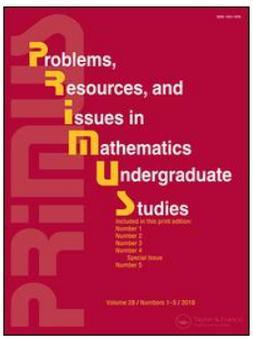

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Active Learning in an Undergraduate Precalculus Course: Insights from a Course Redesign

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ABSTRACT
Addressed toward course coordinators and departmental leaders interested in redesigning an undergraduate mathematics course, we highlight the steps our team at the University of Maryland, College Park has taken in bringing active learning to our Precalculus course. We provide examples of ways in which we have coordinated active learning across redesigned sections, as well as preliminary results of the effects of active learning on student success. Finally, given the broad set of experiences and backgrounds of our team members, we argue for the unique insight our redesign offers in restructuring a gatekeeper mathematics course to be focused on active learning.

KEYWORDS
Active learning; Precalculus; undergraduate mathematics; course redesign

1. CONTEXT OF PROJECT AND COURSE DESCRIPTION

Within the last decade or so, undergraduate mathematics departments have begun to explore the role of active learning, often characterized by students engaging in mathematical discussion [2], in college classrooms [5–7, 8, 11]. Following this exploration, the Math Department at the University of Maryland, College Park (UMCP), a large, R1-public university, has worked to improve the instruction in its undergraduate Precalculus to Calculus 2 (P2C2) courses. In 2017, UMCP joined the NSF supported Student Engagement in Mathematics through an Institutional Network for Active Learning, or SEMINAL network [1], aimed at supporting universities wanting to adopt active learning in their P2C2 courses. In particular, UMCP has chosen their Precalculus course as its primary focus for a redesign.

UMCP's Precalculus course acts as a gatekeeper for all STEM majors whose mathematics placement scores do not give them direct access to calculus coursework. More specifically, Precalculus is a prerequisite for the mainstream Calculus I course taken by students majoring in a STEM field. However, the course has historically had a high failure rate (30–50%). Precalculus' failure rate is a significant concern for UMCP and its students, especially considering a computer

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science student, for example, who fails Precalculus once delays his/her enrollment in the flagship computer science course for a full academic year. Furthermore, our evidence suggests that the Precalculus course at UMCP disproportionately filters underrepresented students. For example, African American (12.9% of the UMCP student population) and Hispanic (9.7%) students represent 32% and 16% of Precalculus, respectively.

Our Precalculus redesign team at UMCP sees active learning as a means to provide all students with opportunities to "take on intellectual authority that [fuels] the collaborative classroom" [10, p. 238]. More specifically, we define active learning as the implementation of classroom practices that lend themselves to student-to-student discussions of core mathematical concepts through engaging with complex tasks. From this perspective, classroom practices entail both what the teacher does to foster student discussion, as well as the purposeful designing of active learning tasks (e.g., conceptual questions, group quizzes, and exploration problems) that guide students in reflecting on their understanding of the material. Additionally, we see active learning as a mindset in which students reflect on and engage with content inside and outside of in-person class meetings. Moreover, evidence suggests that active learning benefits those students who struggle the most in mathematics courses [3], including students of color [9]; thus, we see active learning as an appropriate means to better support all students in their successful completion of Precalculus.

1.1. Versions of Precalculus

There are three versions of Precalculus, historically with little coordination across each, except for the topics covered and a common final exam. For example, sections not a part of the redesign described here often differ in the syllabus and grading scheme they follow. The large lecture version of the course ($\sim$250 students in a given lecture), or Main Precalculus, meets three times per week for a 50-min lecture, and then breaks off into Teaching Assistant (TA) led recitation sections that meet two or three times a week, for 75 or 50 min per meeting. UMCP additionally offers a version of Precalculus through a fall extension program for incoming freshmen, or Bridge Precalculus, for those students officially admitted for the spring semester who wish to begin earning credit in the fall. Bridge Precalculus meets twice a week for 75-min sessions, with no recitation sections. Lastly, UMCP offers an intensive seven-week remedial version of the Precalculus course, or Remedial Precalculus, that follows a six-week developmental algebra skills course and is designed for STEM-intending students who have low mathematics placement test scores. Remedial Precalculus meets five times a week for 50-min meetings, with no recitation sections.

2. OVERVIEW OF PROJECT GOALS AND TIMELINE

The overall goals for the redesign of Precalculus include:

(1) Build and refine a shareable set of active learning resources, strategies, and class assignments;
(2) Coordinate the use of active learning resources, strategies, and assignments, including the use of effective complex tasks and instructional practices [12], across different versions of Precalculus;
(3) Sustain the changes made to Precalculus.

2.1. Timeline of Redesign and Focus of Paper

We present the following timeline (see Figure 1) to succinctly summarize the steps our team has taken thus far in the Precalculus redesign. For clarity, please note that we use the term "redesign" in the sense that continuous adaptations are being made over time to refine the course, as opposed to a single semester change. Additionally, due to changes in the number of redesign team members since 2017, as well as the Math Department only offering Bridge Precalculus sections in fall semesters, we highlight fluctuations in the number of redesigned Precalculus sections. In particular, the fall 2018 semester was the first time in which a Bridge Precalculus section and Main Precalculus, including both the large lecture meeting and recitation sections, were simultaneously in the process of redesign. Currently, our team is beginning to observe Remedial Precalculus sections and share active learning resources used in the Main and Bridge Precalculus sections. However, the redesign of Remedial Precalculus is in its infancy. Thus, the focus of this paper is on the redesign of Main and Bridge Precalculus.

3. REDESIGNING PRECALCULUS

In the sections that follow, we provide in-depth descriptions of the redesign of Precalculus to include active learning across Main and Bridge Precalculus sections. We organize the description of the redesign by the project goals stated above, with each subsection addressing how we have met the goal in consideration.

3.1. Addressing Goal #1: Developing/Refining Active Learning Materials

An essential focus of the project has been developing and refining a repository of active learning materials, in addition to using general active learning strategies (e.g., think-pair-share and partner board-work). Therefore, the team created a Google Drive Team folder to house all of these resources, an appropriate platform to use given that a Team Drive folder allows team members to simultaneously own files, as well as transfer ownership easily to future instructors of Precalculus. For Main Precalculus, active learning happens mostly (but not exclusively) in the recitation meetings. In contrast, active learning is a continuous part of the Bridge Precalculus sections given their limited number of meetings per week and smaller class sizes. As an example, in both the Main recitation sections and Bridge Precalculus sections,

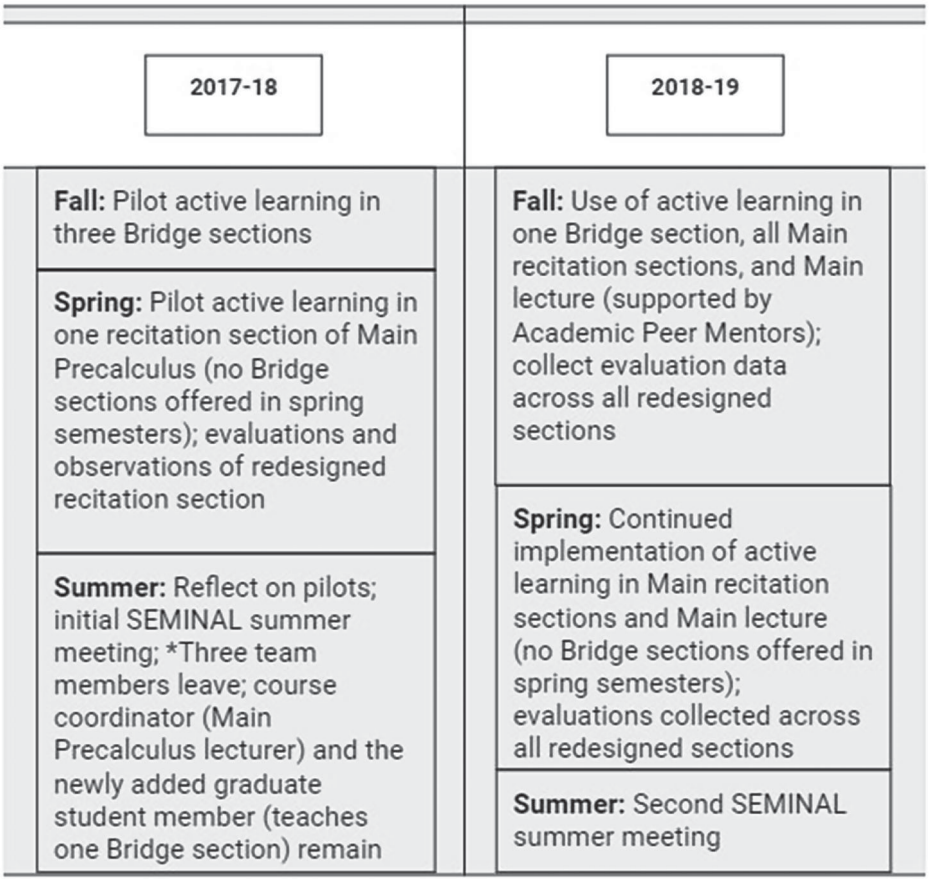

Figure 1. Timeline of Precalculus redesign.

students are often asked to work in groups on a series of problems that are purposefully complex to encourage students to work together in arriving at an answer. In addition, Bridge Precalculus instructors often ask students to report out their results on large poster paper to show different approaches to the same problem.

The sample active learning task included in the Appendix of this paper provides an example of active learning within the classroom. More specifically, the sample task involves students working in groups on a problem that calls for students to graph a rational function given only particular characteristics of the function. Such a problem serves as an example of an active learning task given that it is both challenging (i.e., students must graph the function without knowing the explicit function) and involves students working together. Such a task also provides an immediate means for instructors to engage students in active learning, regardless of the instructor's prior experience with active learning. In other words, the activity is built with active learning in mind through both the task itself and the instructions to work with others, thus serving as a practical first-step for instructors to implement active learning.

3.2. Addressing Goal #1: Active Learning in Class Assignments

A recurring point of discussion over the past two years has centered around helping students grow as learners of mathematics. In particular, we have aimed to help students take-up effective studying strategies and practices, including through the use of the active learning materials mentioned above, to help students be successful in both Precalculus and future mathematics courses taken through the UMCP Math Department. In an attempt to convey our team's vision to students and provide explicit examples of what it means to be an active learner, a significant focus of the redesign has been on the revision of the Precalculus syllabus and associated assignments used across redesigned sections. For example, *Pre-lecture Readings* are assigned to students to read before class as a means to help them develop the habit of beginning to think through the material prior to class.

Furthermore, it was clear from previous iterations of the course that students typically would only review for exams the week of; however, the team valued having students engage with exam-like problems throughout the semester. Therefore, as another example of our use of the syllabus to demonstrate for students what an active learner does, *Exam-prep Questions* are pre-assigned on the syllabus as weekly assignments to help students develop their exam studying practices. These questions include problems taken directly from past Precalculus exams at UMCP. Other examples of active learning assignments include *Pre-lecture Activities* to be done at the start of class (designed to include accessible problems based on the *Pre-lecture Readings*), *Post-lecture Homeworks* for students to complete individually, and *Collaborative Quizzes* for students to complete together.

3.3. Addressing Goal #1: Use of Existing Active Learning Resources

Beyond building and refining active learning materials and assignments, we have sought out resources already at our disposal to bring active learning to Precalculus. For example, our team took two significant steps in the fall of 2018 to explore what active learning looks like in the large lecture of Precalculus, in addition to the recitation sections. First, the Main Precalculus instructor taught in the new Learning and Teaching Center on campus designed with active learning in mind. More specifically, the Main Precalculus instructor taught in a large room that contains several media screens, whiteboards around the entire wall space, and multiple projector screens/televisions at the front of the room for displaying document camera projections. Additionally, there is tiered seating with swiveling chairs to encourage collaboration and discussion. The 2017 pilot sections of Bridge Precalculus were also taught in media classrooms within the Center. Thus, the Center has served as a valuable resource in implementing the team's shared vision for actively engaging Precalculus students by creating a space that fosters student-to-student interaction and discussion around course material.

Second, the team began using Academic Peer Mentors, undergraduates trained in facilitating active learning through a program housed in the Learning and Teaching

Center. Mentors have played an essential role in supporting the instructor's implementation of active learning in the large lecture. For example, mentors support students during group work and quizzes by rotating around the room during class meetings to facilitate small group discussions and answer questions. Furthermore, the use of mentors in Main Precalculus is a practical route to bringing active learning to Precalculus given the mentor program also emphasizes active learning in the required one-credit course all mentors take.

3.4. Addressing Goal #2: Adapting to Variations of Precalculus

Given the structural differences between the Main and Bridge Precalculus sections, adaptations were necessary to coordinate active learning across both redesigned versions of the course. To summarize the level of coordination across the two versions of the course, all redesigned Main and Bridge sections use a common syllabus that outlines the same content covered for a given week. Additionally, all redesigned sections use the same textbook and source of online homework problems, repository of active learning resources (see Section 3.1), and test bank with past exams for students to use in preparation for upcoming exams. Finally, while there are minor variations across the redesigned sections, including which specific activities and problems instructors choose to use from the shared pool of active learning resources, we see these as appropriate variations to effectively address the needs of the individual students within each classroom.

Other variations across redesigned sections are necessary given that the Main Precalculus sections meet more frequently throughout the week than Bridge sections. As an example, Bridge Precalculus instructors often use the Pre-lecture Activities as daily "Warm-ups" that serve multiple purposes. These purposes include having students reflect on the Pre-lecture Reading, checking for student understanding on past content, launching into that day's new content, and leaving time for student questions on Post-lecture Homeworks and Exam-prep Questions. To further address the difference in meeting times between Main and Bridge sections, all sections have access to all of the Post-lecture Homeworks and Exam-prep Questions for the entire week beginning on Monday morning, with a due date at the end of the week. By providing students with an extended set of time to work on problems throughout the week, Main and Bridge Precalculus students have an equal amount of combined time (i.e., inside or outside of class) to ask questions about the assignments, regardless of their class structure.

The level of coordination across redesigned sections of Precalculus demonstrates our team's focus on what Bressoud and Rasmussen [4] describe as intentionally building "communities of practice" in which instructors share "innovative pedagogies, assignments, and approaches to particular aspects of the curriculum" (p. 145). In other words, our team sees the coordination across redesigned sections of Precalculus as a practical example for other course coordinators in the Math Department at UMCP to draw on when considering how to coordinate the implementation of active learning effectively. By providing instructors with a pool of shared active

learning resources, while giving instructors autonomy in choosing which of those assignments/activities to use in their classroom, we hope that more instructors at UMCP will be willing to implement active learning [see 13, p. 101 on the importance of giving ownership to instructors].

3.5. Addressing Goal #3: The Challenge of Sustaining Change

While our team is proud of the development and coordinated use of active learning resources across redesigned sections of Precalculus, a major aim has always been to sustain these changes to the course beyond the current team's involvement. A significant change occurred during the summer of 2018 when three of the four core team members (i.e., members who either taught Precalculus sections or wrote the SEMINAL proposal) moved on from UMCP. Additionally, a graduate student (the first author) from the College of Education joined the project and taught a Bridge Precalculus section in the fall. This change marked a critical timestamp in the redesign as it provided an opportunity for the team to address the third goal of the redesign, namely, sustaining the changes made to Precalculus. As a practical example, those leaving the project shared their resources with the graduate student and gave him access to the set of complex tasks three months before the fall semester so he could prepare for teaching a Bridge Precalculus section. Additionally, the graduate student and those leaving the project discussed active learning strategies that seemed beneficial to students based on the pilot sections. This collection of resources, time, and experience allowed for a seamless continuation of implementing active learning in Precalculus, despite losing multiple team members.

3.6. Addressing Goal #3: Department Adoption of Active Learning

Part of our team's effort in sustaining the changes made to Precalculus has come in the form of more broadly supporting active learning across the UMCP Math Department. Related to this effort, a common theme across the SEMINAL institutions in sustaining changes made to courses such as Precalculus has been the difficult, yet essential work in reshaping the norms and practices of P2C2 courses within the space of deeply held and long-standing instructional beliefs and practices of mathematics departments. In an attempt to shift the culture of teaching practices within the Math Department to be more actively engaging, even beyond Precalculus, our team has discussed implementing peer-observations for those teaching P2C2 courses to encourage active learning strategies, following the work of other SEMINAL institutions. Additionally, UMCP's Math Department has held open meetings for graduate students to discuss what active learning may look like in the classes they teach.

As a result of these discussions, the nature of teaching mathematics courses at UMCP is shifting from one that is reliant on an individual instructor to one centered around a collaboration between colleagues. As Bressoud [3] argues, "faculty need both departmental encouragement and a supportive network if they are to make the

transition to more effective teaching" ("Efforts to Change," para. 2). In addressing this need, we see the redesign of Precalculus at UMCP as a unique example of how course coordinators can work with people of different experiences, as well as varying levels of departmental influence, in creating the "network" necessary to redesign a course and implement effective teaching practices.

Different from other course redesigns that may primarily involve the support of faculty and staff of the course's housing department, our redesign of Precalculus has included the involvement of graduate students, a course coordinator, a department leader, and faculty members from other campus initiatives/programs. In addition, it is interesting to note that the newest member (the first author) of the team had taken the Precalculus course as an undergraduate at UMCP a decade earlier. Therefore, he was able to offer insight into the redesign from a student's perspective while also teaching a section of Bridge Precalculus. Thus, the redesign of Precalculus at UMCP may serve as a novel example of different parties and stakeholders across a large, R1-public university working together in the redesign of a gatekeeper mathematics course. Moreover, the involvement of people from all different experiences and backgrounds demonstrates the feasibility of a diverse group of instructors in implementing active learning teaching practices, regardless of their instructional backgrounds.

4. INDICATORS OF SUCCESS

Across the different versions of Precalculus, there have been indicators of positive effects of active learning on student achievement. For example, Figure 2 presents the distribution of grades from 2015 to 2018 (2019–2020 data to come), grouping fall and spring semester grades together in an attempt to capture overall trends across the different versions of the course offered (e.g., Bridge Precalculus is only offered in the fall semesters). As seen in Figure 2, the fall/spring semesters of 2017, the first semesters in which active learning was introduced into any version of Precalculus, was the first time in which there were more grades of A, B, and C in comparison to grades of D and F. Furthermore, there has been a dramatic decrease in the failure rate (from 30% to 50% historically to 9.40% in 2017), as well as a steady decrease in the withdrawal rate (from 15.88% in 2015 to 10.94% in 2017).

Our team attributes these positive results to the implementation of active learning in Precalculus. To justify these claims, we have begun to explore comparisons across redesigned and "normal" (i.e., sections not a part of the redesign) sections of Precalculus. Note that this comparison has only been possible for fall semesters, given that this is the only time in which there have been both redesigned and normal sections for comparison. As seen in Figure 3, the number of A, B, and C grades in the fall of 2017 were higher in the Bridge redesigned sections of Precalculus in comparison to normal Bridge and Main Precalculus sections, another early win for our team. Furthermore, with the introduction of active learning into Main Precalculus sections in the fall of 2018, these numbers remained mostly consistent.

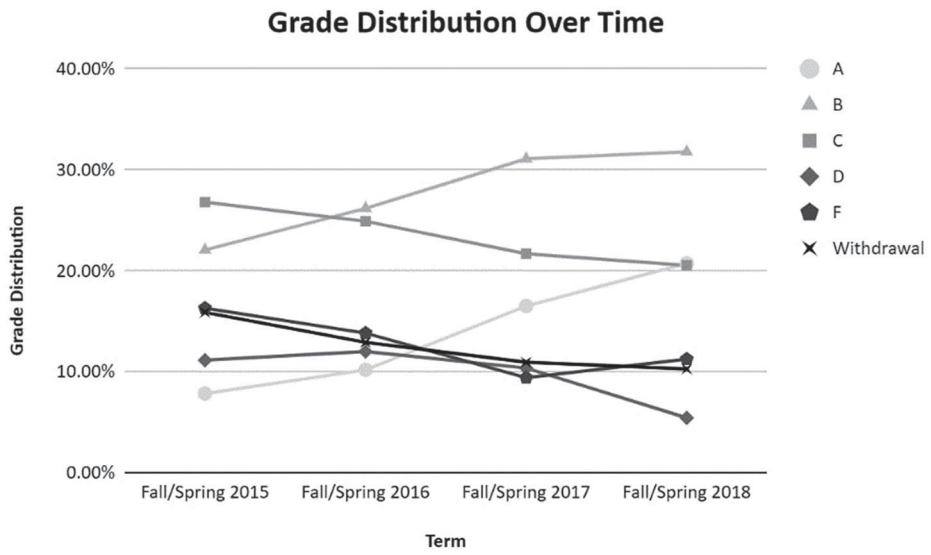

Figure 2. Precalculus grade distribution over four years.

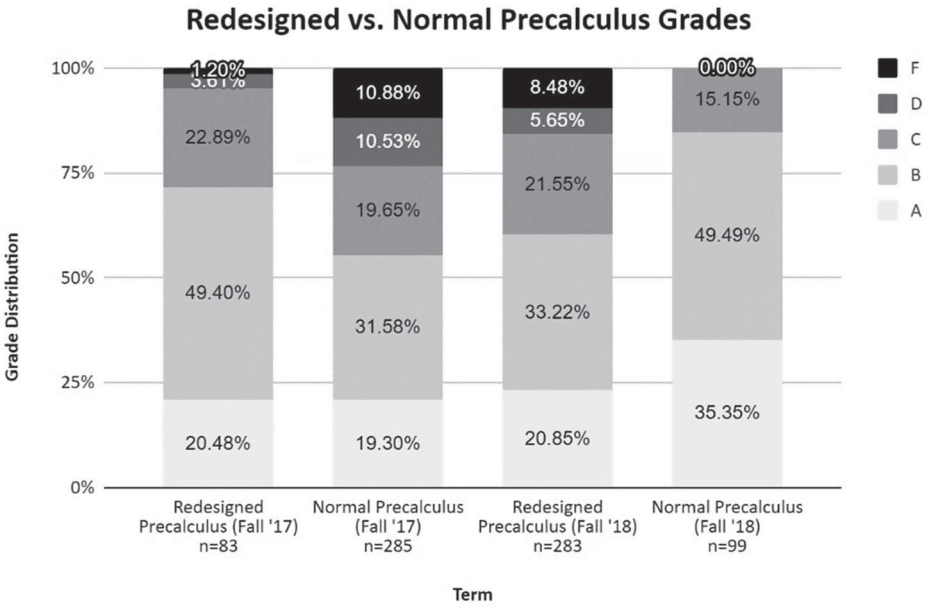

Figure 3. Grade distribution in redesigned and normal Precalculus.

However, our team continues to make sense of the increase in D and F grades in redesigned sections during the fall of 2018. One likely explanation is due to a lack of coordination across normal and redesigned Precalculus sections. More specifically, not all normal sections follow the same grading scheme, let alone follow the same grading scheme of redesigned sections. As a result, normal sections' end-of-semester grades are difficult to compare with those of other normal and redesigned sections. Thus, to have a better basis of comparison, our team will be focusing more

on analyzing grades on the final exam across sections as this is the only exam that is uniform for all students across both redesigned and normal sections.

Additionally, our team plans on disaggregating the grade data to explore the effects of active learning on students of different races, given the disproportionate representation of minority students in Precalculus. Nevertheless, the first look at these comparisons shows hope for the potential benefits of active learning on student success in Precalculus. Anecdotal evidence further suggests benefits from active learning in explaining the increase in achievement. For example, returning TAs have reported an increase in on-task discussion and collaboration between students, and a small but visible increase in the number of students asking questions during the Main Precalculus large lecture.

5. CONCLUSION

There continues to be evidence of a movement within the Math Department at UMCP toward adopting active learning tasks and teaching practices across the many mathematics courses the Math Department offers. In addition to our redesign of Precalculus, other courses at UMCP have begun to implement active learning, including Introductory Statistics (~ 350 students), also taught in the Learning and Teaching Center on campus. Thus, while the redesign of Precalculus is undoubtedly still in progress, we see our work as an essential piece in creating a broader culture that is supportive of active learning practices across the UMCP Math Department.

FUNDING

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APPENDIX

Sample Active Learning Task

For this problem, you're going to be graphing a rational function $f(x)$ with others in your group. However, I'm not going to tell you the function! Here's what you do know:

- $f(0) = 1$
- The degree of the numerator is 1, and the degree of the denominator is 3
- The first and last rows of the table of signs look like this (where X means that the function Does Not Exist at that point)

	$(-\infty,-1)$	-1	$(-1,1)$	1	$(1,2)$	2	$(2,\infty)$
$f(x)$	$+$	X	$+$	X	$-$	0	$+$

(a) Draw a set of axes and label all intercepts of $f(x)$ on it, with their coordinates.
(b) Show any asymptotes of $f(x)$ with dotted lines; label them with their equations.
(c) Using a table of signs, fill in the rest of the graph of $f(x)$.

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BIOGRAPHICAL SKETCHES

Mr. Sean Gruber is a Mathematics Education Ph.D. graduate student in the Department of Teaching and Learning, Policy and Leadership at the University of Maryland, College Park (UMCP). Since beginning his doctoral program, Gruber has taught a section of Math 115 Precalculus through the Freshman Connection program offered at UMCP, three sections of Elements of Geometry and Measurement, and one section of Mathematical Reasoning and Proof for Pre-Service Middle School Teachers. Gruber is a former UMCP graduate, earning both a Bachelor's in Mathematics and a Master's in Curriculum and Instruction through the MCERT program at UMCP. He taught three years in a high school in Montgomery County, as well as six summers in the Summer Transition Program offered through the Academic Achievement Programs at UMCP. His research interests include exploring how the social norms and teacher practices observed within a college math classroom affect students' self-efficacy, achievement, and persistent in mathematics and more broadly, STEM fields of study. More specifically, Gruber is interested in researching and implementing student-centered instructional practices (i.e., active learning) to improve college students' views of and experiences with mathematics.

Dr. Raluca I. Rosca is a lecturer in Mathematics and is in her fourth year as chairperson of the Math 115 Precalculus lecture course. She has over 10 years of teaching experience at the college level, and since coming to UMD has taught Math 115 in both the large lecture format, and the single contact Math 115 Freshman Connection format for thirteen semesters. As the daughter of two first-generation college students and the administrator of an outreach program to middle schools, she is also very interested in using Math 115 as a stepping stone to success in college mathematics, not just in terms of content, but also in terms of creating the social network and the personal skills, habits and dispositions that empowers today's diverse students of Math 115.

Dr. Daniel Chazan is the Jean, Jeffrey, and David Mullan Professor of Teacher Education in the Department of Teaching and Learning, Policy and Leadership, Director of the Center for Mathematics Education, and co-Director of Terrapin Teachers. Chazan's professional interests include student-centered mathematics teaching, the potential of history and philosophy of mathematics for informing such teaching, the role of technology in supporting student classroom exploration and practice-based teacher education, exploring possibilities for constructive links between educational scholarship and practice, and the preparation of future teachers.

Dr. Elizabeth Fleming is currently an applied research mathematician with the U.S. Department of Defense. From 2017 to 2018, she was a postdoctoral fellow in Mathematics Education working with Dr Daniel Chazan. She also collaborated with Dr Kasso Okoudjou on a research project about shifts in his pedagogy in his Advanced Calculus course. Her research interests include how to improve mathematics course experiences for undergraduates, and how shifts in undergraduate course instruction may impact student experiences.

Dr. Steve Balady is an Assistant Professor of Mathematics at Oberlin College and Conservatory. While at UMD, Balady was a lecturer in Mathematics at UMD and taught 13 sections of Math 115 beginning in the fall of 2008, both as a graduate student sole-contact TA and as the instructor of record for Maryland's Freshman Connection. Balady's courses — especially Precalculus — were dominated by student-centered collaborative analysis of multistep problems reflecting student questions and logical misconceptions. For his fall 2017 sections of Math 115, Balady moved his class to a Media Share classroom in Maryland's new Edward St. John Center for Teaching and Learning to promote deeper conversations between students and their proactive use of technology. His long-term research includes how students develop their identities as working mathematicians, particularly those students enrolled in "transition" courses.

Dr. Catherine VanNetta has 12 years of high school teaching experience in the Baltimore City and the Howard County public school systems. From 2014 to 2018, she was a Master Teacher of

Mathematics in Terrapin Teachers, a program designed to produce highly qualified secondary STEM teachers, and a 2017 Elevate Fellow redesigning Math 115 Precalculus. In the fall of 2017 semester, she co-taught the course to a Freshmen Connection section with two undergraduate Terrapin Teacher students. She is interested in facilitating meaningful mathematical discourse and supporting productive struggle in the high school mathematics classroom.

Dr. Kasso A. Okoudjou is Professor of Mathematics. He regularly teaches the Calculus sequence, in large lectures. In the fall of 2017, his Math 140 Calculus I lecture course was taught in one of UMD's Terp rooms designed to encourage peer-to-peer interaction. From July 2016 to June 2018, he was the Associate Chair for Undergraduate Studies and led an effort to administer Learning Outcome Assessments in Mathematics courses. In addition, he has been awarded an Elevate Fellowship by UMD's TLTC to redesign our Advanced Calculus course (MATH 410). As part of this redesign program, he and Fleming conducted a research project on how group work and active learning strategies can help students be more proficient in their advanced calculus course.