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GLAMS: Graduate Learning Assistants in Mathematical Sciences

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ABSTRACT
In the fall of 2020, our department at George Mason University integrated graduate learning assistants (GLAs) into our graduate core courses. GLAs are funded graduate students who assist instructors during class, facilitate active learning preliminary exam problem-solving sessions, hold extra office hours, and serve as peer mentors for beginning graduate students. The GLAMS program was designed to support beginning graduate students as they prepared for their preliminary exams. We describe the program and provide details about how it was implemented. We include preliminary student feedback as well as faculty and GLA reflections. To conclude, we outline our plans for programmatic changes moving forward.

KEYWORDS
Graduate; mathematics; learning assistants; active learning; STEM

1. INTRODUCTION

In the fall of 2020, faculty in the Department of Mathematical Sciences at George Mason University (GMU) was exploring ways to support graduate students as they prepared for preliminary exams. Students often struggled to pass the exams by the program's deadline, causing some to exit the program. Others delayed taking the exams, ultimately delaying their graduation. Faculty suspected that students did not know how to study for the exams, were not starting to study early enough, and/or did not have study groups to work with. Therefore, we decided to implement a program that included advanced PhD students as learning assistants in our core prelim courses. We called these students Graduate Learning Assistants (GLAs), following the model of Undergraduate Learning Assistants (ULAs) that we were familiar with. GLAs assist instructors during class time, facilitate active learning preliminary exam problem-solving sessions outside of class, hold extra office hours, and serve as peer mentors for beginning graduate students. GLAs are funded PhD students who take on this role as half of their graduate teaching assistant assignment for the semester (approximately 10 h per week).

The Graduate Learning Assistants in the Mathematical Sciences (GLAMS) program provides much-needed prelim preparation support for incoming graduate students, and it allows new graduate students the opportunity to cultivate informal

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mentoring relationships with more advanced graduate students. It also benefits the GLAs by giving them the opportunity to teach more advanced material as well as allowing them to shadow a professor in classroom instruction. The paper proceeds as follows: In Section 2, we briefly review the literature that supports the design of the GLAMS program. In Section 3, we give a detailed description of the GLAMS program, including how it was implemented in three core courses in the fall of 2020. In Section 4, we describe student feedback about the program. Sections 5 and 6 contain faculty and GLA reflections, respectively. Finally, Section 7 describes future directions for our GLAMS program, and we conclude with a reflection from our department chair.

2. PEDAGOGICAL BACKGROUND

While there is a considerable amount of information available about the use of ULAs in undergraduate courses, the use of GLAs has been relatively unexplored. The GLAMS program is designed around three pedagogical practices that are student-centred and have been shown to support student success: active learning, learning assistants, and graduate near-peer mentorship.

First, the program leveraged faculty knowledge around active learning [2,10,17,18,21]. We follow Laursen and Rasmussen's [12, p. 138] four-pillars definition of active learning as spaces where:

(1) Students engage deeply with coherent and meaningful mathematical tasks.
(2) Students collaboratively process mathematical ideas.
(3) Instructors inquire into student thinking.
(4) Instructors foster equity in their design and facilitation choices.

In undergraduate classrooms, active learning has been shown to improve learning outcomes [5,8], increase opportunities to explore solutions to problems, and provide opportunities to engage in and critique the mathematical reasoning of others [1]. There is some evidence that active learning may lead to more equitable outcomes for historically excluded students [11], but findings from a recent study indicate that this is not always true [9]. While we are working to incorporate more critical perspectives into our active learning approaches (see [6,20]), our efforts here rely primarily on more traditional approaches that have not yet integrated these critical pedagogies.

Second, we leverage our experience working with ULAs. ULAs have been shown to improve learning outcomes in STEM courses, as well as increase student satisfaction with the course [23]. Some studies have also demonstrated that ULA-supported courses are more equitable than those without ULAs, though again, these results are mixed [26]. Further, ULA experiences have been shown to improve the content knowledge of ULAs [27]. At GMU, we have a well-established ULA program in the College of Science [2,21,22], and typically employ about 30–40 ULAs each semester in mathematics classrooms.

Finally, we incorporate an understanding of near-peer mentorship in graduate STEM education. The GLAs serve as near-peer mentors to complement faculty mentorship in supporting graduate students' academic success [3,15,16,19]. Near-peer mentorship in graduate school has been shown to be beneficial to mentees by supporting academic success, increasing self-confidence and motivation, reducing stress, decreasing feelings of isolation, facilitating the development of academic networks, and cultivating positive career competencies [14,19]. Mentorship of graduate students is a core practice in STEM education, and graduate students are encouraged to develop several supportive mentorship relationships during their studies [16]. Near-peer mentoring relationships are also beneficial to mentors themselves. They encourage mentors to cultivate a sense of belonging and allow students to strengthen their science self-efficacy [24].

3. PROGRAM DESCRIPTION

In this section, we give an overview of the structure of the GLAMS program as it was implemented in fall of 2020. We begin with an overview of our graduate program and then describe the GLAMS program generally. We describe how we prepared for our first GLAMS semester and finish this section with more specifics on how GLAMS was implemented in each core course.

3.1. Departmental Context

To put the program in context, GMU is a large public 4-year R1 university just outside Washington, DC, in Virginia. Current university enrollment hovers at around 45,000 students, including undergraduate and graduate students. The students come from diverse backgrounds, and many PhD students are working full-time while pursuing graduate studies. The math department employs about 30 tenure-line faculty, 15 more instructional faculty, and approximately 15 adjunct faculty. The PhD program in Mathematics has about 45 students enrolled currently, with 8–9 new students each fall. Approximately 3–4 PhD students graduate each year. As part of the PhD degree requirements, all PhD students must pass three preliminary exams before they take their qualifying exam. The prelim exams are based on the material covered in the core courses. Core courses are taken by PhD students, Masters students, non-degree seeking students, and a few undergraduate students. In the department, a typical assignment for Graduate Teaching Assistants (GTAs) is to run recitation sections for large calculus classes. The department has an ULA program for undergraduate classes that consists of undergraduates who assist in active learning classes, lead review sessions, and hold office hours. Prior to the GLAMS program, there have not been assistants for graduate courses.

GMU has been committed to active learning pedagogies since fall of 2013, when they built their first active learning classroom. Several faculty in the math department participated in that first active learning cohort which was

supported by our teaching and learning centre as well as instructional designers. GMU has invested considerably in active learning classrooms and currently houses nearly 50 active learning classrooms, with seating capacity ranging from 24 to 120 students. In addition to this institutional support, the math department is in the middle of a multi-year NSF-IUSE grant to diffuse active learning approaches across several 100-level STEM courses, including Math, Physics, and Computer Science. As part of this grant, several members of the mathematics department began a small Community of Practice centred on active learning [2]. This small community supported a formal initiative to conduct all Calculus I and II recitations as active learning recitations. In addition to this formal initiative, many members of the mathematics department utilize active learning approaches in their classroom. The math department funds approximately 30–40 ULAs each semester to support faculty engaged in active learning, and holds a weekly teaching and learning seminar focused on equitable and active learning pedagogies.

3.2. GLAMS

Under the GLAMS program, each core course was assigned one GLA for 10 h per week (half of their semester GTA duties). The GLA had the following list of responsibilities:

- (3 h) Attend all lectures (or watch online videos) and help facilitate in class problem-solving sessions during synchronous class time with the instructor.
- (1 h for the first three weeks and 2 h after that) Lead a weekly active-learning preliminary exam preparation session. During this time, students work together on selected problems from past prelim exams. The instructor is not present, and this does not necessarily occur during the official class time.
- (2 h) Hold weekly office hours–drop in, no appointments needed.
- (1 h for the first three weeks only) Training on active-learning techniques in a meeting with the three core instructors.
- (1/2 h per week) Planning meeting with an individual instructor.
- (2 1/2 h) Preparing for active learning in class and prelim sessions.

The initial description sent to potential GLAs listed these benefits:

- Benefits for the core course students: Students have an extra mentor, more active learning opportunities, have more time to get help, and get to know a more senior graduate student.
- Benefits to the GLA: GLAs gain experience working in an active learning classroom, learn about how to have constructive interactions with students, improve their math skills, get to know other graduate students, and get to know a faculty member better. During the weekly meeting, the instructor helps to structure the problem sessions to be active and useful.

Table 1. Summary of weekly course time.

	Class and prelim preparation session structure
Linear analysis	Class met twice a week for 75 min each session. One session was fully active learning, in small groups. The other session was allocated for the prelim prep session. To free up this time, 75 min of lecture were delivered asynchronously. One 75-min prelim prep session was held each week during class time.
Numerical analysis	Class met once a week for 160 min. Each class session was 60% interactive lecture; 40% active learning. Two 60-min prelim prep sessions were held each week outside of class time.
Algebra	Class met twice a week for 75 min each session. Both sessions were fully active learning, in small groups. Two 60-min prelim prep sessions were held each week outside of class time.

3.3. Preparation and Communication

For the first three weeks of the semester, all instructors and GLAs met for 1 h per week for active-learning training. The full group met together again halfway through the semester to reflect on the program. After the initial training, each course's instructor and GLA held a 30-min weekly meeting and corresponded regularly via email. The meetings consisted of a discussion of how things were going in class and prelim sessions, a preview of upcoming material, a check that homework and prelim sessions had non-overlapping problems, and planning for future class and session work. This regular communication between GLAs and faculty allowed for small iterative changes to be made throughout the semester.

3.4. Implementation Details

In fall of 2020, we implemented the GLAMS program in all core courses which were offered: Linear Analysis, Abstract Algebra, and Numerical Analysis. All were three-credit-hour classes, taught in a strictly virtual format due to the COVID-19 pandemic. Enrollment in each course ranged from 15 to 22 students, and there were a total of 49 students across all three courses. Each course included lectures, homework, a midterm, and a final exam. The final also served (if the student opted in) as the preliminary exam in the subject area.

All courses were taught online and had some active learning incorporated. When students worked in small groups, the instructor and GLA would both circulate, giving hints, suggestions, or feedback as needed. The classes all included a GLA-led prelim prep session which reviewed problems from previous preliminary exams that aligned with the topic covered that week in class. At least a portion of this prelim prep time was run with active learning and small group work. There were differences in how each course was run and we summarize these in Table 1, giving more details below.

3.4.1. Linear Analysis

For the Linear Analysis course, lecture content was delivered via a weekly asynchronous lecture video (around 75 min) and written notes created by the instructor. The remaining class time (around 75 min) was reserved for active learning and run

jointly by the instructor and the GLA. During active learning class time, students were assigned breakout groups of size 3–5, with groups changing every week. In each session, groups worked together on 2–3 problems they had not seen before, which were tied directly to the lecture. After the groups considered a problem, the class reconvened, and one of the students (or the instructor) would give a sketch of the solution.

A similar format was used for the optional GLA-run prelim session. This structure allowed each group to look at each problem, while preventing students from spending too much time being stuck. No time lengths for problems were set ahead to avoid making anyone feel rushed. The active learning sessions aimed to help students figure out how to start problems and put together the key steps. Writing out detailed proofs was left to the homework. After midsemester feedback from students, the GLA started maintaining a list of the prelim problems covered. Final grades were based on weekly written homework, a midterm, a final exam/prelim, and attendance. Approximately 10 students attended the Linear Analysis prelim session each week.

3.4.2. Numerical Analysis

Numerical analysis consisted of one 3-h block each week, run by the instructor, with the assistance of the GLA, and two optional 60-min, GLA-led prelim sessions. Students were assessed weekly using formative assessments through polls and responses, and less frequently via summative assessments (a midterm and a final exam/prelim), as well as one group project.

The class time focused on an inquiry-based approach, consisting of a mix of lecture and active learning. During the lecture portion, students were prompted to type in the chat as they were learning new material. There were two 15–20 min active learning sessions per class, where students worked on problems connected with the topic of the class. The goal was to get the students to appreciate the need to understand computer arithmetic and the numerical analysis involved. After some time for reflection on the problem, students were asked to use the Zoom chat to present their knowledge. The instructor followed class lectures by providing lecture notes and links to other related examples.

During prelim prep sessions, the GLA posed problems, which students worked on individually, and then in groups of 2–3 students. The collaboration led them to build upon beginning ideas and articulate how they came up with the solution. At the end, the full group shared their solutions, corrected misconceptions, and asked questions. Afterward, the GLA provided full written solutions to the problems discussed, which were posted online for the whole class. Approximately 4–5 students attended the Numerical Analysis prelim sessions each week.

3.4.3. Abstract Algebra

Abstract Algebra consisted of two 75-min classes per week plus two optional 60-min prelim prep session. The class was entirely active learning oriented, and the semester began with a training exercise based on Dana Ernst's "Setting the Stage"

[7]. Students were assessed through weekly homework (graded using a mastery-based approach), two midterm exams, and a final exam/prelim.

During class, students worked on shared documents in groups of 3–5, as the instructor and GLA circulated through the groups. Students were provided with an exercise book with definitions, results, and examples and were asked to prove more significant results. Groups changed three times during the semester.

During prelim sessions, students received worksheets with two problems to solve in the session, and two problems for self study after the session. At the end of the sessions, the GLA outlined the solutions of the first two problems. Initially, problems were scaffolded with simpler questions to help the students develop problem-solving strategies. Subsequently, students were encouraged to write their own scaffolding problems. Approximately six students attended the Abstract Algebra prelim session each week.

4. STUDENT PERCEPTIONS

It was important at this early stage of the program to ask our students how they were impacted by the GLAMS program, as well as to give ourselves space to reflect on our own experiences. Student perceptions were collected through interviews, Likert scale prompts, and open-ended surveys. All 49 students in the GLAMS courses were invited to participate. Nineteen students completed the survey, but the total number of surveys was 25 since students were asked to complete the survey for each course. Ten of the nineteen students were PhD students, and the remaining nine a mixture of undergrad, non-degree seeking, and MS students. Nine students intended to take one prelim exam (three MS and six PhD), one PhD student intended to take two exams, and one PhD student intended to take three prelim exams. All PhD students must pass three preliminary exams before they take their qualifying exam. Master's students can elect to take prelim exams as part of their degree requirements. Master's students fulfill the research and creative portion of their degree requirement by passing three prelim exams, writing a thesis, or presenting a paper to committee. While the prelim exam was administered as the final exam for the class, students had to opt in for it to be graded by the prelim committee to be considered as one of their prelim exam attempts. A passing grade for the prelim almost always corresponds to a passing grade for the course final, but there are usually students who pass the class and fail the prelim.

Seven of the students who completed the survey agreed to be interviewed about their experiences. The interviews consisted of five questions: (1) What went well? (2) What did not go well? (3) What changes need to be made? (4) What did you learn? and (5) Would you recommend GLAMS to other students? Interviews were conducted via Zoom by a faculty member who was not the instructor of the GLAMS course and by Joanna. Interviews lasted between 13 and 28 min, with an average time of 20 min. We coded transcripts and open-ended survey data and formed findings which are presented below. After understanding student perceptions, faculty and GLAs reflected on their own experiences and on the student feedback. While

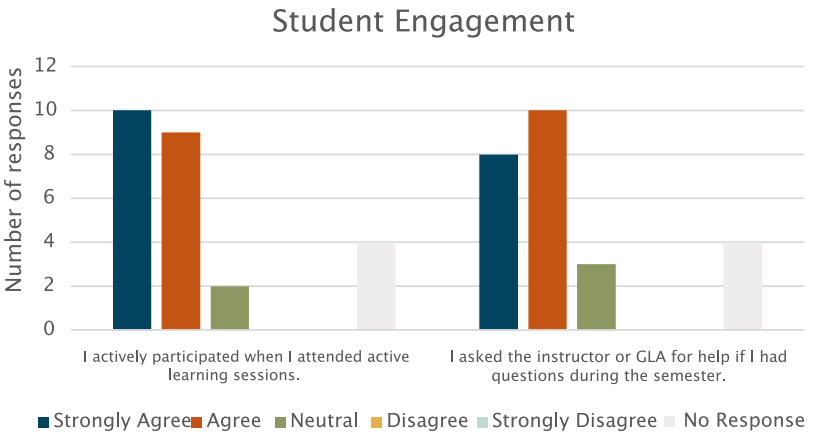

Figure 1. Survey Likert responses about engagement.

we centre the descriptions of GLAMS on Algebra, Numerical Analysis and Linear Analysis for context, the student data also includes student perceptions from two other GLAMS courses Topology and Ordinary Differential Equations, which ran in Spring 2021.

Of particular ethical concern in this study is the issue of privacy of students in a small graduate program [13]. We were very attentive to student privacy concerns, limiting which researchers had access to student pseudonyms, who checked transcriptions, and how we presented data for the public. We pursued trustworthiness [4] throughout the study by including faculty, GLAs, and an education researcher in the process, bringing together a variety of perspectives. The context was well-understood by this group of insider faculty and graduate student researchers familiar with the university, department, student demographics, and common issues faced by early-stage graduate students.

4.1. What Went Well

Students identified four main things that went well in the GLA courses: the way that GLAs facilitated conversation, the extra office hours held by GLAs, the GLA-created reference materials, and the accountability to study provided by the sessions. First, students felt the active learning prelim sessions were helpful when there was good collaboration between students and when discussion was facilitated by the GLA. Most students reported that they learned from others and felt comfortable discussing mathematical ideas with the group, as shown in Figure 1 and the following quote.

> I think graduate assistants were an invaluable component to my learning. I really want to underscore that,… the reality is, in the sciences and math as a science, is that knowledge is a communal activity and the more people that I can interact with who are not, not only on the same level, I would say, but who are engaged in the same subject, and the same topic at the same time, the more learning I do.

GLAs encouraged student interaction by asking questions and giving a "nudge" in the right direction. One student told us the GLA "broke the ice sometimes by visiting [the breakout room] which got everyone talking more." Second, students appreciated the extra office hours held by GLAs. Instructors held 2–3 h and GLAs an additional 1–2 office hours per week. GLA office hours were described as helpful because of the added time or because it was less intimidating to ask GLAs questions. One student commented, "As a graduate student, having the opportunity to discuss the material with someone else in the field [in this case, the GLA] who is more knowledgeable than me is huge." That student also reported that they felt more comfortable going back to the GLA, rather than instructor, several times with the same question if they did not quite understand something.

Third, students found GLA-created reference materials helpful. Reference materials included notes, worksheets, recordings of sessions, or lists of prelim problems covered. In particular, to facilitate the GLAMS prelim prep sessions, GLAs curated lists of past prelim problems aligned with current course content. Students found these lists very helpful. GLAs used them to pick problems for the prelim prep sessions and, when distributed to students, students used them to study. One possible downside to making these materials widely available is that they may deter students from attending sessions: One student told us they stopped attending sessions because recordings of the sessions and solutions to problems were posted on Blackboard. This complicates active learning efforts since low attendance results in less peer interaction. However, discouragement of attendance was not a major sentiment among students.

Finally, students said that prelim prep sessions provided a sense of motivation and accountability to work on prelim problems. This benefit applied whether or not a student was taking the prelim.

> A big thing for me is just the motivation, so just doing the problems is a big thing for me. Like I said, having that scheduled time and knowing that other people are going to be there also. For me, at least, it helped give me some motivation, just to do the problems, and I think just even seeing the problems, even if you don't do them, just look at them, I think is helpful also.

Prelim sessions were seen as more informal than office hours or class, with less "pressure":

> When you compare it to the office hours, I always feel kind of bad showing up to the office hours without having looked at the problem first and formulated questions beforehand, but with these sessions, it felt like there was no expectations… Having a set time for everyone to show up kind of took the pressure off a little bit. I think that's what I really enjoyed about it.

One student noted that this informality opened up space for more questions "because of the little less formal environment there, we also asked questions more."

4.2. What Did Not Go Well

About one-third of the participants told us that nothing went poorly, while other students voiced concerns about certain aspects of the program. Major concerns included feedback that GLAs were not meeting student expectations, that GLAs should do more to cultivate discussion, and that prelim prep sessions were not conveniently scheduled. There was mixed feedback about whether or not students should be expected to prepare before coming to the prelim prep sessions. Feedback was also mixed on how the online environment impacted the program.

First, we had some feedback that some students' experiences did not align with their expectations for the GLA. Some students perceived the GLA as a peer or slightly more accomplished colleague, some as an extra teacher while others viewed GLAs as significantly less experienced or helpful than the professor. Differences in perception led to different expectations of GLAs. For example, one student told us that the GLA did not seem to know the material as well as the instructor (likely true). Another student noted that they left the GLA sessions with questions unanswered, for which they faulted the GLA. A third student said that prelim questions were too hard to cover fully in 1-h prelim sessions. Several students wanted full solutions to be provided, and were concerned that prelim sessions only led to sketches of proofs. In contrast, other students wanted the GLA to provide less detail in order to cover more problems.

This concern was linked to another about how GLAs facilitated conversations in small groups. Several students reflected that the GLAs did not do enough to encourage conversation in the active learning sessions or "withheld" information. Students suggested GLAs should provide more guidance during the problem-solving process and lead more whole-group discussions, instead of asking students to work on problems in small groups. Some students appreciated learning through discovery in the format that GLAs were trying to encourage, while others expected a more GLA-led approach to the problems. Several students commented that groups were only productive when other group members contributed to the discussion, though students did note that GLAs nudged the conversation in the right direction or could nudge it more.

> Often, you would just get stuck and not know what you were doing, and it was really helpful to just have that second person going around because, especially with the Zoom environment, it was very difficult for the professor to cover all of those groups just by herself. So a lot of the time if we were stuck, Hannah would pop in and just kind of nudge us in the right direction.

We reflect on this feedback below in Section 7: Program Reflections.

The third major concern was prelim session scheduling. In two of the three classes, the session time was only announced when the semester started, so student schedules were set before knowing the session time which led to scheduling conflicts:

> "I could not attend all of the GLA sessions due to some schedule clashes."
> "Have the sessions at a more accessible time."

> "The prelim practice sessions last semester and this semester conflict with my work schedule, which is frustrating."

It helped to have the prelim sessions in unused class time. This was done in Linear Analysis. We are considering ways to improve scheduling which we reflect on in Section 7.

In some sessions, the students did not know in advance which problems would be covered. Some students felt that the lack of pressure to come "prepared" made them feel comfortable showing up without having looked at the problems; the casual environment helped them just show up and do what they could. In prelim sessions where problems were provided ahead, students were not always able to look at problems prior to the session, which led to some awkwardness in the session.

> One of the things that happens, as we all know, in graduate school is that everyone is just really, really busy and stressed out. And so, …he would send us the day before, the prelim question that we were going to go over. And none of us had time really to look at it, or to work through it, and so we would get to the prelim session and I think it was uncomfortable for the graduate assistant, and it was uncomfortable for us because it was the first time we were looking at it and he really was trying not to just tell us how to do things. So I don't know that there's a work around that. It's really a question of time, who has time to do some of these things. So I think if everyone had lots of time we'd all be geniuses at these things.

The majority of students felt that the instructor and GLA used technology effectively to facilitate online learning (Figure 2). Reactions were mixed as to how the online environment impacted their learning (Figure 2). A few students faced technical challenges: "There were a lot of issues with technology that sometimes got in the way of having a discussion." Another student felt that the Zoom breakout rooms made communication harder. Not all students noticed drawbacks. One student told us: "it seemed like no one was really having any difficulties." Another thought is that the chat function of online environments actually encouraged students to make room for others' contributions:

> Maybe when you are in the chat part, when you're doing it online, people are more conscious of trying not to be always the same person who answers every question. I actually am very comfortable with throwing out answers, like, it's kind of like playing Jeopardy, you know, the professor asks something, and you type in your answer. But I myself felt very conscious that it was time for me not to submit whatever answer popped into my head to allow others the chance. And that's easier to do when it was online, when you're typing things in, than when you're in person.

Other students mentioned that having access to recorded lectures was very helpful because "suddenly something becomes much more meaningful when you're trying to work through a problem." Overall, there was a positive response to GLAs as an added resource. There were even suggestions to expand the program beyond core classes and to advertise the program better so more students can take the opportunity to attend these sessions.

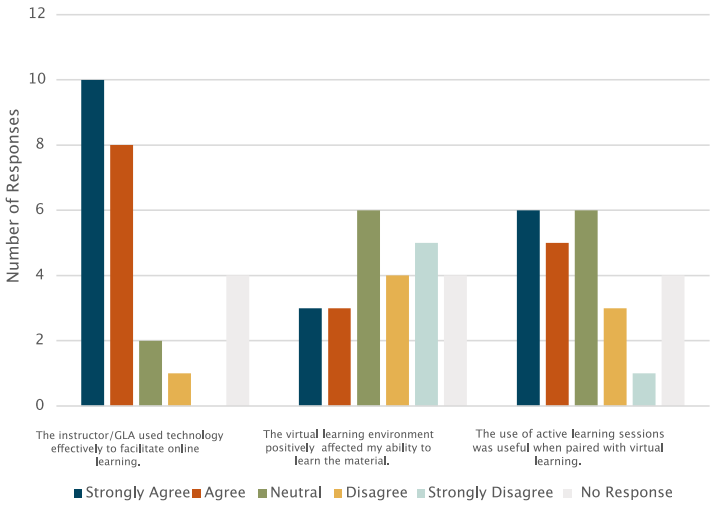

Figure 2. Survey Likert responses about virtual learning.

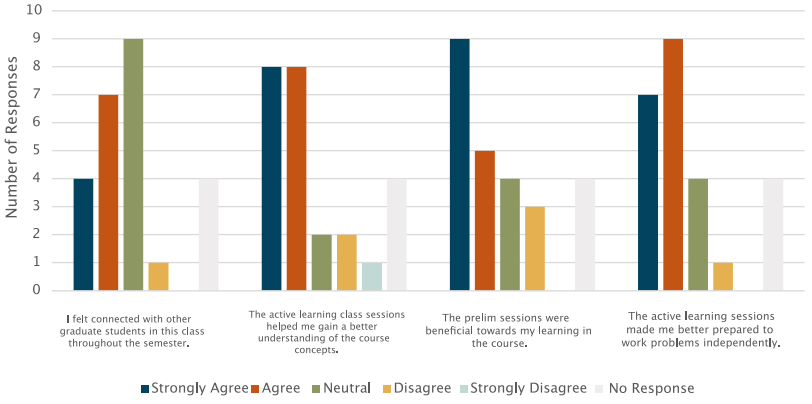

Figure 3. Survey Likert responses about learning.

4.3. What Students Gained

Students reported gains in communication, collaboration, and critical/analytical thinking skills (Figure 3). Several students told us the prelim sessions helped them learn how to "tackle" or "approach" problems that were new:

> I definitely learned more of how to talk about math, how to go about tackling a problem, especially one you haven't looked at before…that no one had seen before.

> In that sense, the prelim sessions were actually helpful because we were actually learning how to apply that stuff…that was a lot helpful for me. That my brain starts working in a particular direction that the question warrants…. From the first day to the last day of the session my brain was actually gradually working on that and now I started learning how to approach a particular problem. Like, if I see even a new question, I know something that is a particular approach to this problem, this should definitely work. That was indeed helpful.

Other students described developing the ability to evaluate different approaches to problems and understand why one approach was chosen over another. That helped them figure out how to really do the problems and not just mimic the professor:

> Especially when we're working the prelim problems, it was a perfect opportunity to say "How come we can't do it this way?" You know that's huge for me, when I learn, I'm not just learning how to mimic how to do the answer correctly. I'm learning how, "What if we did it, How come we can't do it this way?" or "What would happen if we did this?" and those kinds of prelim sessions were perfect for that.

Several students linked the skills modeled by the GLA to increases in their own ability to engage more deeply with material. Students described learning how to "apply" lecture material to actual problems, or how to put lecture into practice. Other students talked about the process of finding out what they did not understand. One student reported developing an understanding of the mathematical attitude toward proof.

Students also reported gaining content knowledge, such as Matlab and other coding techniques, and also spoke generally of better knowledge of mathematical material:

> I thought was like extremely helpful there was one thing with like bifurcation that I didn't quite understand and the GLA like explained it in a way that's like completely different than the way the Professor had explained it so it was really good to get a different explanation of how this topic work. That kind of just clicked more for me personally.

In terms of the overall effect on learning

> That class just got easier and easier, I think the more active learning sessions we did, and then, when I took the final [prelim] I was like whoa…I was expecting…so I thought that I wouldn't, like, be able to answer any questions, but it was actually not bad at all, so I think, like, I did learn a lot.

5. FACULTY REFLECTIONS

Each faculty came into the experience with different backgrounds in active learning. Before GLAMS, Evelyn used active learning in a variety of undergraduate classes, often with the help of undergraduate learning assistants. This is her first time using active learning in the graduate classroom. Rebecca uses active learning in almost all of her classes, both undergraduate and graduate. She began teaching in the calculus program at Michigan, which got her started on active learning, attended a workshop through the Academy for Inquiry-Based Learning, and has since become active in regional inquiry-based learning groups. Padhu employs active learning with technologies to engage students in all his undergraduate and graduate classes. He has observed that using technology effectively with active learning in teaching helps to stimulate the generation of new ideas as well as creative and innovative thinking among students, which leads to improved student learning.

As part of this project, we asked each faculty to reflect on their own experiences and on the GLAMS program as a whole. Faculty reflected positively on the experience and highlighted several main ideas. First, faculty really appreciated collaborating with someone else on the course. Second, faculty valued the curricular materials that GLAs created during the semester and plan to use them in the future. Third, participating in the GLAMS program led to changes in teaching practice for faculty. Fourth, faculty valued the form of group mentorship that occurred in the program.

First, faculty appreciated working with someone else on the course. Collaborating with the GLA on planning and course implementation was beneficial to faculty.

> I very much enjoyed working with a GLA while teaching Linear Analysis. I enjoyed bouncing ideas off of someone who had a perspective closer to the students' perspective. The weekly conversations led to constant improvements in the way the course was taught – improvements that I would not have necessarily been mindful enough to make without the collaboration. (Evelyn, faculty)

> I also enjoyed planning the prelim sessions with my GLA which was useful for us to reflect together on the level of difficulty in the problems from the past as well as identify topics that may have not been covered in the main lecture that the GLA can help cover in the follow-on sessions. (Padmanabhan, faculty)

> Having a second person available during class sessions also enabled us to give enough attention to each of the twenty-one students, even when we needed to spend significant time helping one group. In addition, the GLA had helpful suggestions for improving the classroom dynamics, some as a result of spending additional hours working with the students in the prelim sessions. (Rebecca, faculty)

Second, faculty noted GLA contributions to curricular materials. Several GLAs created materials that will be used in future semesters and one faculty told us this experience encouraged them to revise their own materials.

> The GLA's help with the course was invaluable. Her contributions improve the course in the future, such as list of preliminary exam problems, sorted by topic, and the prelim practice worksheets. (Rebecca, faculty)

> I am hoping that in the coming years, I will build on this idea from the students to potentially write another graduate text that will focus on an inquiry-driven approach to learning Numerical Analysis. I hope to do this by incorporating creative, inquiry-based tools to show other educators what it means to teach numerical analysis in a non-traditional lecture-based approach along with strategies to help students become better at understanding the impact of numerical analysis in the real-world. (Padmanabhan, faculty)

Third, engagement in GLAMS led to improvements in faculty teaching practice:

> The GLA had helpful suggestions for improving the classroom dynamics. While normally I hang back and only interrupt groups if I really need to, the feedback from this survey let me know that students prefer more interaction and a more active instructor role. (Rebecca, faculty)

> I certainly became better at teacher-guided inquiry that helped to motivate students to think critically and appreciate the material they were learning better. (Padmanabhan, faculty)

Finally, faculty recognized the value in the early and ongoing coordination. Coordinating the GLAMS program created a form of group mentorship of the GLAs.

> The early semester meetings helped to establish norms for the program, and both the early-semester meetings and the weekly GLA-faculty meetings helped GLAs see how faculty think about pedagogy and develop their own style of teaching. (Rebecca, faculty)

> The GLA had a teaching mentorship with a faculty member. A close teaching collaboration is not a standard part of the PhD program, but it seems like a valuable addition. (Evelyn, faculty)

6. GLA REFLECTIONS

Similar to faculty, the GLAs had varying backgrounds in active learning. Cigole and Hannah had both led active learning sessions during undergraduate Calculus recitations. Hannah has worked as an undergraduate math mentor and teaching assistant online during her undergraduate degree and also initially when working on her master's degree. She first taught a course online as instructor of record during Summer 2018 and has taught during each summer since then. Cigole started her teaching career as a teaching assistant for Calculus classes at GMU and has taught mainly Calculus courses (both as teaching assistant and instructor) over the course of six years. She was one of the lead GTAs for the NSF-IUSE grant in which active learning was introduced to all Calculus I and II recitations at GMU in 2019–2020 and has been using active learning as an effective tool in teaching since then. Long has led recitations for Calculus and Ordinary Differential Equation courses prior to his experience with GLAMS. Similar to Hannah and Cigole, he also taught those courses in the summer as an instructor of record. During class time, he usually spends 15–20 min letting students solve an interesting problem in groups and exchange thoughts and then facilitates a class discussion on the best ways to approach a correct solution.

We also asked each GLA to reflect on their experiences and the overall GLAMS program. First, GLAs reflected that the experience improved their understanding of the course content. Second, GLAs also valued the experience of creating curricular materials for the program. Third, participating in the GLAMS program led to changes in GLA teaching practice. Fourth, GLAs valued the form of group mentorship that occurred in the program. First, GLAs reflected that the experience helped them strengthen their own understanding of course material.

> Working as a GLA helped me gain a stronger understanding of the course topics…It was interesting to go through the course material from another instructor's perspective and I also learned a couple new things that hadn't been covered during the semester that I took the course. It was useful to get an opportunity to spend time explaining abstract concepts and proof techniques. (Hannah, GLA)

> As a GLA in Numerical Analysis, I had a great opportunity to learn deeper course material from professors as well as some interesting solving skills from graduate students. (Long, GLA)

Second, GLAs who created curricular materials for the project valued that experience.

> The opportunity to create IBL-type worksheets for the prelim sessions was an invaluable experience. Preparing Inquiry-based worksheets for the practice prelim problems made me think about how the students perceive the course material and approach problem-solving while solidifying my understanding of the material. (Cigole, GLA)

Third, engagement in GLAMS helped GLAs think about their own future engagement with active learning:

> In the prelim sessions, I observed that students seemed less likely to share their screen than in the class active-learning sessions. If running an online synchronous active-learning session in the future, I would take a more active approach to getting people to share screen/whiteboard as it seemed to make for better collaboration within the groups. (Hannah, GLA)

> What stood out the most while being a GLA for the Algebra course is the difference between teaching approaches in undergraduate and graduate levels. The difference in mathematical maturity effectively calls for different tactics and methods. (Cigole, GLA)

Fourth, the GLAMS program created a form of group mentorship of the GLAs. GLAs appreciated being able to observe faculty much more closely and reflect on teaching practice.

> I found it beneficial to get experience with running an active-learning session while having a mentor available to ask questions. I also enjoyed hearing and discussing approaches and techniques being used by other instructors and GLAs. (Hannah, GLA)

> The standout benefit for me would be observing how the professor created and organized an active learning course. (Long, GLA)

> The weekly interactions with the instructor were a great mentoring experience. (Cigole, GLA)

Finally, GLAs reflected on their overall growth as instructors.

> GLAMS helped me grow as an educator by giving me insight into the nuances of teaching graduate students and an opportunity to observe, to work alongside and learn from a faculty member about how to teach a graduate class. These reflections helped me mature as an educator and developed a more student-centric approach while teaching. All of these made GLAMS a unique opportunity for my professional development, which would otherwise not have been available to me as a graduate student. As an educator, I consider my most significant growth as my shift in focus from thinking of teaching as 'explaining a concept' to a 'more student-centric approach with student engagement,' which was greatly influenced by my experience with active learning during Calculus sessions as well as the GLA practice prelim sessions. (Cigole, GLA)

> The GLAMS program helped me develop my teaching for graduate courses. One of the most important things that I learned for teaching a graduate course is that I need to

cultivate a creative environment so that students can learn and understand the concepts deeper. (Long, GLA)

I think the experience helped me shape and verbalize my teaching philosophy. I feel more prepared to work with more advanced level material and students after my experience with GLAMS. (Hannah, GLA)

7. PROGRAM REFLECTIONS

Overall, the GLAMS program showed great promise for students, GLAs, and faculty. We have continued the program into the 2021–2022 and 2022–2023 academic years. In this final section, we include some reflections on programmatic changes we plan to make in the next iterations of the program.

7.1. GLA Selection

The GLA selection process needs some refinement. In the first year of its implementation, the instructors were involved in identifying the GLAs. In the second year of the GLAMS program, GLAs were assigned by the math department based primarily on scheduling constraints as part of the normal GTA assignment process. In retrospect, this was not ideal. The GLAs selected need to feel committed to the program and to active learning. In place of GLAs being selected by the Graduate Director, we are considering an application/interview process for graduate students to apply to be GLAs. This will mimic the current process we are using for ULA selection. In that process, faculty would create a job posting, describing the GLA responsibilities and duties. Then, GLAs would apply for specific positions. Instructors would review applications, interview potential GLAs, and talk through expectations for the position. This will ensure that everyone is entering the program with realistic expectations. We believe this process will also become easier as beginning graduate students experience the GLAMS program as students before becoming GLAs later in their studies.

7.2. The Role of GLAs

Comments from students on the perceived role of GLAs revealed an important challenge to the program. Student perceptions of GLAs ranged from being an accomplished peer to an additional teacher outside the class. Students also mentioned that they sometimes felt GLAs were "withholding" information or could have played a more active role in the discussion. Solidifying the nebulous roles of the GLAs is an important goal for enhancing the program in the future. This type of feedback is not unexpected. Similar dynamics have been documented in undergraduate active learning classrooms [25]. In data from the SEMINAL study, undergrad students mentioned that they enjoyed working in groups because it allowed them to explore different ways of solving problems, get to know other students, and concentrate on true understanding of mathematics. But students who did not enjoy

working in groups mentioned awkward social interactions in the groups, or wanting more guidance on the problems [25]. In that work, the authors suggest that intentionally structuring group work is one way to be sure that groups are a productive and positive experience for students. Another suggestion for cultivating student buy-in and understanding is demonstrated by Dana Ernst [7]. Ernst facilitates a beginning-of-class conversation with his students about what the purpose of education is and what students hope to gain from the course. In that conversation, he introduces the ideas of productive failure, of students as producers of knowledge, and of the value of learning how to engage in open-ended inquiry [7]. We are suggesting these changes to new GLAMs faculty for future semesters. We also suggest our faculty collect early semester feedback from students about how the GLA prelim prep sessions are going and make adjustments as needed. Evelyn did that in her class and felt the feedback was very helpful to this young program. We are hopeful that a combination of early surveys, engaging students in early semester conversations about active learning, and structuring the active learning group sessions may address the differences in student experiences that our interviews identified.

7.3. Initial Orientation

The structure of the GLAMS program included an initial coordinated orientation that was conducted during the first three weeks of the semester. This was an opportunity for instructors and their respective GLAs to meet, discuss and share effective active learning practices. We plan to continue these early semester group meetings, as they were valued by both faculty and the GLAs. In future years, we will have a cohort of past GLAs who can share their experience with new GLAs and we believe this will be a powerful addition to the program as well.

7.4. Logistics of Preliminary Exam Preparation Sessions

Since the introduction of the GLAMS program, we have changed the way we are running the preliminary exam preparation sessions themselves. First, we have made changes to the virtual/in-person format of the sessions. Initially, all sessions were held online. We have now switched to a hybrid format, where students can attend in-person or online. This allows students who cannot travel to campus to attend the sessions. Second, we have changed the size of the groups in the sessions. In the first year, most sessions included small breakout groups. In the second year, all three GLAs had the students work in a single larger group (up to 7–8 students) to solve problems. This is something that the GLAs found worked in an in-person session better than it worked online so we are still refining that structure. Finally, we found that it is important that the GLAs and instructors announce the prelim session times before the students finalize their semester schedules so that more students can attend the weekly prelim sessions.

7.5. Course Materials

Prior to GLAMs, students always had access to an unorganized list of prior-year prelim problems. Under the GLAMs program, a list of prior year prelim problems that were aligned with course content was created. The annotated lists have been passed down to the second-year GLAs so that they do not need to recreate these. Some faculty are sharing these lists with students at the beginning of the semester to inform their study for the exam. However, other faculty chose not to distribute the organized list to students and instead only provided it to the GLA to choose problems for the prelim session. One instructor had concerns about giving the full organized list to students because of the potential of this approach to "teach to the test." Generally, these materials are seen as very valuable to the program and we will continue to use them.

7.6. Faculty Buy-in

While some of the faculty that teach the core classes see the benefit of GLAMS, it is not yet clear how the program will be perceived by other faculty that are not as engaged. In particular, the GLAMS program provides the opportunity to use active learning in a graduate classroom, something which only some faculty do in their undergraduate classes. We hope after a few years, many more faculty members will have the opportunity to participate in this program, which can help spread awareness of its importance to other faculty in the department. Faculty buy-in to active learning, to graduate student mentorship, and to the GLAMS program in general is a major concern for the program moving forward.

8. CONCLUSION

We conclude our article with a reflection from our department chair, Maria Emelianenko, who was graduate director when the GLAMS program was implemented:

> GLAMS has made a profound influence on our graduate program. As a graduate program director, I came to the realization that we were not setting students up for success in the first two years of the program. We had a large failure rate in the core classes for several years, and many students have not been able to finish the preliminary exams in the required time. When meeting with students, I often heard them complaining about the lack of support and the overwhelming amount of stress they feel when taking their core classes. The challenges associated with first-year graduate school transition were exacerbated by the disconnect between faculty expectations and the level of support provided to the students. The GLAMS program was a perfect way to address the need for additional support to better prepare students for the final exams in these classes. GLA sessions really helped with that, in addition to providing a more student-oriented active learning environment, allowing students to bond with each other and with more senior students, while also getting a new mathematical perspective through peer discussions. I feel that our graduate program has made a giant leap due to these changes in the last few years.

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