Research-Informed Practice to Improve Inquiry-Based Calculus with Learning Assistants

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Despite the promise of inquiry approaches, student resistance can occur because active learning opposes their expectations of classroom norms and responsibilities. This study reports on students' experiences in inquiry-based learning (IBL) Calculus supported by learning assistants (LAs). We used an iterative process adapted from Hine (2013) to make changes to our study across three semesters to improve student experiences in IBL Calculus. Survey data of 285 students across 7 sections of IBL Calculus was supported by our observations of IBL Calculus and weekly LA seminars with 12 LAs to determine changes needed each semester. Quantitative data were analyzed using descriptive statistics and z-tests, and qualitative data were open-coded to evaluate the effectiveness of changes. We report changes made to LA preparation and course structure to support LAs' instructional practices and increase student buy-in to IBL Calculus. Over the three semesters, the overall student experience in IBL Calculus improved.

Keywords: research informed practice, inquiry-based learning, learning assistants

As practitioners, we strive to improve the experience, learning, and understanding of students in our own courses. As researchers, we strive to push the bounds of our knowledge of student experience, student learning, and student understanding in *all* mathematics classrooms. Our research should inform our practice so that we systematically use our new knowledge to directly and positively impact our students. While researching the implementation of inquiry-based learning (IBL) in Calculus supported by learning assistants (LAs), we determined aspects of LAs' work preparation and Calculus students' classroom experiences that were ineffective. We sough to answer the question, "How can an action research cycle be used to improve students' experiences in Calculus IBL classrooms with LAs?" Based on our data analysis, we made changes each semester to develop practices that support positive experiences for both students and LAs. In this paper, we describe the data-supported, iterative revision process we used over three semesters to redesign the Calculus course structure and LA preparation and report the results of these changes on student perceptions of the course.

Literature Review

One of the goals of research is to inform practice, but it can be challenging to translate research into practical strategies (Carlson & Rasmussen, 2008). Through action research, educators conduct research in their own classrooms with the practice-based goals of improving their instruction and the experiences of their students (Gibbs et al., 2017; Hine, 2013). Action research is commonly used in higher education to obtain "evidence of how practice can be improved and its impact on the learning of students" (Gibbs et al., 2017, p. 17). The cyclic nature of action research allows for refinement of current issues, a systematic approach to inquiry, and continuous learning for the educator (Hine, 2013). We used an iterative process adapted from Hine (2013) (Figure 1) to study our implementation of IBL in Calculus over three semesters. Whereas Hine's model moves directly from reporting outcomes to taking action, we added a critical intermediate step, "determining future changes" to capture the work of interpreting the results to hypothesize what changes to our IBL structure might improve student outcomes.

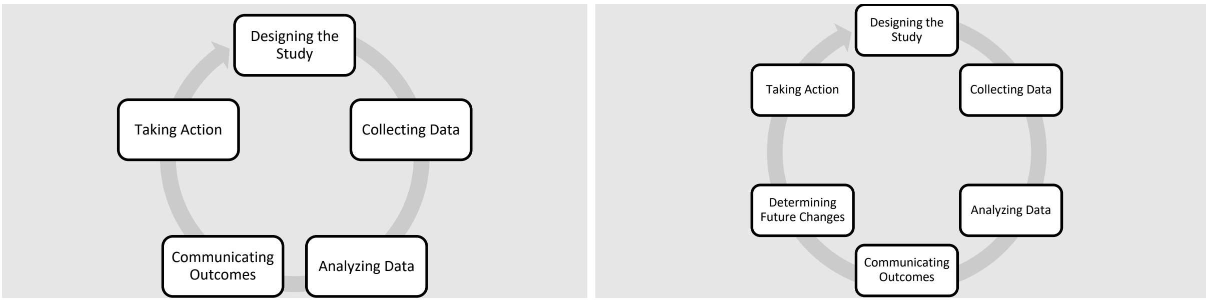

Figure 1: Action Research Cycle (Hine, 2013) and Modified Action Research Cycle (adapted from Hine, 2013)

Inquiry approaches to learning continue to grow in mathematics education (Laursen & Rasmussen, 2019). In IBL, students work through a "carefully scaffolded sequence of mathematical tasks" (Ernst et al., 2017, p. 570) under the guidance of an instructor to construct their own understanding of a given concept. Research has found that students in inquiry classes have reported improvements in learning specific content, developing affective skills, and communicating and collaborating with peers (Laursen et al., 2011). Despite the promise of IBL, students can be resistant because its structure contradicts their expectations of classroom norms and student/teacher responsibilities (Deslauriers et al., 2019). Students must develop autonomy in problem solving to be successful in an IBL setting, where instructors support student work instead of providing direct instruction on how to solve problems.

Student resistance to the change in student/teacher responsibilities has been associated with poorer student course performance (Cavanagh et al., 2016), and successful implementation of any inquiry approach to teaching and learning must account for student resistance to changed norms. Some ways instructors might combat student resistance to IBL include discussing reasons for the course structure (Deslauriers et al., 2019; Yoshinobu, 2019), presenting students with videos outlining the importance of working in groups (Clinton & Kelly, 2020), and explaining the importance of having a growth mindset (Cavanagh et al., 2018). In our implementation of IBL Calculus, we used LAs to help alleviate student resistance, by providing students more available access to help. LAs act as apprentice instructors, facilitate group work alongside the instructor, and have been shown to improve student outcomes in STEM courses. Barrasso and Spilios' (2021) meta-analysis indicates that students in LA-supported STEM courses have better attitudes, course satisfaction, and learning gains than students in STEM courses without LAs.

Method of Inquiry

Context

This study was conducted within IBL sections of Calculus I courses in a large, public, midwestern university across three semesters. The IBL sections used the textbook *Active Calculus: Single Variable* (Boelkins et al., 2018) which was designed for use with an inquiry-based approach to instruction. Students spend the majority of class time working in small groups facilitated by the instructor and LAs to solve problems that emphasize key concepts and relationships of calculus. While groups worked on tasks, the instructor and LAs circulated to troubleshoot student difficulties, pose questions, check student understanding, encourage group discussions, and generally encourage student thinking and autonomy in problem solving. Of 303 students enrolled in IBL Calculus across three semesters of this study, 285 agreed to participate.

LAs attended IBL Calculus class three times per week and met with the course instructor once a week to discuss both their experiences as an LA in IBL Calculus and readings on active learning. This study incorporated 12 LAs in 7 sections of IBL Calculus. LAs were a mix of undergraduate and graduate students, males and females, international and domestic students, and all had an interest in active learning in mathematics.

Data Collection and Analysis

We collected LA weekly written reflections, field notes of LA seminar meetings, and observations of IBL Calculus. Two weeks prior to the end of the semester, we used a survey to gather student perceptions of the course. The surveys consisted of Likert scale questions and open-ended questions, all of which explored various aspects of students' IBL Calculus experiences. To analyze qualitative data, we open-coded free response questions, which were answered by all respondents. To analyze quantitative survey data, we calculated descriptive statistics and performed independent samples z-tests to determine the significance of changes in student responses from semester to semester. Employing our modified action research cycle (adapted from Hine, 2013) we interpreted the results to determine future changes needed to our enactment of IBL Calculus, which we implemented in subsequent semesters to continue our cyclical process. Here, we report the changes we identified from our analysis each semester and the impact of those changes on students' experiences in IBL Calculus (for additional details of the study see Bubp et al., 2020).

Results

Semester 1 Key Findings

After our first semester, we used student survey responses to determine students' assessment of their interactions with LAs. In particular, students reported the LAs were less helpful in class than the instructor and their peers, with 36% of students responding that LAs were 'little to no help'. Further, they identified the following LA actions to be 'little to no help': ask questions about your work (33%), ask you to explain your work (38%), give feedback on your work (24%), and help you but do not directly answer your question (50%). In the open-ended response questions, 20% of students indicated negative interactions with LAs. One student described their interactions as: "TA's coming over and staring over your shoulder, correcting your work only to give you a more confusing explanation." Similarly, from observations we noticed LAs struggled to employ effective questioning strategies and facilitate discussions in small groups.

Using student surveys, LA reflections, and LA seminar field notes we identified two problems with our LA preparation that contributed to their struggles interacting with students. First, by choosing LAs with strong content knowledge and some prior experience with active learning, we assumed that minimal preparation for facilitating student group work in advance of the semester start would be needed. However, LAs' content backgrounds had some gaps, and since IBL Calculus relied on objects-in-motion and graphing approaches with which some LAs were unfamiliar, many had difficulty helping students understand these approaches. Second, our weekly LA seminar did not sufficiently support the LAs in developing practical aspects of implementing and supporting IBL in the classroom. Instead, we read and discussed research literature on IBL to support our graduate students in developing their understanding of the current state of IBL research and consider how they might analyze data of IBL classrooms.

Semester 2 Revisions

To address these issues, we made strategic changes for the second semester. First, to better prepare LAs for their role in the classroom, we provided pre-semester preparation and communicated clear expectations for their role. A first-semester LA drafted an *LA Manual*, which we reviewed and required LAs to read prior to the start of the semester. We set the expectation that LAs had to complete for themselves all IBL Calculus classwork in advance of each class meeting where they would be assisting students on that work. The *LA Manual* also emphasized the importance of asking questions to move students forward in their work without giving them direct answers to problems. We shared ways to connect with students such as by learning names and ways to build trust by admitting mistakes and listening carefully to students.

Second, we improved during-the-semester preparation by making LA weekly seminars less focused on theory and research and more focused on classroom activity and problems of practice: what concepts students struggled with or excelled at, how groups worked together, instances of inequitable participation, and instances of LAs not knowing how to respond to a student. We specifically discussed strategies to help LAs develop an awareness of student understanding and an ability to improve their interactions with students and students' interactions with each other.

Third, in addition to improving LA questioning techniques, we changed some structural elements of how LAs functioned in the class to improve students' perceptions of their interactions with them. In the first semester we had three LAs to a section for a total of four teachers. This led to students being asked the same question repeatedly by different LAs and hearing too many different explanations from LAs. In the second semester we only used two LAs per section, assigned each LA to specific groups, and established a norm of LAs asking groups if they had already been questioned by someone about their work.

Semester 2 Key Findings

Second semester students found LAs to be more helpful than their instructor and peers, with 67% of students saying LAs 'helped a lot or the most' and only 13% saying LAs 'helped little or not at all' as compared to 46% and 35%, respectively, from the previous semester. Students who reported specific types of interactions with LAs (Table 1) as 'usually or very helpful' statistically significantly increased from the first semester and those reporting the interactions as 'little or not helpful' statistically significantly decreased.

Table 1. Percent of students reporting these interactions with LAs were or were not helpful.

Interactions	Semester 1		Semester 2	
	% little or not helpful	**% usually or very helpful**	**% little or not helpful**	**% usually or very helpful**
Question students' work	32.50	38.75	13.10*	61.90*
Ask students to explain work	37.50	36.25	8.33*	61.90*
Give feedback on students' work	23.75	51.25	6.02*	81.93*
Help but no direct answers	50.00	29.48	24.39*	52.44*

*Indicates statistically significant ($\alpha = .05$)

Although we saw important improvements in student-LA interactions in the second semester, we yet identified areas in need of improvement for the following semesters. Students indicated these interactions with the LAs occurred 'every day or nearly every day': waiting too long for help from LA (11%), LAs solving problems directly for students (32%), LAs providing an incorrect answer (6%), and LAs contradicting one another (6%). Students waiting too long for help indicated we needed to attend more carefully to how LAs monitored students. Though few students stated that LAs provided an incorrect answer or contradicted one another, that this was happening at all was cause for concern. While students might have considered LAs directly solving problems for them as beneficial, this was a practice we wanted to discourage.

Second semester findings showed that only 39% of students reported that the class structure 'helped a lot or most'. Additionally, we noted issues in the effective functioning of groups as 87% of students reported negative experiences working with groups. Specifically, 30% felt their group members were not knowledgeable, 11% believed their group members were on a different level, 14% indicated their group members did not regularly attend class, and 13% did not want to rely on group members over their instructor. We observed that student attendance issues impacted the groups through time lost to groups catching up absent students, inequitable contributions, and groups feeling responsible for carrying weak or non-contributing members. We hypothesized that students' struggles with group work influenced their appreciation of the IBL structure. The 67% of students who made negative comments about IBL referenced a need for more direct help from the instructor and less reliance on their groups: 26% wanted more lecture, 21% did not want to figure things out on their own, 21% wanted lecture for new material, 13% wanted more examples, and 13% did not want to depend on their peers.

Semester 3 Revisions

We made additional changes to the weekly LA seminar, shifting the focus from how to research IBL to understanding student thinking and facilitating group interactions. We hypothesized that students' continued poor reviews of classroom interactions were due to LAs responding to student questions and difficulties on-the-fly. Therefore, we oriented the seminar to prepare for what was coming up in class each week and not only what had previously happened. In addition to completing course materials in advance, we asked LAs to consider possible student misconceptions and questions they could pose to students in the upcoming classes. To further improve their pedagogical skills, LAs also read articles about pedagogical techniques such as questioning techniques, ways of providing feedback, and cognitive demand. LAs reflected on their readings and identified ways to apply them to their classroom practice.

Based on open-ended survey results, we hypothesized that student reaction to their and the instructors' changed responsibilities contributed to their dissatisfaction with the course structure. To address this student resistance, we developed four "Learning about Learning" (LaL) assignments that students completed early in the semester and were intended to help them understand the value of IBL and feel more comfortable as independent problem solvers who collaborated with their peers and communicated their mathematical ideas. The LaL assignments included readings (Anderton, 2019; Dunlosky et al., 2013) and the online course 'How to Learn Math for Students' (Boaler, n.d.) which addressed ideas such as: common misconceptions about math, good study habits, growth mindset, productive struggle and mistakes, communicating mathematical ideas, and collaboration. Each LaL assignment required a written reflection in which students discussed what they learned and how that related to their success in Calculus.

To address students' dislike of group work we used more purposeful groupings with similar majors grouped together and balanced by gender. To minimize group difficulties due to attendance, we deducted points for missing more than 4 classes per semester.

Semester 3 Key Findings

In the third semester, we observed further improvements in student interactions with LAs, a more positive response to the IBL structure, and more effective group work. Students had to wait for help statistically significantly less often, and additionally, although not statistically significant, LAs were solving problems for students, giving incorrect answers, and contradicting other LAs less often (see Table 2). In the open-survey questions, a student described, "They [LAs] were able to guide you in the right direction without giving you the answer outright... [and] we never had to wait long if we had a question." Another responded, "They provided help quickly when it was needed and helped us to understand concepts to solve a problem rather than telling us exactly how to solve the problem." This supports the quantitative analysis that student wait time was shorter and that LAs were no longer directly solving problems for students.

Table 2. Percent of students reporting the following frequencies of these actions occurring with LAs.

Interactions	Semester 2	Semester 3
	% occur every or nearly every day	**% occur every or nearly every day**
Wait too long for help	10.71	1.33*
Solve problem for students	32.14	21.33
Give an incorrect answer	5.95	1.33
Contradict each other	5.95	1.33

*Indicates statistically significant ($\alpha = .05$)

The response to the IBL structure statistically significantly improved by the third semester, with the proportion of students reporting the course structure 'helped a lot' or 'helped most' increasing from 39% to 58%. In addition, statistically significantly fewer students responded that they needed lecture for new material and that they did not want to figure things out on their own. Although not statistically significant, fewer students responded that they needed more lecture in general and that they wanted more examples (Table 3). We note here that the percentage of students who reported needing more lecture remains high and we attribute this to the difficulty of overcoming students' expectations of what teaching and learning mathematics should be. We expect this issue to be an on-going focus of future revisions.

Table 3. Percent of students' open-ended responses coded with the following codes.

Code	% Semester 2	% Semester 3
Lecture needed for new material	20.24	5.93*
Want more examples	13.10	7.63
Need more lecture	26.19	22.88
Had to figure out on own	21.43	10.17 *
Didn't want to depend on peers instead of professor	13.10	5.08*
Group members not knowledgeable	29.76	27.97
Group members move on without me/at a different level	10.71	14.41
Group members not attending	14.29	5.93*

*Indicates statistically significant ($\alpha = .05$)

With the changes to group structures, statistically significant more students valued their peers both in- and out-of-class (Table 4). Furthermore, statistically significantly fewer students responded that they did not want to depend on their peers instead of their instructor and that their group members were not attending class (Table 3). Qualitative data supported this finding; one student described, "My group is really amazing and we do a good job of collaborating and helping each other when one of us is stuck in or out of the classroom. They are all pretty good at explaining why they got a certain answer." We also note that some students still report group members are not knowledgeable, and hence not considered a good classroom resource, and that too much variability in groups made students feel left behind. This points to our need to continue addressing supporting students in working in groups.

Changes Across All Semesters

Across all three semesters of this iterative process, when we focused on understanding reasons behind our results, we were better positioned to determine changes for the future and take action. In determining changes from the first semester, we recognized the need to improve the LAs' interactions with students by better preparing LAs for their role in an inquiry-based classroom. And, in the second semester, we observed statistically significant improvements in students' responses to the LAs; the percent of students who found them unhelpful decreased and the percent of students who found them helpful increased (Table 4). Results also pointed to a need to focus on IBL structure, students' perceptions of that structure, and group interactions. And in the third semester we saw statistically significant improvements in students finding their peers more helpful (Table 4). On the other hand, there was no significant change in the student responses to the LAs being helpful and available in class. We interpret this reduced perception of LA helpfulness as the result of students becoming more comfortable with productive struggle with their peers. One interpretation of this finding is that as students' value for their peers increased, they became more autonomous in solving problems and less dependent on the LAs. Reduced need for assistance from LAs could in turn explain the decrease in the proportion of students who responded that the LAs 'helped a lot' or 'helped the most' with their learning.

Table 4. Percent of students reporting the following class features as helpful or not helpful.

Class Feature	Semester 1		Semester 2		Semester 3	
	% little/ no help	**% helped lot/most**	**% little/ no help**	**% helped lot/most**	**% little/ no help**	**% helped lot/most**
IBL Structure	38.55	31.32	39.29	39.29	21.56^{**}	57.76^{**}
LAs in Class	34.94	45.78	13.41^{*}	67.07^{*}	12.28	59.65
Peers in Class	25.30	56.62	21.69	46.99	9.57^{**}	66.96^{**}
Peers out of Class	30.16	39.10	46.99	27.12	25.00^{**}	45.00^{**}

*Indicates statistically significant from Semester 1 to Semester 2 ($\alpha = .05$)
**Indicates statistically significant from Semester 2 to Semester 3 ($\alpha = .05$)

Implications for Practice

In our work, we have again confirmed the power of using research to improve practice. We sought to use an iterative systematic process to improve the implementation of an innovative pedagogical structure and over three semesters were able to make that happen. Drilling down to identify specific difficulties students were having with our courses was essential for making appropriate revisions. The changes we made in our enactment of IBL Calculus were small, yet they often had a statistically significant positive impact on students' experience in the classroom. Through two sets of revisions, we improved LA preparation, in-class group interactions, and student appreciation for IBL. From this study we have learned some critical aspects of introducing novel pedagogical approaches: the importance of instructor preparation, of fostering student buy-in and understanding of the rationale for the pedagogical approach, and a systematic approach to understanding and reacting to students' experiences.

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