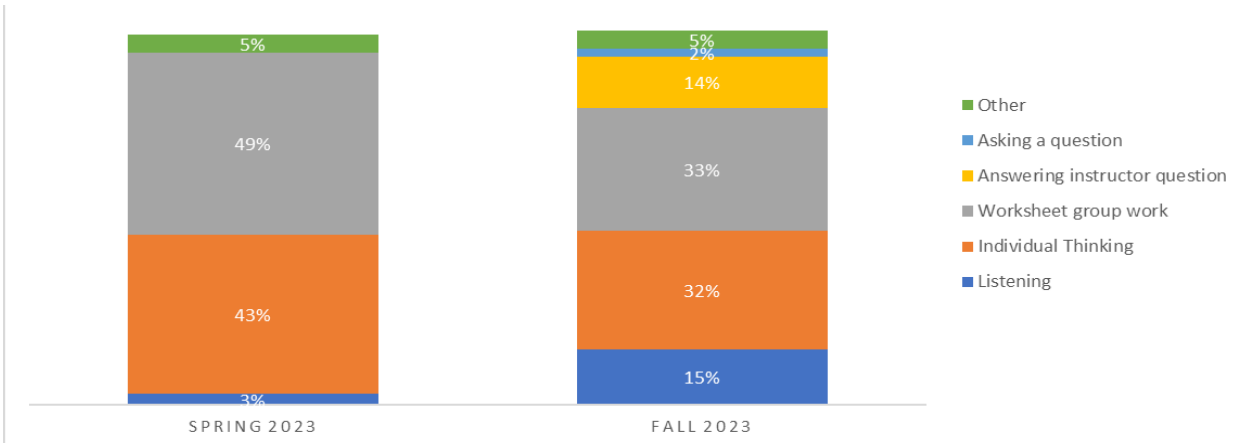

Figure 2. Classroom actions of students in Cole's classrooms.

Cole was a first-year Ph.D. student in statistics in Spring 2023, when he first acted as a teaching assistant for Calculus I. At this time, he was in his second semester of teaching as a graduate student, having taught precalculus without an LA or conceptually oriented activities in his first semester. His only teaching experience before entering the Ph.D. program was as a virtual one-on-one tutor in a program for gifted elementary students. He reported no previous experience with active learning as a teacher or a student. He "barely asked [his] teacher a question" as a student, and he would "pretty much work alone."

In contrast to his own experience as a student, Cole's working definition of active learning during the Spring 2023 semester, his first time teaching in an active learning setting, was "engagement." He believed that "most of [the] students would just copy paste notes and just leave it there. So, they learn nothing, but they think they learned a lot." Engagement and interaction were his antidote to the "copy paste" mentality of students. His actions in Spring 2023 from Figure 1 reflected his emphasis on interaction with the students -- 58% of his classroom actions were m*oving and guiding*. *Moving and guiding* was coded when the instructor moves around the classroom, interacting with students working on the activity individually or in groups. Cole's emphasis on allowing students to engage with the activity was also reflected in the student actions from Spring 2023 as well (Figure 2), as 92% of their actions were either *group work* or *individual work*.

Cole described himself as a "tutor" in his first semester as a Calculus I GTA – his first semester in a purposefully-designed course using group work and active learning. The lack of any *lecturing*, *follow-up* or *real-time writing* in his actions corroborates this description. He described that his role in the classroom was to "learn if [students] are active, thinking or learning or not ... I definitely will walk around so I'll ... check their work." In contrast, he described how students from his previous semester without active learning would "just listen to me and then copy what I wrote on a board," and characterized himself as a "lecturer." His "tutor" status was also reflected through an abundance of *waiting* codes. Because he viewed himself as a tutor, he waited for students to ask for assistance.

Ann acted similarly to Cole in the 2023 semester. In Figure 1, we see that Ann spent her time in recitation either interacting with groups (63% of her COPUS codes were *moving and guiding*) or *waiting* to interact with students (37% of her COPUS codes were *waiting*). While she spent a significant proportion of her time *waiting* to assist students, she explained in her interview that this was because, as a novice LA, it took her some time to "get more comfortable with the students" and be able to "go out of my comfort zone and initiate questions with the students". Additionally, her primary engagement in *moving and guiding* is consistent with the

responsibilities of an LA in this context as they were primarily facilitators of small group discussion. It is also consistent with her description of her role as an LA, as she stated her role is "answering questions" and acting as a "second brain" for Cole. That is, as a recent learner in the course, she provided a "second way to think about" course content and reported that Cole often sought her advice when addressing student questions, saying "when he felt like he couldn't answer it that well, he would come to me and ask, can you explain this?". From Ann's description, we see Cole's disposition toward collaboration with his LA, with Cole actively enlisting the expertise of his LA as a recent Calculus learner.

While Ann's actions of *waiting* and *moving and guiding* were consistent with and typical of the responsibilities of an LA in this environment, Fran showed more variation in her classroom actions. We see that Fran also engaged in *writing on the board* (11% of her COPUS codes) and *lecturing* students (5% of her COPUS codes). *Writing on the board* included instances when Fran would work out a solution at the chalkboard at the front of the room, walking through the steps of the problem by soliciting these steps from students around the room. She also briefly lectured about course content, explaining general concepts to students. Like Ann, these actions were consistent with her description of her classroom role, saying:

> "[Cole] and I work really well together. I feel like we pretty much have the same role. He obviously is grading the homework and stuff like that. And towards the end of class, if there's an overall concept announcement or we want to go over L'Hospital or something, he'll do that as the TA. But working in the classroom, we pretty much do the same thing"

In contrast to Ann, who viewed herself as more of an assistant to Cole, Fran viewed herself and Cole as having nearly identical roles. This alternate view was rooted in Fran's previous LA experience, since she previously worked with an experienced GTA who supported her in taking on a more active role, saying this GTA made her "feel like another TA in the class". While Fran had a higher proportion of *waiting* codes than Ann, this is attributable to both a smaller class size in Fran's semester (i.e., there were fewer students to engage with) and the increase in Cole's actions related to whole-class engagement. Overall, we see that Fran's previous experience as an LA paired with a supportive and experienced GTA, empowered her to take on a more active role in her teaching with Cole.

We see in Figure 1 that Cole's actions in the classroom changed when working with Fran. In addition to the *moving-guiding* and *waiting* codes, 16% of his COPUS codes were *lecturing*, and 9% were *writing on the board*. We notice that Fran also includes *lecturing* and *writing* with the *moving and guiding* and *waiting* expected from an LA facilitating group work. Often, Cole built upon Fran's engagement of the whole class, adding a short explanation (*lecture*) addressed to the class, or to *follow up* (6% of his COPUS codes) on a student question or problem from the activity. While Cole, like Fran, had a high proportion of *waiting*, the class was smaller and more independent in their group work, leading to less time where Cole and Fran were working with the groups.

Cole's perception of his role in the classroom also changed after working with Fran. In his interview at the end of the Fall 2023 semester, he talked about how he had "transferred [himself] from the teacher to the guide" and pointed out that his new goal was to "mix these things together." He sought to combine the "lecturer" of his first semester of teaching with the "tutor" of Spring 2023. His classroom actions indicate that he was successful in meeting this goal. His students' actions are also much more varied in Fall 2023: only 65% of their actions are either *group work* or *individual thinking* on the activity, compared to 92% in Spring 2023. In accordance with Cole's change to include more *lecturing*, 31% of their actions are *listening,*

answering instructor questions or *asking questions*. Some of the *other* codes for students include a student writing an answer on the board and explaining the problem to the class, a contrast to the *other* codes in Spring 2023, when the *other* codes were exclusively for off-task students or packing up to leave class.

When asked what advice he had for GTAs implementing active learning in the future, his response was that they should "learn from [Fran]." He mentions that she is "able to teach on the stage" and also adept at "teaching everything to the students". That is, Cole learned from Fran's example how to incorporate appropriate scaffolding through whole-class engagement into his teaching in the active setting. Cole and Fran take a similar role in the classroom, with Fran diverging from the traditional role of an LA, and Cole welcoming and assimilating her teaching actions.

Discussion

Cole's teaching actions changed dramatically in his second semester of leading an active learning recitation for Calculus I. In his first semester, he took the relatively passive role of a "tutor", spending a significant amount of time waiting for questions and interacting directly with the groups. His only interaction with the whole class was administrative in nature – giving directions or reminders. His LA, Ann, used similar actions, implementing the standard role of a learning assistant. When working with Fran the following semester, he incorporated more lecture and class discussions into his recitation. This more varied set of teaching moves led to more engagement with students, and by Cole's own definition, more active learning.

While we cannot point to any single reason for this change, Cole and Fran both describe their relationship as an important aspect of the classroom dynamic. Cole was going into his second semester in an active learning facilitation role, while Fran was in her fourth semester as a learning assistant. Fran was given the opportunity to take on more responsibility than a traditional LA, and Cole varied his teaching actions in a similar way to her. Cole cited Fran as an inspirational figure for teaching, indicating that she impacted him through their time working together.

While including LAs in a course is often viewed as a professional development experience for LAs themselves, we offer evidence that this relationship can be bidirectional, with LAs also acting as model teachers for the instructors with whom they work. Experienced LAs can be agents of change in promoting practical active learning teaching actions in the classroom. Our study has practical implications for GTA professional development programs, showing how novice GTAs can be supported by the presence of LAs in their classrooms and suggests that GTAs can benefit from real-time illustrations of pedagogy in their institutional contexts. Likewise, our results carry implications for LAs' pedagogy courses, showing that such courses should support LAs in confidently enacting innovative teaching techniques.

Overall, we emphasize that the collaboration between LAs and instructors, especially when they differ in experience, fosters a mutually beneficial professional growth process. This partnership can also enhance the implementation of active learning practices in more scaffolded ways. Our findings suggest that expanding LA programs and integrating them more closely into GTA professional development can play a critical role in advancing teaching effectiveness in higher education.

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