Inquiry-based Learning in Lower Division Undergraduate Mathematics Courses as a Recruiting Tool for Future Mathematics Teachers

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Abstract

We report how the Research Action Cluster (RAC) on active learning has impacted institutional change at one university in calculus and precalculus, including recruitment efforts for future teachers. We describe how inquiry-based learning (IBL) has been implemented in the calculus sequence over the last five years and a pilot precalclulus program has begun. The IBL format of the courses allow students environments in which they feel comfortable exploring and doing challenging mathematics; an environment in which failure and struggle is not stigmatized. Results show that students think about mathematics in terms of problem solving, making sense, persevering, and where self and peer critiques are the norm. Moreover, as instructors using an IBL format, we found it a powerful framework in which to identify students with a strong capacity for communication and reasoning and thus target our recruiting efforts. We hypothesize that encouraging students to focus on sense making and problem solving, along with providing rich extra-curricular activities and personal recruiting efforts drove our success in recruiting students from IBL classes into the teacher pathway programs.

Keywords: Inquiry-based learning, active learning, teacher recruitment, calculus, precalculus

Introduction

For the past five years, the University of Nebraska at Omaha (UNO) has collaborated with other universities engaged in the Math Teacher Education Partnership (MTE-Partnership) Active Learning Mathematics Research Action Cluster (ALM RAC) to create institutional change in the way teachers learn mathematics at UNO. The group's focus was on the improvement of mathematics instruction in introductory mathematics courses. UNO has collaborated in both defining and implementing the plan for the RAC with a focus on first- and second-semester calculus by implementing inquiry-based learning (IBL) in the courses. Additionally, one section of precalculus implemented IBL. The two main goals of the implementation were 1) to improve learning in the courses and 2) to serve as a recruiting tool for future mathematics teachers.

Description

Transforming Calculus

Two faculty in the mathematics department at UNO were the nucleus for the transformation of calculus I and II. The faculty went through significant training in the use of IBL in the classroom. They recruited two other faculty to utilize this approach in their classrooms. The additional faculty were engaged for a short time, but the two primary faculty members have worked diligently over the past five years on developing activities and problem sets (worksheets) in their IBL calculus classrooms. The long-term goals of these efforts were to significantly

increase student learning and to recruit more students into mathematics and mathematics education. Rather than showing facts or a clear, smooth path to a solution, the instructor guides students via well-crafted problems through an adventure in mathematical discovery (Kogan & Laursen, 2014). The United States calculus study (Bressoud, Mesa, & Rasmussen, 2015) suggests that the calculus sequence may be the ideal place to provide future teachers with such learning experiences.

Calculus is often the course that either steers people into STEM majors or out of them depending on their success in the course (Meyer & Marx, 2014). This includes students pursuing mathematics teaching degrees. According to world-class standards for mathematics teachers (Schmidt, Burroughs, & Cogan, 2013), the gold standard for mathematical coursework includes three semesters of university calculus (beginning calculus, calculus, and multivariate calculus). Schmidt, Burroughs, and Cogan discussed the importance of calculus for mathematics teacher preparation. Our teaching in this course impacts a large number of students who have potential in the science, technology, engineering, and mathematics (STEM) fields, including those who already intend to be future mathematics teachers and those who we could recruit into teaching if they are inspired to do so based upon their experiences in the calculus sequence (Mesa & Burn, 2015). Calculus I and Calculus II were targeted as courses for IBL instruction because students interested in STEM fields are enrolled in these courses and most are first-year college students. Many first-year students make decisions regarding their major field of study. Many are not certain of their career goals, but they know they are good at mathematics. This time presents an opportunity to inspire students based upon positive experiences in the calculus sequence. Students who are thus inspired are more likely to switch to education as a possible career.

It is often quoted that "teachers teach as they were taught" (e.g., Hall et al., 2006). Current research reveals that teachers actually teach in the way they preferr to be taught, or the way they believe their students will learn best. (Cox, 2014). For teachers to integrate the mathematical practices of teaching (Cobb et al., 2011), they must have productive experiences first as students.

The use of active learning, which IBL may be categorized as, promotes the mathematical practices of teaching (Common Core State Standards Initiative, 2010). This is a learner-centered method focusing on sense-making activities. Students do more than take notes and write down definitions. Rather, they tackle tasks that require them to engage with one another, to experiment, and to explore the mathematics presented. The role of the instructor is to guide the students in their sense making.

Following the University of Colorado Boulder learning assistant model, the UNO faculty began the use of learning assistants in their respective Calculus II sections. The faculty trained the learning assistants to serve as support personnel for the students throughout the course. The use of a learning assistant is critical in this process, as the calculus students are usually working within groups of three to four students, and it is imperative that some direction and assistance be given at appropriate times. When class sizes are large, the addition of a learning assistant helps to have more hands on deck to help guide students if they are feeling stuck or lost. The learning assistant, like the instructor, does not tell the answers, but rather she/he aids the students by asking appropriate questions and helping them to feel confident in doing the mathematics.

The UNO faculty, in partnership with faculty from the University of Colorado Boulder, created a plethora of activities and worksheets for Calculus I and II classrooms. These activities are now openly available to calculus instructors. These activities include "TACTivities," which are hands-on manipulatives of cards or objects as well as worksheets created for daily classroom work.

Extending the Reach of IBL into Precalculus

Inclusion of the precalculus course in the IBL format was a result of positive experiences of students in the calculus courses. One of those students became a participant in the Noyce Scholarship program. The program was

initiated at UNO to support future secondary math teachers (Noyce Scholars) that agree to teach in high-need schools. As part of this program, the Noyce Scholars are required to initiate or be involved in programs and activities throughout the community that promote mathematics education. The impact of IBL instruction in calculus on this Scholar was significant. She came to believe that students can learn best in this environment. When she consulted with a faculty mentor regarding projects for the upcoming year, she suggested implementing IBL in the precalculus course. The faculty member was already using IBL in teaching a History of Mathematics class and elements of IBL in mathematics courses for elementary teachers, but he had no experience teaching a more traditional mathematics course such as calculus or precalculus using this format. Having taught trigonometry twice using a traditional lecture approach and having seen the high D-Fail-Withdraw (DFW) rates that were common at UNO, following national trends (Babaali & Gonzalez, 2015; Brusi, Portnoy, & Toro, 2013), this faculty member was open to change. This faculty member had also seen the significant impact IBL instruction in terms of recruiting future teachers and thought that an IBL precalculus class might be a sensible next step to try. The goals of the pilot study that concluded last year were to implement IBL in the precalculus curriculum and to decrease DFW rates, along with hopefully having an impact in recruiting students into teaching careers.

Homework Room

The inclusion of "homework room" in the IBL format at UNO has proven to be an important component. Faculty and learning assistants staff an open-study room for students one hour before class daily. Students are encouraged to attend and work on homework problems. The format of the study room is much like the classroom. Students work together, while faculty and learning assistants guide them. The faculty and learning assistants do not simply provide a solution. Students are encouraged to find their own solutions. Efforts are made to carefully examine student work to determine the source of the confusion. Through this process, "the light comes on" for students. The faculty role is not simply that of the conveyor of information. Rather, the faculty engages with the student, listens to the explanations and steers them to an understanding of not only the specific homework problem, but an understanding of the underlying concepts.

The Classroom

Changes to the physical environment facilitated active learning. Traditional desks were replaced by tables and chairs. The arrangement encouraged students to focus their attention on one another and on their personal exchanges, rather than on "the sage on the stage." Students were initially in self-selected groups, but some instructors switched groups throughout the semester.

As class begins, table groups determine if any significant questions remain from the homework. As needed, up four problems were presented to the class (typically 3-4). Students volunteered to present their solutions to the class. Often a student would say, "I'm not sure if I have it right, but I'll put up what I have." This is a great testimony to the strong support students give to each other and their willingness to work cooperatively. Often, more is learned from the presentations with errors than those that are correct.

After an initial introduction of the day's topic, students are provided guided activities to complete at their tables. Typically, the brief presentation (5 minutes) simply allows the instructor to "set the stage" for the activities and the concepts for the day. The activities are typically worksheets that guide the students through specific ideas and concepts, and hands-on manipulatives are used intermittently as well. While students are working together on activities, the instructor and learning assistant circulate around the room listening to students and their exchanges, and give "gentle nudges" when needed rather than simply providing an answer. If a common question surfaces around the room, or there is a major point of confusion among several of the students, the groups may "report out" their work and they may all work jointly to develop a solution. Importantly the IBL classroom is one in which

students feel comfortable failing, evaluating and trying again (Miller-Reilly, 2007). An attitude of resilience and persistence in solving problems is the goal.

Participation

As an example of how participation was graded, we cite the participation breakdown for the precalculus course. Participation was graded similarly for the calculus sequence. The "active participation" grade was a key element in what made our course different from traditional mathematics classes. It was decided that students would be required to present three times (four if they wanted extra credit) before the end of the semester as part of their participation grade. Homework problems to be presented were chosen because they had important concepts embedded within the problem. These were selected by the instructor and learning assistant prior to class time. Students signed up to present homework problems after their work was checked to make sure that their efforts were at least on the right path, and would lead to a discussion of the topic at hand. Only six students in precalculus failed to complete their three presentations (no one who came to class failed to complete this requirement in the calculus sequence). During class, presenting a problem meant that a student would put his or her work up on the board after the class had sufficient time to work through the problem within their group. As time allowed the student who presented would explain some of their work. The participation grade was more than just presentations. Students were expected to attend class regularly (and for the calculus sequence attend homework room and other mathematics activities). When in class, students were expected to be working within their groups and asking questions during class presentations.

Methods

The faculty have conducted various research initiatives to measure the success of the IBL teaching in the calculus sequence (including precalculus). An in-depth study of the students over the course of the last few years, including pre-post-surveys on student attitudes about mathematics, persistence data, qualitative data (including math autobiographies), student performance data, student work samples, and data from the writing activity we will describe here. The surveys were given at the beginning of the semester and end of the semester. All other data has been collected on an ongoing basis.

The results demonstrated how student beliefs about teaching and learning mathematics can change by taking one or two courses that employ the active learning method of teaching.

Results

We report the results in several parts. First, we discuss the impact on the IBL calculus on dispositions toward problem solving and mathematical thinking. Second, we report the impact on the IBL precalculus on pass-fail rates. Finally, we talk about impacts of IBL calculus classes on teacher recruitment efforts.

Calculus Results

Each semester students were given a writing activity mid-semester. This writing activity is called a "rose, bud, and thorn" activity. The students are asked to write about one thing they think has blossomed as a result of this course (the rose), one thing that is developing (the bud), and one thing that is still a sticky point (the thorn). The activity has generated data that suggest the active learning calculus is getting students to think about the mathematical practices of teaching as well as getting them to reflect on how they think mathematics best be learned. The following are four representative quotations to help illustrate the results.

Reflecting on mathematics

> This course has opened me up to a new way of learning math. In the past, my math classes really only involved somebody lecturing. I like how in this class we go through more examples/homework and how I

have a group of people to bounce ideas off of. There really is not much to complain about. I believe this class has made me have a new understanding of math. I used to just memorize equations, now I understand how to actually solve those equations.

Making sense of problems and persevering in solving them

I think that the open table work is a rose because it allows us to learn together and share how we learned the material. It helps us to understand a problem in different ways and see new approaches to a problem. A thorn would be the lack of lectures. There are times in class where I feel like all I know is the procedure to solving the problem and not the way. There are times when I feel like I couldn't explain why I solved a problem this way either than the fact that it is the procedure. The bud goes with the rose in that you can grow when you see the approach that other people use to solve the problem.

At first, I was overwhelmed because it had been a long time since I had had Calc I. It was discouraging and very challenging at first. It has gotten better but I still find myself recovering prior knowledge I had forgotten. It is a constant learning process. I am glad I stuck it out because I really do like math. This class is my favorite class because there are several opportunities for growth. I also love the group learning atmosphere. I have gained some good friends through Calc II. It will be interesting to see where I go with math in the future.

Constructing viable arguments and critique the reasoning of others

This course is fantastic for peer-group building and learning experience. It really forces students to interact and discuss topics, which is very refreshing for a math class. Bud: The mixture of professor-led lectures and student-led examples is a great idea, but I felt that the ratio might have been off slightly. I would have preferred fewer presentations, but I'm sure others would have liked even more of them. Summary/Thorn: There really aren't any purely negative things about this class. The content is challenging but there are multiple resources for help provided. The teaching style is different, but the lectures are engaging and there is a massive sharing of ideas occurring at all times. Again, nothing is objectively bad here. Great class!

Pre-Calculus Results

One of the goals of the precalculus IBL class was to improve the pass-fail rate. The results were promising. The DFW rate (28 percent) for the IBL precalculus section taught in fall 2016 was better than the historical average at to 40.8 percent for the historical average since 1995. See the box-and-whisker plot in Figure 1 to see how this course faired compared to 99 other precalculus courses since 1995.

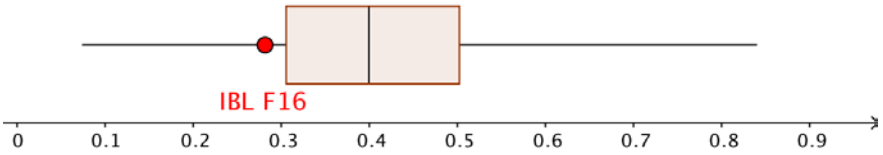

Figure 1. DFW Rates of Math 1340 at UNO from Fall 1995 to Spring 2016.

The successes in both the DFW rates dropping and also the positive feedback from our surveys suggest that there are good things happening in the IBL courses at UNO. In addition, we have found our IBL classes to help us in the recruitment of future mathematics teachers.

Recruiting Future Teachers

The active learning nature of these classrooms allows us to recruit students into mathematics education. Every day, as instructors, we get to hear our students think and watch them work collaboratively with other students. We literally see how our students interact and how they help others in the classroom. This allows us to hand pick students who we think would be good future teachers.

Once we identify students who would potentially make good future teachers, we invite them to: a) apply to be a Noyce summer intern (an internship in teaching), b) visit with our advisor to take more mathematics courses, c) work with us on mathematics education research and other projects, and/or d) work as learning assistants in our mathematics courses.

These efforts have been very successful. Almost all of our 30 Noyce interns/scholars have been recruited from IBL classrooms. These students go on to be future mathematics teachers, who will also have experiences being part of an IBL classroom. Many of these students were not originally planning on being teachers initially. Overall, we have seen a marked increase in the number of students who are going into our B.S. in Mathematics with initial teacher certification pathway. The number of students taking this pathway has increased by more than 100 percent from four years ago when the IBL calculus classes started. While we do not believe that all of this increase is due to the IBL calculus classes, much of it does seem to be related. The recruitment is a result of the efforts tied to the "Active-Learning Mathematics" RAC within the MTE-Partnership. A goal was to institutionalize active learning into our calculus sequence, and use these teaching techniques as recruiting tools for future mathematics teachers. Although we have not reached the institutional level of implementation, the successes with students and future teachers have expanded to other courses.

In the precalculus classes, the instructor went in with a goal of recruiting future teachers by identifying students and encouraging them to continue with IBL calculus. The instructor looks for promising students, as is also the case in the calculus sequence. When we say promising, we mean that they seemed to enjoy the mathematics, especially the challenge of working through the harder problems. The students also worked well in their groups and did a good job explaining their reasoning and solutions when talking to the whole class. We feel like these promising students became accustomed and thrived while learning in an IBL format. They may be heavily influenced toward teaching in future classes because of this early IBL experience. We encouraged many of them to take an IBL calculus section in their next class.

In all of our IBL classes, we also invite or require students to participate in various mathematics outreach events such as the High School Math Contest, the UNO Calculus Bee, Cool Math Talks, and various UNO Math Club events (both social and academic). We have had the best success with this recruitment tactic as a requirement of the course. For precalculus, these events were recommended and few students attended these extra mathematics events. For the calculus series, we require three to four outside of class activities, which we feel has had a large impact on our success in recruiting students in the mathematics major/mathematics education major.

Future Plans and Conclusions

The faculty will continue to work on active learning calculus materials for first and second semester calculus, as well as precalculus. The distribution of the materials to other universities throughout the country is ongoing. Data have been collected regarding the effectiveness of IBL in the calculus and the precalculus classrooms. More students are being trained to serve as Learning Assistants. Additional faculty will be recruited to be incorporate IBL into their classrooms. Faculty are analyzing data and writing articles to be submitted to peer reviewed journals.

By daily engaging in mathematics, communicating mathematics, and even arguing about mathematics, the students in active learning calculus have grown to think that active learning, which aligns with the mathematical practices of teaching, is the best way to learn mathematics. Since we are asking our teachers to instruct this way in the classroom, we value this outcome. If Cox (2014) is correct, this leads us to believe that the future teachers in these active learning calculus classrooms will also teach mathematics in an active manner. As a result, they will be better prepared to teach kids directly incorporating the mathematical practices of teaching. We realize there is still a great deal of work to be done in this research area. We plan to perform a longitudinal study and observe our teachers in their own classrooms to have evidence of their personal teaching styles. In addition to implications for teaching majors, we are also finding lower drop/fail rates in active learning calculus classes, more people switching to math majors after taking an IBL mathematics class, and an increased number of students that volunteer for community outreach events coming from these classes. Hence, there are more areas to explore and we are willing to share our findings and ideas on any areas of which we have collected data.

For More Information

To learn more about inquiry-based learning in calculus, please contact either Dr. Janice Rech at the University of Nebraska at Omaha (jrech@unomaha.edu) or Dr. Angie Hodge at Northern Arizona University (ang.hodge@gmail.com). For more information about inquiry-based learning in precalculus, please contact Dr. Michael Matthews at the University of Nebraska at Omaha (michaelmatthews@unomaha.edu).

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