Addressing High Failure Rates in Algebra through the Examination of Relationships Between Engagement, Mathematics Attitudes, and Instructional Practices

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The purpose of this study was to examine the impact and interactions of student-centered instructional techniques on College Algebra student engagement, mathematics attitudes, and achievement. At my place of practice, instructional shifts towards student-centered and social-efficiency models of instruction are taking place, supported by administrative initiatives, to individualize student learning and better prepare students for the workforce. This project focused on using inquiry-based and collaborative methods of instruction in a College Algebra classroom throughout the course of one semester using an instructional approach known as POGIL. Instructor implementation of inquiry-based collaborative methods aimed for students to build positive mathematical attitudes, actively engage in their learning, and be more likely to show positive math learning outcomes –including higher achievements with the use of productive struggle and collaborative learning instructional techniques. Qualitative results showed student attitudes toward mathematics in introductory college algebra classrooms were primary influenced by teacher practices in their K-12 mathematics classrooms and the feelings ranging from fear to joy that resulted from these past practices and suggested that POGIL activities may have helped with student attitudes by shifting negative experience of fear and dread to the excitement and increased sense of camaraderie amongst peers. No quantitative self-reported Likert scaled survey items showed a statistically significant ($p<0.05$) differences at the two time-points for items corresponding to attitude, engagement, or content retention based on paired t-tests. However,

results indicated a “cohort effect” within the classroom with trends showing different responses regarding survey items and summative test results between the three cohorts examined.

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Preface

Acknowledgements

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1.0 Introduction and Rationale: Framing the Problem of Practice

1.1 Broader Problem Area

Since the early 2000s, curriculum advancements have emphasized the importance of the knowledge and skills from the disciplines of science, technology, engineering, and mathematics (STEM), examining links between STEM skills with success in the workforce, critical thinking, innovation, and the abilities to tackle societal issues. Since the Natural Science Foundation's (NSF) coining of the acronym "STEM," researchers and educators have begun to formalize its definition and competencies. However, student achievement in STEM fields within the United States has fallen behind those of other countries, as indicated by international reports such as the Trends in International Mathematics and Science Study (TIMSS) (Mullis, Martin, et al. 2020) and the Program for International Student Assessment (PISA) (Barshay, 2020). Achievement gaps found through these formalized assessments have prompted investigations to identify gaps in traditional instructional practices and ensure initiatives in STEM education were appropriately implemented in United States classrooms.

1.2 Organizational System

My university is a small, rural, regional campus of a more extensive university system, located approximately 35 miles south of Pittsburgh. The university student body comprises approximately 1500 full-time students, the majority (60%) commuter students. Most of these students come from surrounding rural and suburban areas with Alleghany and Westmoreland counties (67%). A large group of students (~30%) opt to transfer to the main campus after their first two years to continue their education. For this reason, the campus is primarily composed of first- and second-year students. Demographically, many students (92%) are of typical undergraduate age (24 or under), with the majority, 77%, self-identifying as white, 6.5% identifying as Hispanic, 6.8% identifying as Black, 3.5% identifying as Asian, and 3.8% identifying as Multi-Ethnic.

First-year students enter my university with average SAT scores roughly 200 points lower than students at the main campus. Of the 400 incoming students who took the mathematics placement test in 2019, 42% placed into MATH0031 – Algebra, the lowest level course offered on our campus. Placements score thresholds differ based on a student's major, Table 1. Within these placement scores, a large span of understanding exists. About 37% of these incoming students earn placement scores below the threshold for Algebra; however, we do not offer remedial mathematics courses at my place of practice. Unlike other campuses, where students can take a two- 1.5 credit course Algebra sequence, those who score below the placement threshold at my university are placed directly into traditional Algebra sections. This makes Algebra one of the highest failed math courses on my campus, with an average failure rate of 26% over the past five years. Algebra is a required mathematics course is a prerequisite for all other mathematics courses; therefore, those who do not pass the course are required to retake the course in subsequent semesters to satisfy requirements for graduation.

Table 1 First Year Mathematics Placement Score Thresholds and Program Requirements

Placement Score	**Program Requirements**		
	Algebra Only	Algebra, Pre-Calculus, Business Calculus 1	Algebra, Pre-calculus, Scientific Calculus 1, Additional courses
0 - 30%	***Optional*** completion of online modules to increase score to 30		
31 - 46%	Algebra	Algebra	Algebra
47 - 60%	Exempt Basic competencies met	Pre-calculus	
61 - 75%		Business calculus	Pre-calculus

I have been a full-time statistics and mathematics instructor at my place of practice since 2014. I currently teach introductory statistics courses that target natural science students, nursing students, and business students. More recently, as needed, I have been instructing upper-level statistical methods courses and foundational mathematics classes –such as Algebra. Foundational courses, such as Algebra, satisfy quantitative reasoning competencies required for graduation.

Concerning their math learning, I often notice that students who have lower achievement in their mathematics classes typically have lower class attendance, lower participation during class, and lower assessment scores. Class sizes in introductory mathematics and statistics courses often range from 24-36 students per section, making it noticeable when students do not attend. When absent, most students rarely email me for missed work. My mathematics classrooms are often very interactive, with open discussions of homework and problems before class starts. Still, students become silent once lectures begin and are reluctant to answer questions or interact during lectures. Students are often reluctant to participate in the classroom setting. Students typically are hesitant to interact when asked questions or allotted in-class work time. Students do not always take advantage of in-class time and often sit in silence and work on projects independently. Students also give little feedback regarding preferences in instructional practices or lecture delivery. Many of these students opt for a more traditional lecture rather than wanting to perform tasks to gain knowledge to “save time” or prevent them from actively participating in the classroom.

As an educator in the university setting, I have the flexibility to determine the way in which course materials are taught, opportunity to choose and develop course materials, and ability to modify aspects of the students’ learning environment as long as the curriculum context follows university outlines for the course. The majority of my courses are traditional lecture with teacher-directed whole class instruction and the incorporation of some small group activities and homework. Over time, I have tried to modify topics within the classroom to better target student interest, incorporate multiple assessment methods to help those with test anxiety, incorporate time for additional collaborative group work to improve classroom relationships, and have made modifications to syllabi to accommodate students’ other coursework (to try to ensure tests do not coincide with other classes); however, the problems of engagement persist in my mathematics classes.

1.3 Stakeholders

The significant stakeholders surrounding this issue are the students, instructors, and university administration. Each stakeholder may view the problem of practice and root causes contributing to the more significant issue of high failure rates in mathematics courses differently. Students are primary stakeholders since they experience problems at the ground level. Students may view schooling to achieve a goal or a career and therefore have some expectation of what they want to get out of a particular class. Faced with various extrinsic motivational factors (e.g., money, grades, degree obtainment), students are directly influenced by the inconsistent enacted curriculum (content taught), especially in mathematics, amongst instructors where classes build upon the foundational bases of previous work (Posamentier, 2013).

At my place of practice, inconsistent enacted curriculum is an ongoing issue within my department. Over the past few years, common syllabi, textbooks, and common finals have been implemented to begin to address this issue. Students need to successfully complete, or place out of, mathematics course prerequisites in place to join the higher-level courses. Each sequential course then covers content following the prerequisite course materials with the expectation is that students should know information based on the curriculum guidelines within the university. During initial investigations, through empathy interviews with a small group of upper-level mathematics students at my university, I gathered a wider understanding of issues that may contribute to high failure rates in Algebra through stories of students' past experiences. I used the vantage points and takeaways from student interviews to inform the fishbone diagram (seen later in Figure 1), which organizes the problem of high failure rates in introductory mathematics courses.

Faculty and staff often pose a significant resistance to standardizing curriculum due to views and issues surrounding academic freedom. Instructors are provided with a syllabus outlining the overt curriculum identified by the university; however, polarized opinions and individual teaching styles influence the delivery methods and what is thought necessary. Tenured faculty and staff, historically, have been wary of transformational changes in institutional culture. This mindset has recently shifted at my place of practice due to decreasing enrollment and a new campus president. These factors have begun to empower a group of faculty and staff across the university to go beyond their comfort zones to support institutional changes and improve the campus mindset on learning. As students struggle in mathematics classrooms, it becomes more difficult for faculty to maintain a pace that always allows them to complete the list of topics on the overt curriculum guide. Ideally, students would all receive the same enacted curriculum, regardless of instructor, to allow for an equitable starting point in future classes; however, through empathy interviews, I found that this is not the case. Students indicated that some instructors often take the liberty to skip topics that have been traditionally difficult for students or skip topics they feel are not important. Students and faculty usually do not recognize the gaps in knowledge until students move to the next course.

Administrative leaders (e.g., department chairs, academic affairs) also have an investment in this issue due to their responsibility to schedule classes. They heed student complaints, issues within the department and university, and curriculum development. There is often a disconnect between those in administration and those in the classroom. With administration facing constant financial stress and budget concerns, they sometimes overlook classroom situations requiring more financial investments (e.g., hiring more faculty or compensating individuals to overhaul instructional practices). With the appointment of a new campus president in 2019, a shift in mentality is present amongst many academic staff and faculty on campus to influence the system in a positive manner, such as using innovative instructional practices.

1.4 Fishbone Diagram

Fishbone diagrams can identify and organize root causes contributing to a problem of practice. These fishbones are iterative and often influenced by research and insights from stakeholders at all levels. The fishbone diagram in Figure 1, was developed with insights from stakeholders at my place of practice and information gained through empathy interviews with students. Figure 1 outlines some potential root causes of my problem of practice. The Theory of

Improvement driver diagram, seen in Figure 2 (Section 3.1), provides a visual of root causes that are central to this study.

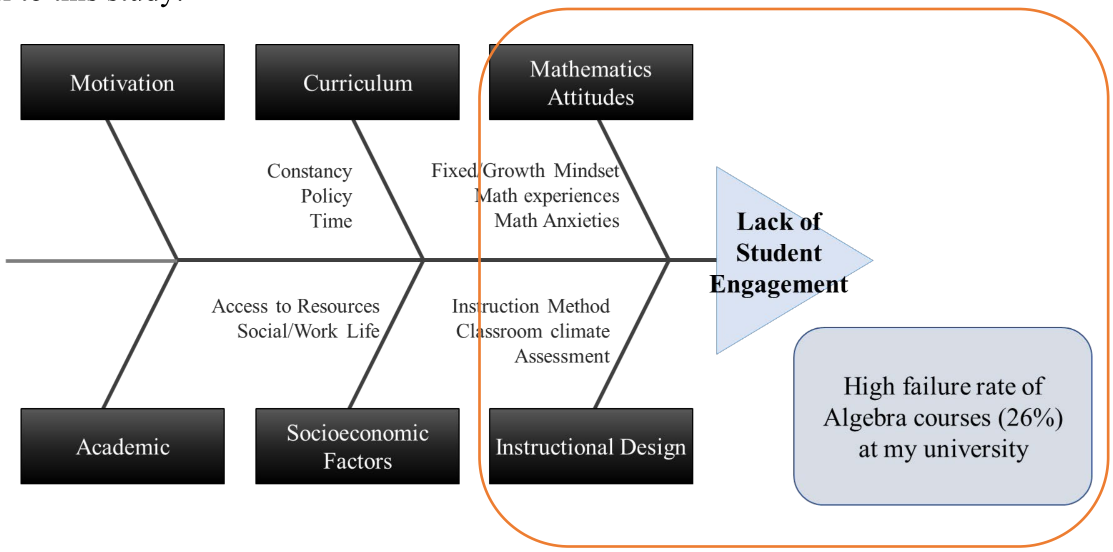


Figure 1 Overview Of Root Causes Contributing to Lack of Student Engagement and High Failure Rates In Mathematics Courses

Figure 2 shows factors contributing to student engagement and achievement in College Algebra classrooms consists of complex, non-linear interactions of drivers including curriculum, instruction, socio-economic issues, student mindset, academic influences, and motivation. As part of this research, I looked at the influence of instructional design on student engagement, attitudes, and academic success. Students have helped to bring forth the magnitude of inconsistencies seen between instructors in terms of the curriculum during interviews. Through these empathy interviews, I gained a greater understanding of student motivating factors and the stresses of "outside factors" such as work, family, etc., and their impact on learning or coming to class. Empathy interviews with faculty helped to frame root causes or potential reasoning contributing to problems in mathematics achievement. Student and faculty empathy interviews collectively have led to a revision of my problem of practice to focus on engagement, attitudes, and achievement and the influence of instructional methods that promote student accountability and self-efficacy on these outcomes. Thus, for this project, I have chosen to focus on further understanding the impact of active instructional methods on student engagement, attitudes towards mathematics, and student learning.

1.5 Problem Statement

My problem of practice involves an overwhelming high failure and withdrawal rate of undergraduate students in introductory mathematics courses at my university. This rate could partially be contributed to by the lack of student engagement and negative attitudes towards mathematics. Engagement issues, which may be linked to low mathematics attitudes, may contribute to overall achievement. Research has indicated that student engagement is critical for academic achievement (Putwain et al., 2018; Rodriguez et al., 2019). I have noticed that in my mathematics classes, students with low achievement learning outcomes also have inconsistent engagement in the learning process, lower classroom attendance, more missed work, and less likely to participate in classroom activities. My colleagues have shared that they also notice engagement issues amongst these students in other classes, both within and outside their core coursework.

2.0 Literature Review

As mentioned above, curriculum advancements have begun to emphasize the importance of the knowledge and skills from the disciplines of science, technology, engineering, and mathematics (STEM). Yet, student achievement in STEM fields within the United States has fallen behind those of other countries. In this section, I examine current research regarding potential drivers of student mathematics achievement, including influences of classroom structures, student engagement, student attitudes, and instructional methodology.

2.1 Description of problem area research

2.1.1 Influence of Culture, Beliefs, and Classroom Structures

The differences in math achievement between the United States and other countries have been partially contributed to cultural influences based on differences in beliefs and structure within the classroom protocol, procedures, and structure. Structures of classrooms seen in the Americas and Europe have traditionally focused on individualistic, open learning, where respect is earned, and leadership is praised for getting the correct answer. In contrast, structures of classrooms seen in Asia and the Middle East have primarily focused on collectivistic open learning, which avoids confrontation (Leung et al., 2006). To address the question of the influence of culture, researchers have conducted formal comparisons of the structures of math education in these societies. This examination could help to explain the overwhelming outperformance of students in East Asia versus their western counterparts in multiple assessments of mathematics achievements (Lapointe et al., 1992).

The examination of factors, students' view of math importance, students' attitudes, self-concept, the availability of resources, the country's economic status, and curriculum structures in the classroom have previously been reported to influence math achievement positively. Eastern students' views of math importance, attitudes, and self-concept did not show the positive correlations with mathematics achievement that were seen within the literature. Students of the highest achieving Eastern countries fell below average in the index of interest in mathematics, attitudes in mathematics, self-concept, and importance of doing well in mathematics compared to their western counterparts. This suggests that additional factors such as classroom structure and instructional methodology may have strong relationships with student mathematics achievement (Leung et al., 2006).

Traditionally, mathematics instruction has focused on specific skills that can be practiced one at a time using recitation as the primary instruction strategy (Sleeter, 1997). Throughout time, the importance of increasing student self-esteem, incorporating multicultural education, creating personal and professional development opportunities, and identifying how teachers could successfully incorporate these concepts became a tool to close achievement gaps observed in mathematics learning (Sleeter, 1997). The multifaceted drivers of mathematics achievement extend beyond what is seen in the classroom. To further understand and close the gaps amongst certain populations of students, it is important to study classroom structures and the way information is presented, which may relate to the personal beliefs of the students (e.g., attitudes). With the focus more recently on individualized efforts for each student, in conjunction with looking at the following outside contributing factors, we may start to address the gaps and contributing factors of academic achievement in mathematics. Through implementing instructional methodologies that build upon student collaboration and confidence building, my research investigates the influence of shifting the way information is presented and classroom structures on mathematics achievement.

2.1.2 Promoting Student Engagement

Large-scale meta-analyses have been conducted to examine the conflicting results amongst researchers regarding student engagement. These analyses helped to investigate if engagement is or is not a predictor of academic success. Mediators of engagement included the definition and specification of methods used to engage students, the importance of cultural value, and identified influences of gender identity (Lei et al., 2018). Studies focusing on students' engagement in mathematics education identified relationships between mathematics interest, perceived usefulness of schooling, behavioral engagement, participation in mathematics learning activities, and cognitive engagement in problem-solving as key tools in engagement promotion (Fung, 2018). The issue is that engagement does not always have a constant definition within education literature. Engagement has been defined using various educational psychology components, including behavioral engagement or active participation (Putwain et al., 2018; Rodriguez et al., 2019), motivation (Lazarides, 2017; Wu, 2019), and self-concept (Nagy, 2010; Priess-Groben, 2017).

Researchers have found behavioral engagement, or a student's active participation in classroom activities, to be a mediating factor in achievement goals learning. Students' prior achievements are predictive of their future engagements and achievements in the classroom, with behavioral engagement as a targeted concept that can actively increase student learning (Putwain et al., 2018; Rodriguez et al., 2019). However, engaging students to develop their understandings and connections of mathematics concepts is a difficult aspect of instruction due to the strong influences of student math attitudes and willingness to engage (Boaler et al., 2018).

In K-12 settings, promoting engagement was facilitated based on taking into account a student's own learning and achievement goals. Goals that focus on improvement from past experiences, as it relates to their futures, include feedback with improvement methods, and focuses on the mastery of a topic without comparisons to others were all found to influence engagement (Putwain et al., 2018). A learner's mindset has a moderating role in student motivation on engagement, and motivation is a mediating factor to achievement based on surveys assessing the quality of work (Rodriguez et al., 2019).

Motivation is seen to decline for many adolescents as they move through the education system. Still, students' mathematics values and mathematics-related career plans remain linked to parents' beliefs and behaviors (Lazarides, 2017). Motivating factors for adult students were found to be more predictive of academic success than engagement alone (Wu, 2019). The suggestion that mastery approaches of instruction, which separate large complex learning goals into a multistep iterative process and are tailored to improvement and personal goals, found by Putwain et al. (2018) in K-12 settings, may be a tactic to increase engagement for students, if implemented, in post-secondary mathematics classrooms. My research investigates how the incorporation of improvement goals and promotion of engagement using student-centered instructional methodology in a higher education setting, may improve attitudes and engagement.

2.1.3 Attitudes Towards Mathematics

Over the past few decades, literature began to examine the importance of mindsets (fixed vs. growth) and student attitudes with engagement and achievement**.** Visser's (2006) *An Interview* *with Carol Dweck the author of Mindset: The New Psychology of Success* outlined the benefits of having a growth mindset with learning. Growth mindset refers to the belief that a person's mental attributes can be changed with effort (Dweck, 1999; 2006). With the idea that intelligence is incremental and not some sort of innate gift; students begin to not only believe in themselves but also succeed. Students with a growth mindset are less likely to experience math anxiety and boredom as hinderances to their learning (Visser, 2006). Researchers have also examined the relationships and correlations that exist between student attitudes and academic success, with associations for students who fail the course with multiple aspects of math anxiety as well as personal wellness issues such as lower self-asteem, self-confidence, and motivation than others in their cohort (Núñez-Peña, 2013).

Student attitudes influence engagement and act as a mediator of achievement. Mindset Mathematics was developed to create active student engagement using creative, and visual mathematics (Boaler, et.al, 2018). The goal of Mindset Mathematics is to improve student test scores and increase self-esteem in mathematics by examining the differences in concepts of memorization versus conceptual engagement, mathematical critical thinking, and understanding the "big ideas of mathematics" allowing for a broader understanding of how mathematical rules and methods are interconnected. These methods focus on the importance of mistakes, struggles, and challenges for brain growth with a focus on the Common Core State Standards (CCSS), which have been identified to be able to be implemented in any curriculum setting (Boaler et.al, 2018). Through the transformation of traditional lecture classrooms to ones that focuses on aspects of mindset mathematics, comparisons could begin to understand further the influence of collaboration and productive struggle in mathematics attitudes of post-secondary students.

2.1.4 Student-Centered Instruction

Reform efforts in the teaching of mathematics indicate difficulties in creating a change of practice. Boyd (2015) identified two contrasting perspectives of math instruction– the first style sees mathematics as a set of truths which evolved into the scholar academic ideology, lecture instruction followed by individual practice, and a second style views mathematics as a human activity identified as ‘mathematics in the making’ with critical focus thinking, creative reasoning, the generation of individualized learning (Boyd, 2015).

One pedagogical approach has been found to increase student engagement – student-centered instruction (Mascolo, 2009). This approach includes productive struggle, group work, and scaffolding. Vazquez et al. (2020) defines productive struggle as “expending effort to make sense of something beyond one's current level of understanding—aids in learning mathematics concepts and procedures” (Vazquez et al., 2020, p. 179). The National Council of Teachers of Mathematics has identified that allowing students to experience productive struggle is an effective teaching practice, ensuring successful mathematics learning for all (NCTM, 2014). Stein et al. (2000) identifies task characteristics that promote engagement often are associated with productive struggle and include elements that require complex thinking, concept exploration, self-reflection, and cognitive effort; however, incorporating these activities into instruction is difficult. Instructors often struggle while beginning to implement productive struggle tasks into their classroom and, if not careful, will revert to transferring of knowledge through traditional lecture as they attempt to support students (Lemley et.al., 2019).

Engaging students and facilitating connections between mathematics concepts was the most difficult aspect of instruction. To help bridge this gap, the concept of visualization, play, and investigation allowed for the incorporation of more critical thinking into mathematics instruction.

These methods focus on the importance of mistakes, struggles, and challenge for brain growth with focus on the CCSS (Boaler et. al., 2018).

Sofroniou & Poutos (2016) examined the use of groupwork as a means for college students to begin to gain content knowledge, concepts, facts, and theorems relating a subject area through discussion of topics related to integration. The authors found that groups struggled while working through the activity; but ultimately were able to work through the concepts and gain clarity. Survey results of this study indicated that students felt they learned more from their groups. Subsequent grade analysis showed that those who learned how to integrate functions using group work scored significantly higher on formal assessments than those who learned using traditional methods (Sofroniou & Poutos., 2016). Lastly, the use of scaffolded activities, which guide students though their activities and learning, provides more structure for students during their struggles (Yildirim et al., 2010) and aids in the co-construction of knowledge through group interactions (Mazziotti, 2019).

2.1.5 POGIL: A Form of Student-centered Learning

Process Oriented Guided Inquiry Learning (POGIL) is a student-centered, active learning instructional method that was developed in the mid-1990's for chemistry classrooms. The POGIL Project (POGIL.org, 2021) has since expanded its content base and methodologies to many of the STEM sciences in both the K-12 and higher education settings (Chase, 2013). POGIL instructional methodology uses active learning and group work to give students a deeper understanding of course content and task characteristics that promote engagement (Stein, 2000). POGIL also focuses on improving process skills such as oral and written communication, teamwork, problem-solving, critical thinking, management, information processing, and assessment (both with selfassessment and metacognition), using guided inquiry-based activities. This instructional method has been found to increase overall positive student achievement outcomes, and long-term retention within the STEM (science, technology, engineering, and mathematics) disciplines (Vanags, 2013; Walker, 2017), and activities are still being developed for come contextual subject areas—such as Algebra.

POGIL implementation changes the structure of a traditional classroom into one in which students use specifically designed activities that follow the learning cycle. This instructional practice allows students to grow their own understanding, like the 'mathematics in the making' ideology of instruction (Boyd, 2015). As students work through activities where they explore models, develop concepts, and perform applications, they begin to build upon prior knowledge and develop their understandings. This active learning approach places more accountability on students to build understanding rather than simply memorizing a topic (Vanags, 2013).

POGIL methodology also changes the role of the instructor into one who facilitates learning rather than one who presents information. Groupwork is fundamental, with students being placed in groups of three to four individuals, each with their own set of responsibilities and roles. Traditional POGIL roles include the manager, recorder, presenter, and reflector.

- The **Manager** ensures that members are fulfilling roles, that group members stay on task, and that all members are actively participating and understanding the context.
- The **Recorder** keeps track of group discussions, observations, and insights, and maintains a record of activity group work.
- The **Presenter** communicated for the group while consulting the instructor, other groups, or reporting in the classroom.
- The **Reflector** notes the group's progression throughout the activity and communicates

successes and areas of improvement with group interactions.

While these roles are typical in practice, additional roles can be created and used, as needed, to facilitate group activities in the classroom (Moog, 2020).

With the successful implementation in science and mathematics classrooms, studies about POGIL instructional techniques have shown increased student learning outcomes in terms of student achievement, retention of content knowledge, and many of the 21st century skills needed in the workforce such as communication, problem-solving, time management, teamwork, information processing, and self-reflection and assessment (Moog, 2008). POGIL activities support students in developing their own understandings of mathematics concepts, encourage active participation in the mathematics classroom, and promote successful completion of mathematics courses.

Bénéteau et al. (2017) examined the impact of implementing POGIL instructional methodology in calculus classrooms. Throughout their study, Bénéteau et al. compared student grades at one small, comprehensive public university and one large, public research university before and after the transition to using POGIL methodology in the classroom. Preliminary results showed that in semesters in which POGIL was implemented, the Drop, Fail, withdraw (DFW) rate fell drastically from 40% to 16% at one university and from 33% to 23% at the other (Bénéteau et al.,2017). This study examined if the creation and use of POGIL-type activities in introductory mathematics classrooms provide a method to encourage student engagement and improve mathematics attitudes and as a tool to increase mathematics achievement in post-secondary education.

3.0 Methodology

3.1 Theory of Improvement

This study's focused change idea targets instructional methods and their impact on mathematics attitudes and engagement throughout one Plan-Do-Study-Act (PDSA) cycle using an improvement science methodology (See Figure 2). Instructional delivery methods of Algebra topics were modified to include student-centered instruction with POGIL methodologies. Using productive struggle through POGIL, I hypothesized that if a student begins to experience positive attitudes toward mathematics and becomes actively engaged in their learning, students will be academically successful in my classroom. The theory of improvement (Figure 2) suggests that by implementing the use of student-centered POGIL activities, drivers contributing to my problem of practice will be positively influenced, which will contribute to the achievement of the aim of this study. More specifically, when POGIL instructional activities are introduced in Algebra classrooms, this will create a positive shift in student engagement and mathematics attitudes and ultimately increase success rates in Algebra courses.

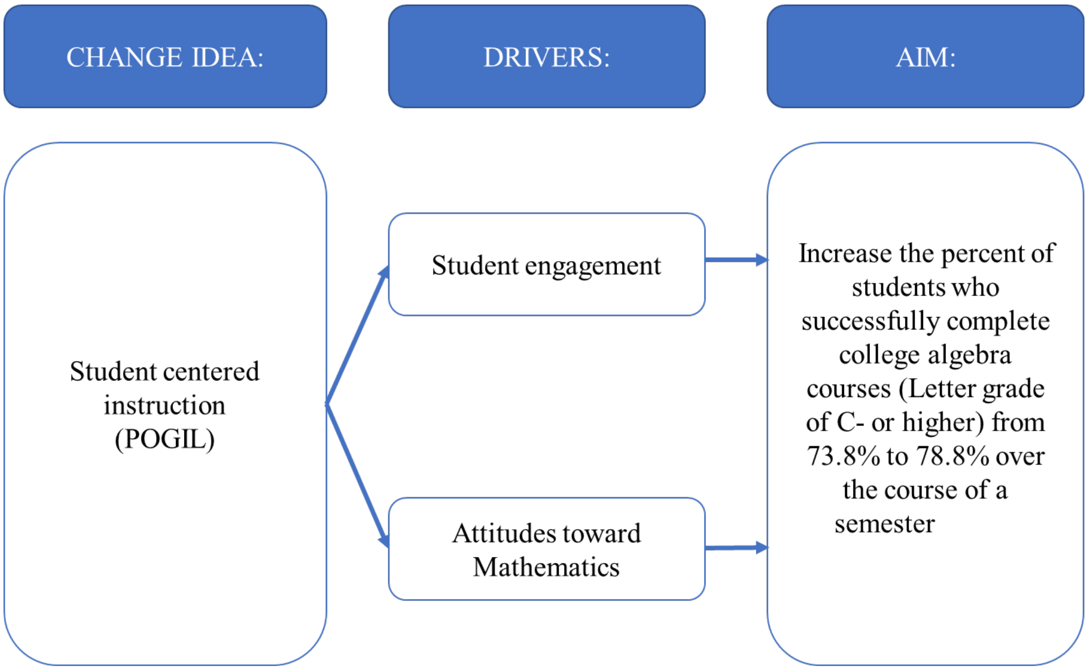


Figure 2 Theory of Improvement

3.2 Change Idea

3.2.1 Process Oriented Guided Inquiry Learning (POGIL)

POGIL is a student-centered instructional approach to learning. Using group work, students use guided inquiry-based activities, and assigned roles (manager, presenter, recorder) to build content knowledge and develop understandings. POGIL activities are structured to enable students to develop process skills, such as teamwork, communication, critical thinking, problem-solving, management, and information processing. Within a typical POGIL classroom, the instructor acts as a facilitator as students work through activities with question types that target the stages of the learning cycle—exploration, concept intervention, and application (POGIL, 2019).

For this project, I helped develop course materials with a colleague co-teaching the course with me. Course materials incorporated POGIL instructional techniques learned from attending two summer POGIL writing workshops. These POGIL activities can and will be continuously modified based on classroom observations and student feedback. Using a mixed-methods approach, I examined the influence of student-centered instructional methods on student learning outcomes, specifically by examining how the introduction of productive struggle with guided inquiry, time for reflection, and mathematics attitudes influence mathematics retention and learning.

3.2.2 Traditional Classroom Structure

Within a traditional classroom structure on my campus, College Algebra is offered in three 50-minute sessions per week or two 1-hour, 15-minute sessions per week. Within my classroom, class typically begins with an opportunity for students to ask questions and a short overview of the previous class content. I present lectures using PowerPoint, provided to students in advance, with blank example problems given in class to be completed throughout the lecture. After full in-class examples are covered, students can work to complete similar problems independently or in small groups. I provide students with homework problem sets online which students can complete for additional practice before formal in-class assessments.

3.2.3 Proposed Intervention Classroom Structure

Implementation of POGIL activities occurred during the COVID-19 pandemic; therefore, the number of students who could be in the classroom together in-person, was restricted, and most learnings was moved to a virtual format due to university mandates. The capacity of students in each classroom for the Fall 2020 semester was set to one-third the room capacity (25 students). My POGIL classroom section class size was restricted to 65 students. Due to classroom restrictions, the 65 registered students were grouped into three cohorts (Cohort A, B, and C). During regularly scheduled class meeting times, each cohort was scheduled to meet live (in-person or synchronously online) on one of the three meeting days. Under the university's plan, students who chose to attend class virtually had the option to participate on their assigned live days via Zoom.

When students met in person or synchronously online, they learned topics using POGIL instructional activities. Other cohorts, who were not scheduled in person, were introduced to topics asynchronously utilizing a combination of pre-recorded lectures and problem sets that we administered through the university's learning management system, Canvas. Cohorts were coded into Canvas to ensure student cohorts had access to their respective course materials. Group members and roles changed every two chapters—a total of three times throughout the semester—to ensure all students gained experience in group roles of presenter, reporter, and manager.

During each day of class, myself, my co-instructor, and two undergraduate teaching assistants were present in person to facilitate live POGIL instruction regardless of if cohorts were meeting in person or on zoom. The two undergraduate TAs were both upperclassman at the University, one TA was female Mathematics major, and one TA was a male Chemistry major. TAs helped to facilitate activities and answer student questions during class time.

For Cohorts A and B, in-person POGIL, students were also present in the classroom working in groups, while maintaining social distancing and classroom capacity requirements and abiding to mask mandates set forth by the university. Instructors and TA's facilitated activities in person. Students who tested positive for COVID-19 throughout the semester, in the in-person Cohorts, were required to quarantine and not attend class in person but were able to still complete POGIL group activities by Zooming into class with their in-person groups, who would bring a computer to connect to quarantining individuals.

For Cohort C, online POGIL, students logged into synchronous zoom meetings in which both instructors and TAs were present. Instructors and TAs were assigned as hosts and cohosts of the meeting. Group work was facilitated through the use of breakout rooms. Instructors and TAs would enter group breakout rooms regularly throughout the class meeting to facilitate activities. Instructors had also informed students of the "Ask for Help" controls function in zoom breakout sessions which allowed groups to request help from any cohost as questions came up during group work.

3.3 Inquiry Questions and Aim Statement

3.3.1 Inquiry Questions

In this study, I planned to examine the following inquiry questions to examine the interactions between student-centered instruction, mathematics achievement, mathematics attitudes, and engagement.

1. To what extent does student-centered instruction use improve student achievement in mathematics?
2. To what extent does using POGIL in a College Algebra classroom improve student attitudes toward mathematics?
3. To what extent does using student-centered instructional techniques improve student engagement?

3.3.2 AIM Statement (Primary goal)

The primary aim of this study was to increase the percent of students who complete College Algebra courses (Letter grade of C- or higher) by 5%, from 73.8% to 78.8%, over the course of a semester at Pitt-Greensburg through exposure to student-centered instructional methods— Process Oriented Guided Inquiry Learning (POGIL).

3.3.3 Positionality Statement

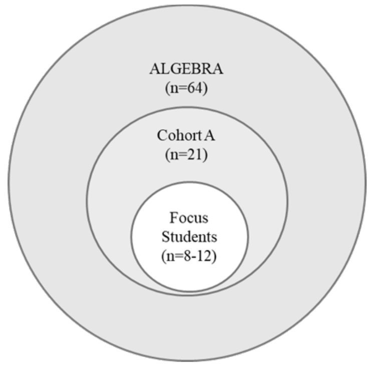
I have six years' experience teaching in higher education at a small liberal arts school in a rural region of southwestern Pennsylvania at—which I attended and obtained my bachelor's degrees in applied mathematics, biology, and chemistry. Prior to beginning my doctoral work, I had no formal training in education and modeled my teaching based solely on those who I believe were effective educators and avoided any aspects of instruction that remined me of the bad experiences I've had during my schooling. My upbringing was somewhat untraditional with my early homelife being full of trauma, due to the toxic relationship of my parents, mental health issues of my mother, and the conflicts in identity being a person of color being raised by my strict, single, white, veteran father who was insistent that I was also white when others would attempt to segregate or label me.

Education was one aspect that was always stressed to me. The importance of doing well in school reigned over all other aspects of life. It is important to acknowledge that I am coming from a position where there were always pressures to complete my education, but always the fear of repercussions of failures. I approach this research with the intent to transform my classrooms into one in which students feel supported, can be expressive, as well as gain positive experiences in education without the fear that I had felt as a student.

3.4 Methods and Measures

During the Fall of 2020, I collected data to investigate if the intervention of incorporating POGIL activities would improve student attitudes and engagement in introductory college mathematics courses. This study used a mixed methods approach with qualitative and quantitative data sources and analysis of a classroom case study to answer the inquiry questions listed above. The inquiry questions, data sources, and times for collection of this project are organized in Tables 2, 4, and 5. Classroom case study and focus student selection

During the Fall 2020 semester, my section of Algebra consisted of 64 registered students divided into three cohorts (Cohort A, B, and C). All students submitted surveys for quantitative analysis. Weekly analytic memos documented my noticing and notes of classroom interactions for each cohort. Since each cohort received varying POGIL activities based on scheduled meeting days, for qualitative data collection (e.g., field notes and student observations) and analysis, I focused on the classroom case of Cohort A (n=21), ***Figure 3***.



Mathematics Attitudes	Student Engagement
$Highest\ +\ (3\ students)$	$Highest\ +\ (3\ students)$
$Lowest\ -\ (3\ students)$	$Lowest\ -\ (3\ students)$

Figure 3 Classroom Case Study and Focus Student Selection

Focusing on the classroom case of Cohort A allowed for consistency in student POGIL activities completed and allowed for data collection during the cohort's face-to-face in-person meetings. Within the case of Cohort A, focus students (n=8) were identified and selected based on initial short survey responses. These focus students were intended to be composed six students, three with the most positive and three with the most negative scores in each category of math attitudes and engagement. To select focus students when "ties" occurred in scores, I used initial autobiography analysis to select additional individuals to ensure at least eight unique individuals were included in this study and that focus students had also provided both initial autobiographies and final course reflections for comparison. I followed focus group of students for the collection and analysis of qualitative data for this project (e.g., classroom observations, autobiography, post-course reflections, and open-ended survey responses).

3.5 Data Sources

3.5.1 IQ1: Data Sources to Evaluate the Influence of Student-centered Instruction on Mathematics Achievement

I analyzed student summative scores from quizzes and exams to explore the effectiveness of student-centered instructional practices on student learning outcomes. Data Sources for IQ1 are shown in Table 2.

Table 2 Data Sources for IQ1

Inquiry Question 1	Data Sources	Data Collected
To what extent does the use of student-centered instruction improve student achievement in mathematics?	Student surveys	Long: 2 times (Midterm and end of term)
		Short: End of each chapter
	Quizzes	5 times (every chapter)
	Exams	2 times (Midterm and end of term)
	Final Grades	End of term

Students were scheduled in person one day a week and asynchronously online the other two times per week. Each class meeting corresponded to a chapter section of content that was to be covered as part of the university's curriculum guidelines for Algebra. Over the course of the semester, the instructional method used for each topic was individually tracked for each student. Twice a week, cohorts learned topics using online recorded lecture videos and guided notes. During student's scheduled in-person meeting day, students learned topics using student-centered POGIL activities –see Table 3 for cohort instructional methods during one chapter.

Table 3 One-chapter Course Instructional Modes for Cohorts A, B, and C

Date	Cohort A	Cohort B	Cohort C
W Aug 19		Course Overview	
F Aug 21		Autobiography	
M Aug 24	Video R1	Video R1	POGIL (1)
W Aug 26	POGIL (2)	Video R2	Video R2
F Aug 28	Video R3	POGIL (3)	Video R3
M Aug 31	Video R4	Video R4	POGIL (4)
W Sept 2	POGIL (5)	Video R5	Video R5
F Sept 4	Video R6	POGIL (6)	Video R6
M Sept 7	Video R7	Video R7	POGIL (7)
W Sept 9		**Quiz (Chapter R)**	

** POGIL indicates in person instruction, Videos correspond to asynchronous learning*

3.5.1.1 Student Survey Structure

I used surveys to answer IQ1, IQ2, and IQ3. Two survey types were administered throughout the course of the semester— referred to as "short" and "long" surveys. *Short surveys* were issued following each chapter, totaling 5 throughout the semester, and were composed of five 10-point Likert scaled questions as well as three-ended question that examine student's opinions on (1) instructional techniques and structure of activities, and personal opinions on (2) engagement and (3) attitudes in mathematics (see Appendix C). *Long surveys* were administered twice, once at midterms and again at the end of the semester. Long surveys consisted of Likert scaled questions that look at the influence of POGIL instruction on achievement (8 questions), attitudes (15 questions), and engagement (5 questions) (See Appendix D). Some questions also evaluated the student's perspectives on their own changes over time. All surveys were administered through Qualtrics. These surveys were adapted based on Heffernan's (2016) dissertation work, which made use of a 40-item survey which examined anxiety, values, goals, and ability perceptions (Heffernan, 2016).

3.5.1.2 Quiz and Exam Scores

For each quiz and exam question, I matched content to the chapter section in which they were introduced and the method of instruction. Comparisons were made investigating the percent of correct responses between Cohorts who had learned chapter sections using POGIL versus Cohorts who learned chapter sections using asynchronous online video lectures.

3.5.1.3 Final Grades

I calculated students' final grades by weighing scores from classroom participation (10% of grade), homework (15% of grade), assignments (15% of grade), quizzes (15% of grade), and exams (45% of grade).

3.5.1.4 IQ1: Data Analysis to Evaluate the Influence of Intervention and Achievement

The data I collected for IQ1 consisted of student surveys, quiz scores, midterm and final exams, and final course grades. I used a quantitative method approach to analyze these data. For each survey question, I computed average scores corresponding to students ranking of their own content knowledge retention with POGIL and online asynchronous learning. I then examined the retention of content knowledge, based on mode of instruction, by comparing the number of correct responses of students who learned using POGIL activities versus those who learned using asynchronous lecture videos. I used Chi-square tests of independence to identify if certain instructional methods were related to increased correct answer responses on quizzes and exams. All analysis was performed using SPSS26 statistics software. I then used final exam scores to evaluate the AIM of this project – to determine if the introduction of POGIL activities resulted in an increase in the proportion of students who successfully completed the course compared to prior year averages.

3.5.2 IQ2: Data Sources to Examine the Effect of Intervention on Student Mathematics Attitudes

Student short surveys, long surveys, autobiographies, and post-course reflections provided information of student attitudes throughout the course of the semester and allowed for examination of the potential shifts in these attitudes over time due to exposure to the student-centered instruction. Data Sources for IQ2 are shown in ***Table 4***, *below*.

Table 4 Data Sources for IQ2

Inquiry Question 2	Data Sources	Data Collected
To what extent does the use of POGIL in Algebra classrooms improve student attitudes in mathematics?	Student surveys	Long: 2 times (Midterm and end of term)
		Short: End of each chapter
	Math autobiography	One time (Beginning of term)
	Post-course reflection	One time (End of term)

I identified students' baseline levels of "willingness to engage" and "math attitudes prior to exposure and implementation of POGIL activities" at the beginning of the semester through the use of a short survey.

3.5.2.1 Student Survey Structure

See description in Section 3.5.1.1.

3.5.2.2 Mathematics Autobiography Structure

I used a student mathematics autobiography assignment to gain insight into students' initial views, attitudes, and experiences in mathematics courses. The assignment was modeled based on one developed by Christine Von Renesse found on Discovering the art of Mathematics website (Von Renesse, 2014). Autobiographies offered insight into student experiences and attitudes in mathematics and can be seen in Appendix B. The mathematics autobiography was assigned and collected through Canvas.

3.5.2.3 Post-course Reflection Structure

Like the mathematics autobiography assignment, students completed an assignment in which they reflected on their experiences in class and described in their own words if and how POGIL activities changed or influenced their views on mathematics at the end of the semester. By comparing autobiographies to post-course reflections, the effect of POGIL was examined to explore the number of students who showed a shift in attitudes towards mathematics. The reflections also allowed students to provide feedback on activities to inform future iterations of the PDSA cycle (See Appendix E). The post-course reflection was assigned and collected through Canvas.

3.5.2.4 IQ2: Data Analysis to Examine the Effect of Intervention on Student Mathematics Attitudes

I had collected student surveys, student math autobiographies, and student post-course reflections to examine IQ2 and used a mixed methods approach to analyze these data collected from focused students as part of this classroom case study. I analyzed students individual survey results quantitatively. Survey data compared the number of students who experienced negative/neutral/positive mathematics attitudes before and after the implementation of the intervention. For each survey question corresponding to math attitudes, I summarized student Likert responses to examine average opinions of scaled measurements and variability in responses for the focus student group, each cohort, and the entire section of Algebra. I then examined pre- and post-numeric differences in each question using paired t-tests to evaluate changes in math attitudes over time.

I employed qualitative analysis to examine shifts in student attitudes in mathematics for focus students. I used thematic coding of artifacts collected – such as the mathematics autobiography and post-course reflection. I created a deductive code book using existing literature themes corresponding to mathematics (Saldana, 2009) to examine shifts in mathematics attitudes throughout the semester. I used NVivo qualitative software to organize the qualitative data I coded for this analysis. I then used triangulation of quantitative and qualitative information to determine the effect of POGIL student-centered on student math attitudes.

3.5.3 IQ3: Data Sources to Examine the Effect of Intervention on Student Engagement

I examined student surveys, questionnaires, and observation field notes of student work in class over the semester to study student engagement. Surveys, as described in the previous question, helped gather information on student's willingness to engage in classrooms with peers, TAs, and instructors. Short surveys, also discussed above, were used to measure opinions of instructional activities, and provide information on group dynamics.

Classroom observation field notes of focus students in Cohort A allowed me to gain a comprehensive understanding of the dynamics in the classroom and understand to what extent the intervention influenced engagement and explanations for survey findings. Classroom observations were used to help measure student engagement by tracking engagement in collaborative group work, questions, and participation in class for individual groups of students throughout the semester. Data Sources for IQ3 are shown in ***Table 5.***

Table 5 Data Sources for IQ3

Inquiry Question 3	Data Sources	Data Collected
To what extent does the use of student-centered instructional techniques improve student engagement?	Student survey	Long: 2 times (Midterm and end of term)
		Short: End of each chapter
	Classroom Observation Field Notes	Once per week (Focus students)
	Teaching Journal/ Analytic Memo	Weekly

3.5.3.1 Student Survey Structure

See description in Section 3.5.1.1.

3.5.3.2 Observation Field Notes

During each in-person meeting of Cohort A, I recorded observational field notes to track student interactions in the classroom—including student questions, interactions, and group dynamics. During Cohort A in-person class sessions, 21 students attended class and worked in seven groups. Each class had two instructors (myself and a colleague) and two undergraduates TAs present as facilitators for the students' daily POGIL activities. During the 50-min session, students engaged in group work and productive struggle to complete the day’s task. With the presence of two instructors and two TAs, the recording of observations simultaneously occurred in the classroom.

3.5.3.3 Teaching Journal/Analytic Memo

I wrote weekly teaching journals and analytic memos to track my noticing of the classroom during each cohort's synchronous meeting. This data source focused on aspects of classroom management, activity length/timing, student questions, and areas in which activities may need modifications or restructuring.

3.5.3.4 IQ3: Data Analysis to Examine the Effect of Intervention on Student Engagement

The data I collected for IQ3 consisted of student surveys and observation field notes. I used a mixed methods approach to analyze these data. I analyzed students' individual survey responses quantitatively. For each survey question corresponding to student engagement, I summarized student Likert responses to examine average opinions of scaled measurements and variability. I then examined pre- and post-numeric differences of each question using a paired t-test to assess changes in willingness to engage over time.

I examined shifts in students' willingness to engage qualitatively using thematic coding of artifacts collected –observational field notes and questionnaires. A deductive code book was created using existing literature themes corresponding to engagement (Saldana, 2009). My thematic coding of artifacts allowed me to examine changes in engagement throughout the semester. I used NVivo qualitative software to organize qualitative coded data for analysis.

3.5.4 Study Timeline

The timeline for this project's implementation can be seen in Figure 4, and the general PDSA cycle is outlined in Appendix I. The study took place throughout the Fall 2020 semester. Students completed one POGIL activity per week and submitted initial autobiographies at the beginning of the semester. I recorded classroom observations analytic journal entries weekly for Cohort A. Student short surveys were administered to all students after covering one to two chapters of their textbook, and long surveys were administered to all students after the midterm and the final exam. Lastly, post-course reflections were collected during the students scheduled final examination period.

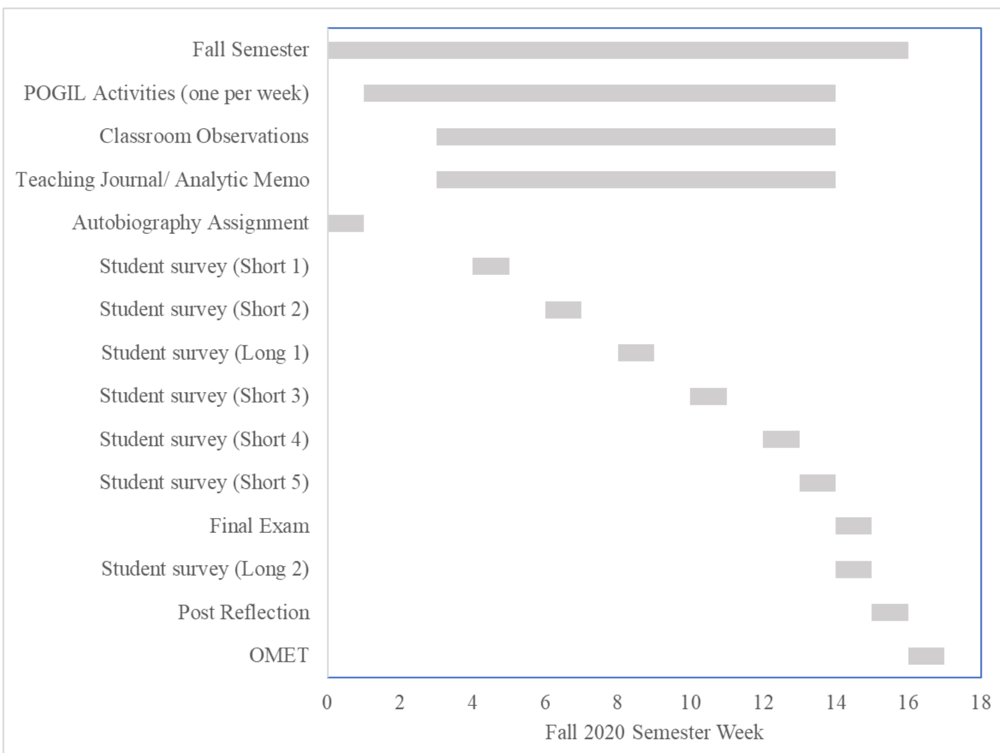


Figure 4 Timeline of Assessment and Implementation for One PDSA Cycle

4.0 Results

4.1 IQ1 Results: To What Extent Does the Use of Student-centered Instruction Improve Student Achievement in Mathematics?

The primary aim of this study was to increase the percent of students who successfully complete college algebra courses (Letter grade of C- or higher) from 73.8% to 78.8% over the course of a semester at Pitt-Greensburg through exposure to student-centered instructional methods— Process Oriented Guided Inquiry Learning (POGIL). I chose the goal of reaching a 78.8% pass rate as the instructor of the college algebra courses, because I aimed to increase previous pass rates of 73.8% by 5%. The goal of 78.8% of students passing the college algebra course was achieved by the focus group, Cohort A (in-person POGIL once a week), with 80% of students receiving a final letter grade of C- or higher. However, it was not achieved with Cohort B (in-person POGIL once a week), with 58.8% of students receiving a C- or higher, with many of the students who did not pass within Cohort B not completing assignments or surveys throughout the semester. Cohort C (online synchronous POGIL via Zoom once a week) also did not meet the goal of 73.8%, with only 63.6% of students receiving a C- or higher. Overall, the aim of this study was not met when examining all cohorts together with only 68% of students receiving a C- or higher. My examination of formal summative assessments (quiz, midterm, and exam scores) showed an unexpected "cohort effect" in which students in Cohort B had higher fail rates, lower quiz and exam scores, and lower survey response rates than the other two cohorts, Cohort A (focus of qualitative analysis) and Cohort C (online POGIL cohort). I discuss this cohort effect in detail throughout the Results section below.

4.1.1 Examination of Student Official Posted Grades

While each cohort's official posted grade medians were approximately the same; there was considerable variability with final grades. The great variation in the spread of grades by cohort is evident in these boxplots in Figure 5, which show distributions of official grades posted. Final course grade distributions by cohort can also be seen in Table 6. The focus cohort, Cohort A, had the smallest standard deviation and the least occurrences of extremely low final course grades. These results indicate that the percentage of students who failed the course differed significantly amongst cohorts. About 10% of students in Cohort A received F's as final course grades as compared to 41.2% of students in Cohort B, and 22.7% of students in Cohort C. Within the focus cohort, Cohort A (who had received in-person POGIL instruction), two students had been identified as scoring unusually low (each with F grades) in comparison to the others in their cohort. This suggests that the use of in-person POGIL activities decreased the amount of variability within grade distributions if students continued to participate.

Alarmingly, in Cohort B, which had also received in-person POGIL instruction like Cohort A, by the end of the semester, 41.2% of students received failing grades in the course (all of which were F's, no D's), primarily due to not attending class or completing assignments. Unexpectedly, Cohort C who had received online POGIL instruction had a lower percentage of students who received a F in the course (22.7%) than Cohort B (41.2%). The lower percentage of students receiving F's in Cohort C (online POGIL) and Cohort B (in-person POGIL) may be contributed to Cohort C's ability to attend virtually and may provide evidence that the flexibility of attending in the online format and not having to travel to campus, encouraged students to complete assignments even though the majority of groups working on POGIL activities in Cohort C (the online POGIL format) chose to work independently, or not at all (muted, no camera on). This suggested that online attendance during synchronous class meeting times is better than not attending class at all, like many students in Cohort B.

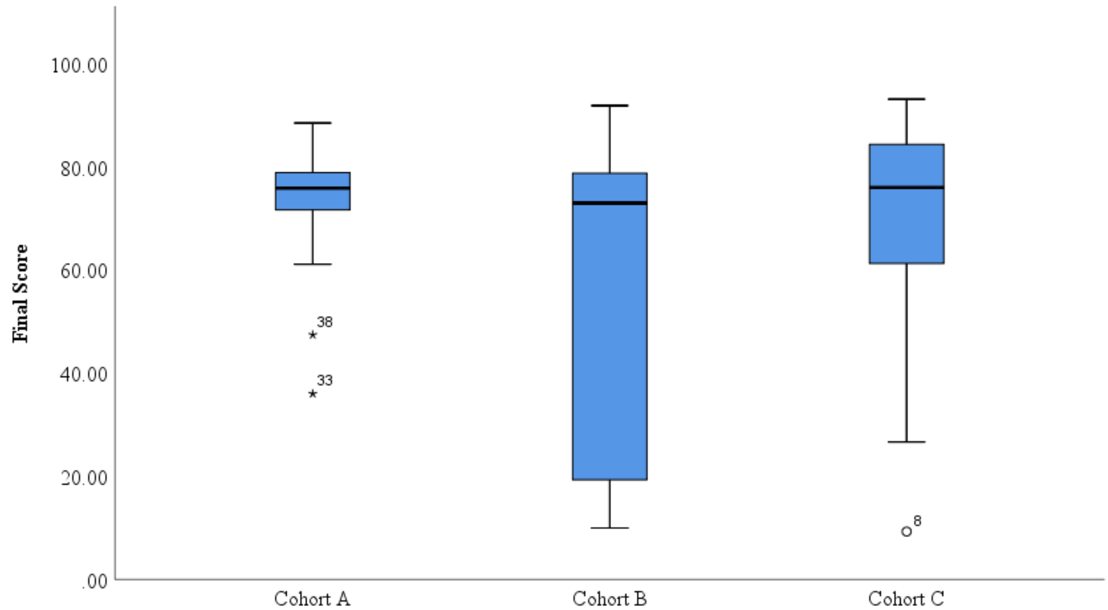


Figure 5 Final Official Grade Distributions by Cohort

Table 6 Final Course Letter Grade Distributions by Cohort

	Final Course Grade	Frequency	Percent	Cumulative Percent
Cohort A (n=20)	B	5	25.0	25.0
	C	11	55.0	80.0
	D	2	10.0	90.0
	F	2	10.0	100.0
Cohort B (n=17)	A	1	5.9	5.9
	B	3	17.6	23.5
	C	6	35.3	58.8
	F	7	41.2	100.0
Cohort C (n=22)	A	1	4.5	4.5
	B	9	40.9	45.5
	C	4	18.2	63.6
	D	3	13.6	77.3
	F	5	22.7	100.0

4.1.2 Influence of Cohort and Achievement

As mentioned, complex interactions emerged corresponding to a "cohort effect" on the differences in course grades. I discuss this cohort effect throughout analysis of my response to IQ1 below as a potential explanation of differences seen both within variability of course grades, survey responses, and summative assessments items. Students were given the opportunity to select if they wanted to attend class in person or stay completely virtual. Students who responded that they wanted to attend in person were placed first in Cohort A and then in Cohort B, which allowed for in person POGIL instruction based on classroom occupancies, once a week. To allow for POGIL activity and group work for those who selected to be completely virtual, Cohort C meet synchronously on zoom once a week.

Since Cohort groupings were not at random, and Cohort A was comprised of those students who first selected that they had wanted to attend in person, it is possible that the students in Cohort A were the "go getters" of the group, since they had taken the initiative to respond to their preferences in class meetings first. Absences during in-person meetings were significantly higher in Cohort B than the other two cohorts, although students had the option to attend virtually if they were unable to make it in person. This difference in attendance may have contributed to the Cohort effect observed and large proportion of students receiving an F in the course. "Zoom burnout" and lack of collaboration in zoom breakout rooms of Cohort C may help to partially explain the large proportion of students in Cohort C that did not pass the course with a C- or higher.

It was also difficult for me to formally evaluate the influence of POGIL instruction on student assessments and final course grades due to complications and limitations on classroom structure throughout the semester. Students were only exposed to POGIL methodology for one class meeting per week in all three cohorts. In addition, I conducted this research during the Fall of 2020, during the COVID pandemic. Classroom occupancy was limited to 25 people, but class enrollment sizes were not lowered to reflect the occupancy restrictions (63 students enrolled, who were then distributed into the Cohorts A, B, and C, with Cohort C meeting only online via Zoom).

4.1.3 Examination of Student Survey Responses by Cohort and Final Course Grades

Not surprisingly, those who failed the class were also those who did not complete the surveys throughout the semester, which suggests that survey response rates may be an indicator of student engagement in the course. All but two students who received a final grade of F did not complete the final survey. Table 7 provides a formal examination of student grades and student response rates for the final survey. Based on survey response rates, it is evident that, students in Cohort B, did not complete assignments, choose not to participate, or did not attend classes at the highest rate during the semester, with only about 53% of students completing the final course survey.

Table 7 Distribution of Survey Response Rates Based on Final Letter Grades

Cohort	Survey Status	Letter Grade	Frequency	Percent
Cohort A (n=20)	Did not complete (n=1)	F	1	100.0
	Completed (n=19)	B	5	26.3
		C	11	57.9
		D	2	10.5
		F	1	5.3
Cohort B (n=17)	Did not complete (n=8)	C	1	12.5
		F	7	87.5
	Completed (n=9)	A	1	11.1
		B	3	33.3
		C	5	55.6
Cohort C (n=22)	Did not complete (n=4)	F	4	100.0
	Completed (n=18)	A	1	5.6
		B	9	50.0
		C	4	22.2
		D	3	16.7
		F	1	5.6

4.1.4 Student Opinions of POGIL Activities on Learning, Content Retention, and Concept Clarity

Longitudinal survey results (which examined surveys that I administered at the beginning and end of the term) allowed for the examination of preference by cohort for which mode of instruction (POGIL, asynchronous lecture videos) students preferred and if this changed over time. No survey questions showed a statistically significant ($p < 0.05$) difference at the two time points within each cohort regarding the students self-reported opinions on POGIL activities on learning new content, content retention, or concept clarity (See Appendix G.1). Although not statistically significant, trends in data indicated that throughout the semester Cohorts A and C felt that POGIL activities were less useful in their learning processes as the semester continued.

Survey results showed that the focus cohort, Cohort A, and the purely online cohort, Cohort C, tended to respond similarly, feeling that POGIL activities were less useful in their learning as the semester progressed, although they did not all experience the same type of learning environment. The overall trend of students' perceived decrease in retention of course content (based on student responses in final course surveys) could also be partially due to content material and order in which it was covered in the course, with more difficult concepts covered at the end of the semester. For the online Cohort, Cohort C, group breakout rooms were likely to be silent, muted, cameras off, with students working independently. Without group interactions, it is likely that students' opinions on content understanding and usefulness of POGIL activities decreased throughout the semester, which may help to partially explain the increase of opinions on pre-recorded lecture videos amongst those who preferred to learn independently. These trends (although not statistically significant) were further examined using qualitative data sources (explained later in this section).

Cohort B's responses suggested that students thought that activities helped more as the semester continued. In Cohort B many students stopped attending class, submitting assignments, and submitting surveys. Therefore, those who thought the activities helped more were simply those who continued to participate in class and submit survey responses. Students who didn't think POGIL activities helped more as the semester continued are likely those who didn't attend class or submit a survey.

4.1.5 Comparisons of Summative Assessments Administered During the Semester Based on Cohort

Given the cohort effect, differences in grades, and survey responses, I conducted additional quantitative analyses to provide a comparison of summative assessment scores by first examining if any differences were seen between learning in the in-person versus online environment and then amongst each cohort. These results showed there was not a significant difference in assessment grades between in-person and online groups based on two sample independent t-tests. However, significant differences were observed when comparing each cohort's individual assessment scores to each other using one way ANOVA analysis (Cohort A v. Cohort B v. Cohort C). The ANOVA results indications that there was a significant difference in assessment averages amongst Cohorts. Subsequent post-hoc tests determined which groups were scoring differently (this will be discussed on the following section). The difference in means of Cohort assessment may be partially explained based on the survey results which showed that Cohorts A and C were very similar in their opinions on survey items (seen in Appendix G.1) with both cohorts overall reporting a slight negative change on opinions of survey items over the course of the semester corresponding to reported helpfulness of POGIL on learning new mathematic concepts, clarity of concepts learned through POGIL activities, and feelings of learning through POGIL activities. Survey response rates from those in Cohort B were lower than that of Cohort's A and B, which may have indicated that only those who persevered the whole semester in Cohort B completed assignments and actively participated in class. By combining Cohorts B and C as a comparison to focus group, Cohort A, resulted in a cancelling out effect in which assessment averages of Cohort B and C averages remained like that of Cohort A.

4.1.6 Comparisons of Individual Assessments (Quizzes, Exams, and Final Course Grades)

Table 8 shows comparisons of each summative assessment administered during the semester. This allowed for comparing all Cohorts. Results show a statistically significant difference in test scores for Quiz 4 and average quiz scores for the semester between the three groups. Since ANOVAs only can provide insight into if there are any group differences in assessment scores, post-hoc tests were run to determine which groups were different. Cohort A was found to score statistically different than Cohort B based on quiz four results ($p=0.020$), quiz averages ($p=0.038$), and final scores for the course ($p=0.018$). These results indicate that Cohort B, once again, scored lower for these summative assessments than focus Cohort A, and Cohort A and C statistically scored similarly on all formal assessments.

Table 8 ANOVA Comparisons of Quiz and Exam Scores by Cohort

Assessment	Cohort A Average (Std. Dev)	Cohort B Average (Std. Dev)	Cohort C Average (Std. Dev)	ANOVA p-value
Quiz 1	66.56 (20.52)	52.43 (27.60)	67.61 (24.50)	0.116
Quiz 2	68.76 (21.32)	53.28 (33.90)	70.36 (25.22)	0.115
Quiz 3	80.98 (19.65)	63.71 (38.1)	78.45 (27.39)	0.183
Quiz 4	68.74 (15.93)	48.14 (33.76)	69.52 (17.83)	0.012 **
Quiz 5	66.17 (28.69)	46.66 (36.81)	61.98 (31.31)	0.168
Average Quiz	71.27 (16.58)	55.90 (30.95)	72.79 (13.14)	0.044 **
Midterm Exam	67.40 (14.08)	54.78 (28.32)	63.54 (18.85)	0.181
Final Exam	65.90 (15.31)	45.89 (32.39)	64.33 (32.39)	0.085
Final Score	72.68 (12.45)	54.33 (31.27)	68.15 (22.38)	0.049 **

* Scores reported as a percentage (out of 100)

** Denotes statistically significant p-values < 0.05

4.1.7 Method of Instruction and Percent Correct Responses on Midterm and Finals Exams

To determine if certain instructional methods resulted in a higher proportion of correct responses to specific exam questions, I conducted chi-square tests of independence. The mode of instruction did not correlate to differences in correctness for most questions on the midterm. Significant results are presented in Table 9. Based on the aim of this study, I hypothesized that POGIL activities would increase content retention and students who learned through this mode of instruction would respond correctly at higher rates than those who learned through online, asynchronous lecture videos. However, only four questions showed statistically different correct response rates based on the mode of instruction. Most differences in the percentage of correct responses support the cohort effect identified above, with lower correct responses rate groups occurring in Cohort B.

Table 9 Significant Differences in Midterm Questions Based on Method of Instruction

Midterm Question	POGIL instruction % Correct Responses	Other instruction % Correct Responses	X^2 p-value
Q3. Find the slope and the equation of a line that passes through the points (-1,2) and (3,8)	23.5 (Cohort B)	52.4 (Cohort A+C)	0.043
Q5. What is the only real number that does not have a multiplicative inverse? Explain why it does not have a multiplicative inverse	100 (Cohort A)	74.4 (Cohort B+C)	0.012
Q19. Graph $y = -3x + 4$	64.7 (Cohort B)	92.9 (Cohort A+C)	0.013
Q24. Explain why the following worked example is incorrect $3x + 4 - (x + 1) = 2x + 3$ $3x + 4 - x - 1 = 2x + 3$ $2x + 3 = 2x + 3$ $3 = 3 \longrightarrow \textit{No solution}$	25.0 (Cohort B)	58.1 (Cohort A+C)	0.024

* All differences show those in Cohort B answering incorrectly in larger proportions.

I conducted similar analyses on questions that appeared on students' final exams. Table 10 shows statistically significant ($p < 0.05$) and borderline ($p < 0.1$) differences found during the analysis. Like the Midterm, only four questions were statistically different based on the mode of instruction. Based on the aim of this study, I hypothesized that POGIL activities would increase content retention, and students who learned through this mode of instruction would respond correctly at higher rates than those who learned through online, asynchronous lecture videos. These results also provided evidence for the cohort effect described above, with Cohort B belonging to the group with the least number of correct responses, regardless of the mode of instruction.

Unexpectedly, two questions (Q8 and Q23) show a higher proportion of correct responses from those who learned topics using asynchronous lecture videos. Questions 4 and 10 showed a higher correct response rate of those who learned the content using "live" in-person POGIL activities. Since the final exam was cumulative, results indicate that POGIL activities may have increased retention of content information using active learning instructional methods based on Q4 and Q10, which evaluated content taught earlier in the semester. The majority of differences in the percentage of correct responses supported the cohort effect identified above, with lower correct responses rate in groups including Cohort B, suggesting that the cohort a student was a part of had a higher influence on student assessment outcomes than a mode of instruction.

Table 10 Significant Differences in Final Questions Based on Method of Instruction

Final Question	POGIL instruction % Correct Responses	Other instruction % Correct Responses	X^2 p-value
Q4. Classify the number -3 with the appropriate real number category(ies)	65.0 (Cohort A)	33.3 (Cohorts B + C)	0.020
Q8. True or False: The equation $9x^2 + 6x + 1 = 16$ has the same solution set as the equation 3x + 1 = 4. Explain.	18.8 (Cohort B)	51.2 (Cohorts A + C)	0.025
Q10. Factor $16y^2 - 9$	95.0 (Cohort A)	74.4 (Cohorts B + C)	0.051
Q23. Find the equation of the line with a slope of -2 that goes through the point (-1,0).	35.3 (Cohort B)	64.3 (Cohorts A + C)	0.042

* All differences show those in Cohort B answering incorrectly in larger proportions

4.1.8 Additional Analyses Exploring the Influence of Cohort and Achievement

Knowing that a difference was observed amongst each cohort, I conducted even further analysis to determine if the instructional methods or cohort effect were responsible for the differences in correct responses for each of the questions listed in Table 9 and Table 10. ANOVA analysis of final scores showed a significant difference in grade distributions. Results of this analysis suggests that the cohort differences may explain the difference in correct responses rather than the instructional method. The questions in which POGIL instruction yielded a lower percentage of correct responses than those who learned with online lecture videos, corresponded to Cohort B's POGIL activities. This suggests more analysis could be done in future studies to determine why this was the case. Differences in cohort results could be related specifically to the topics covered, students' motivation, students' past experiences, in-class group work interactions, or simply the number of students who quit partially through the semester. Most students who earned failing grades, did not respond to the final classroom survey. This lack of engagement in the course overall could help to explain why trends, especially for Cohort B, although not significantly significant, were not consistent amongst all three cohorts.

4.2 IQ2 Results: To What Extent Does the Use of POGIL in an Algebra Classroom Improve Student Attitudes in Mathematics?

4.2.1 Survey Items Corresponding to Attitudes in Mathematics

I had administered surveys at the beginning and end of the course aimed to explore potential improvement in students' attitudes towards mathematics. No questions on the surveys showed a statistically significant ($p < 0.05$) difference at the two time-points based on paired t-tests (See Appendix G.2). Changes in opinions at the two time points varied on the Likert scale by less than 0.20 points in either direction for the initial rankings for all changes observed. Responses, although not statistically significant, indicated trends that students experienced:

- increased student interest in mathematics assignments
- decreased enthusiasm about attending "live" synchronous class meetings
- decreased confidence in their abilities to learn
- decreased feelings of being "good" at mathematics
- increased feelings of dread, anxiety, and fear with completion of assignments

While these results may seem concerning, they are not statistically significant, and trends indicate only slight changes of scores (< 0.20 points) throughout the semester. These concerning survey trends could be partially contributed to the content of the course—with increasing difficulty of topics as the term progressed. Survey responses further supported the cohort effect seen in achievement results and Cohort B responding less than Cohorts A and C. Qualitative data analysis was used to further investigate the themes bulleted above. Results of Qualitative analysis focused on Cohort A, with analysis of autobiographies and reflections, indicated a positive shift in mathematics attitudes corresponding to mathematics interest. Qualitative results of Cohort A also gave indications of struggles students experienced with the online learning environment and zoom burnout as a potential explanation for the lack of statistically significant changes in attitudes throughout the semester and can also be used to partially explain why focus Cohort A was the only cohort in which the proposed pass rate of over 78.8% was achieved.

4.2.2 Themes From the Comparison of Mathematics Autobiography with Student Reflections on Student Attitudes Toward Mathematics

Although quantitative changes in survey responses were not statistically significant, qualitative data from focus students in Cohort A illuminated how POGIL instruction influenced student mathematics attitudes. Of those in Cohort A, focus students were identified based on scoring initially the highest and lowest in categories of student attitude on "long survey" items administered at the beginning of the semester before use of POGIL instructional methods. Pseudonyms were created for each focus student. The "positive" attitude focus student (PAFS) group consisted of students Benjamin, Chris, Anna, and Frank. The "negative" attitude focus student (NAFS) group consisted of students Daniel, Adam, Emmanuel, and Grant.

Comparison of qualitative data collected included math autobiographies (intended to explore "incoming" attitudes at the beginning of the course) and self-evaluations in post-course reflections (intended to explore "exiting" attitudes at the end of the course) for focus students selected from Cohort A. I assigned the mathematics autobiography during the first-class meeting. I used this assignment as an indicator of "incoming" attitudes of focus students by prompting students to elaborate on their early experiences, both good and bad, and how their attitude toward mathematics has changed over the years, if at all. The post-course reflection indicated student "exiting" attitudes because it was assigned at the end of the course after all mathematics content material was covered. I then used both assignments to examine changes in attitudes based on the implementation of the POGIL methodology throughout the semester.

Students in both the PAFS group and the NAFS group reported enjoying the activities and social interactions resulting from using active learning activities in the classroom. Positive effects from engaging in operational learning POGIL activities were seen in qualitative data of PAFS, which will be described later, and included indications of increased student confidence, willingness to seek help, and willingness to collaborate with peers. The NAFS statements indicated that students had experienced more difficulties in grasping math concepts, lower self-concept on their abilities in mathematics, and less overall interest in the subject. NAFS statements indicated issues regarding fears of not being good enough, struggle, and themes relating to boredom and bad teaching within their comments.

4.2.3 "Incoming" Attitudes of Focus Students of Cohort A (Math Autobiography)

4.2.3.1 Feelings of Fear, Worry, and Nervousness Stem from Teacher Practices

A few common themes emerged from the autobiography data (intended to illuminate "incoming attitudes toward mathematics") of Cohort A focus students. These themes were consistent in PAFS and NAFS, with each focus group having mixed feelings regarding mathematics. Autobiographies indicated that prior teacher practices, course experiences, and corresponding emotional responses framed students' incoming mathematics attitudes. Within autobiographies, most students indicated that their past teachers influenced their views on mathematics. Past experiences often solicited negative emotions of fear or anxiety and impacted student confidence in the classroom, even for those in the PAFS group. PAFS sentiments below illustrate these trends:

Benjamin (PAFS): "I had a teacher who was an elder and really mean to my class and made it intimidating to ask questions."

Benjamin explicitly expressed indications of negative emotions and a fear of asking questions due to past experiences of feelings of intimidation based on teacher practices. Anna expressed similar sentiments to Benjamin.

Anna (PAFS): "Throughout the year, anytime I would ask a question, she [high school teacher] would make me feel like I was the only one not understanding it, and the other kids in the class would look at me when I would ask anything. My teacher also explained to the class about how she has to act like a college teacher to get us prepared for it—honestly, she made me nervous."

Anna expressed how past experiences influenced her present outlook on reaching out for help with teacher practices invoking feelings of being singled out and nervous.

Anna's and Benjamin's quotes suggested that teacher practices may significantly influence a student's outlook on mathematics. Fear of comparisons and judgment of peers for seeking help introduced a fear of mathematics. Chris offers a more complex attitude toward mathematics.

Chris (PAFS): "In other classes, if I struggle with something, I always have had a better chance of understanding it. If I don't understand something in math, it terrifies me and worries me. I usually get whatever I'm struggling with in math, but it can scare me more than in other classes."

While survey responses indicated Chris to have a positive mathematics outlook, his corresponding autobiography showed indications of a fixed mindset with feelings, where he felt he had a better chance of success in other subjects. But he also indicated that he is usually able to "get" the concept in mathematics eventually. Chris highlighted his ideas of fearing a subject because the concepts do not necessarily make sense right away, but he expressed that he could understand, suggesting he may have a growth mindset.

Frank was one of the only focus students who viewed his mathematics ability with high confidence in his mathematics autobiography. He detailed each year's memories of his mathematics courses stemming back to preschool. The following excerpt shows an overview of his experiences:

Frank (NAFS): "I have always loved math ever since I could remember. I still have notebooks from when I was in preschool… [i]n Kindergarten I was given extra homework (for fun, not graded). I knew more than some of the fourth graders. In first grade, I had a falling out because of my ego, I thought I was the best in the world, then I fell flat on my face realizing I am not the best in math… In high school, the math started to get tough. My ninth-grade year was by far the worst as it was the only time I averaged below an A in any math class. However, the teacher was nice and I quickly rebounded and was able to get myself back on track."

Frank also mentioned teaching practices throughout his assignment and indicated he had a high level of confidence in the subject at an early age and his enthusiasm for the subject by mentioning that he had done extra homework for fun. By the first grade, Frank began to have feelings of not being “the best in math” and indicated that he had started to experience struggle. Teacher practices in his high school math courses allowed him to regain confidence and succeed in his math courses.

Although each of the PAFS members’ attitudes toward mathematics were influenced by negative classroom experiences, all PAFS showed indications of a growth mindset, perseverance to succeed, and self-confidence in their abilities to understand content information. The negative attitude focused students also indicated negative experiences with previous math teachers and negative emotions. However, instead of feeling empowered that they could still learn the mathematics content (growth mindset), like the PAFS group, the NAFS felt defeated about ever learning mathematics (fixed mindset).

Daniel (NAFS): “My earliest memories of mathematics were in my middle school years, and I struggled a lot during middle school. I believe I acquired these feelings because the teachers at my school would find the valedictorian of each class and only focus on those students… Once I thought I wasn’t smart enough for math, I didn't want anything to do with it.”

Daniel’s autobiography highlighted his past experiences of struggle and constant comparisons to others in their class, feelings of not being smart enough, and indications of “giving up” on the subject due to teacher practices. Daniel also indicated feelings of being ignored since he was not the “valedictorian.” Unlike those in the positive attitude group, those in the negative attitude group did not express the same sentiments of being able to succeed amid challenge and instead gave up on the subject.

Other students within the NAFS also indicated teacher practices as influential to their attitudes about mathematics. Emmanuel provided the following quote:

Emmanuel (NAFS): "It was not until the sixth grade when we got a new teacher. She had a horrible way of doing things and teaching us the concepts of literally everything."

Emmanuel expressed that he liked mathematics until the sixth grade but indicated that his attitude change toward the subject was based on teacher practices in the sixth grade. While Emmanuel did not elaborate on the teaching practices, he noted that his teacher was not effective in her teaching of concepts. Emmanuel did not mention trying to reach out or seek help, but much like the others in the negative attitude focus group, he seemed to have given up on mathematics.

Grant's (NAFS) autobiography displayed a positive attitude due to his motivation to become an engineer. The following statement is an excerpt from his autobiography:

Grant (NAFS): "Ever since early elementary, I was one of the top students in my math classes until 8th grade. My school was not the greatest and I had a teacher who hated his job and sometimes did not show up to class."

Grant then explained his experience with the Pennsylvania State Keystone exam (which required 1500 to pass) at the end of his 8th-grade year.

> "I, unfortunately, had a failing grade of 1499. That affected [sic] my high school math career by putting me in a yearlong algebra 2 class my first year while other students would [be ahead and able to take] AP Calculus junior year… in my Algebra 2 class I sought out to do well and even overachieve, and I followed through on that goal. I was best in my class, and when it came to retaking the Algebra Keystone, I got a score above 1600, which is above average."

Grant displays a high level of confidence in his abilities yet much like others in the NAFS cohort, placed blame of small "failures" on his teachers initially, but based on his own career goals showed perseverance in future courses to improve on his standardized test scores and progress through subsequent classes in which he felt his teachers recognized his efforts.

4.2.3.2 Feelings of Boredom

While teacher practices may have related to common themes of feelings of fear, anxiety, and being singled out from both PAFS and NAFS, the theme of boredom was also seen in NAFS autobiographies. Adam, in the NAFS group, provided the following excerpt in his autobiography:

Adam (NAFS): "Well it is just not my thing. I can do it alright. Yes, I do get confused here and there with problems, but once I get examples, I can fluently do problems. I just find math to be a bore to be honest."

Adam expressed lack of interest in mathematics with the statements of mathematics to be boring. Adam indicated he felt he could succeed when examples are provided but did not see the benefits or usefulness of mathematics concepts. Adam's quote suggests that he views mathematics knowledge as something that can be memorized, rather than as a subject to understand conceptually. For Adam, the act of memorization becomes repetitive over time, which may be an explanation to his boredom with the subject. It is also possible that since students often find concepts in mathematics unrelatable to their current life, they deem topics as boring because they do not recognize mathematic concepts to have any "real life" applications or how they will use these concepts in their future lives.

4.2.4 "Exiting" Attitudes of Focus Students of Cohort A (Post Course Reflections)

I used the post-course reflections as an indicator of "exiting" attitudes, to explore how student attitudes may have changed after experiencing POGIL instructional strategies. The post-course reflection was due right before finals week. Post course reflections of Cohort A focus students suggested some shifts in attitudes in mathematics by the end of the term. The PAFS group felt engaged using POGIL activities and group work with feelings of camaraderie with peers and increased excitement to attending "live" in-person class meetings. Many mentioned the effects of the COVID-19 pandemic and how excited they felt on POGIL days because they were able to work in groups and see their friends in person with sentiments like the following:

Benjamin (PAFS): "At first, I expected them [POGILs] to be just a harder, pointless way to learn something, but I kept an open mind to it, and I ended up being wrong. POGILS have helped me understand math better and helped me realize that I might not be the only one having problems with something in math."

Initially, Benjamin, along with others, felt that POGIL activities would be more work and pointless. By working through activities with their peers, their attitude shift to realize they can understand algebra concepts and led to the realization that they are not the only ones who have questions. Anna, who had indicated feelings of being singled out and nervous to ask questions in her math autobiography wrote:

Anna (PAFS): "After completing the course, I came out with a brighter mindset and a better understanding of algebra. I had a more positive look toward math and my professors. With online learning, I thought that the POGIL activities were extremely helpful. It helped me look forward to Mondays because I knew I would be able to see my friends and be able to learn in person…I now understand that not every math teacher is mean! I also learned that asking questions is normal and the best way to understand a topic."

Anna reflected on her past experiences and retained a better outlook and attitude in mathematics. Anna mentioned looking forward to coming to class due to her relationships with her peers. She indicated the usefulness of collaboration with their peers and that asking questions can help clarify topics and now does not view "every math teacher is mean!" which again highlights the teacher's influence on student attitudes towards mathematics.

Other students in the PAFS also indicated feelings of enjoyment of the POGIL instructional methodology. Chris, in his initial attitude, highlighted his fear of mathematics because the concepts do not necessarily make sense right away but expressed that he can understand. Chris's attitude towards mathematics showed a positive shift in his "exiting" reflection.

Chris (PAFS): "The POGIL activities were different and very helpful. It helped break down each algebra concept we learned. I thoroughly enjoyed the activities. The activities were different, and a change of pace on learning math. It is easier to grasp the concepts when dumbed down or when going step by step. You could easily understand the concepts as well. It helped give me reminders since I haven't taken Algebra in years, so it was an easy transition to remember the concepts because of the pogil activities."

Chris gained confidence in himself and his ability to learn mathematics concepts through the POGIL methodology, which shifted his fear to enjoyment. He indicated that the new instruction helped him to gain more interest and further his understanding. Another student whose reflection showed an increased level of confidence was Frank.

Frank provided the following statements in his reflection:

Frank (PAFS): "I went from "I don't know anyone, what if I mess up somehow?" to "Hey, what's up?" I did have to change how I would solve some answers to better explain to my classmates how I came up with those answers."

Through Frank's comments, he displayed increased confidence in the ability to explain and understand mathematics to their peers, as well as indications that their initial fears of getting the problems incorrect had turned into opportunities for learning.

Overall, PAFS course reflections suggest reluctance to try something new, but willingness to keep an open mind (growth mindset). PAFS reflections also showed trends of students conveying their appreciation for group interactions during a pandemic and shifts in mindset corresponding to the fear of failing initially and openness to seeking help and support when needed. PAFS reflections also showed positive shifts in mathematics attitudes with most students displaying a higher confidence in their own mathematics abilities, a better outlook on teacher practices, and gained enjoyment of mathematics due to comradery with peers in the classroom.

Overall, the NAFS sentiments mirrored those of the positive group in post course reflections with indications of gaining a greater understanding of topics and increased interest in the subject. Some students also touched upon process skills they had gained using POGIL instruction (Teamwork, Oral and Written Communication, Management, Information Processing, Critical Thinking, and Problem Solving). Throughout their reflections, many NAFS students mentioned the importance of priorities and schooling—which represented personal growth and responsibility for their education. Daniel and Adam's reflection indicated personal realizations of priorities in their accountabilities in their learning.

Daniel, whose autobiography discussed past experiences of struggle and constant comparisons to others in their class, feelings of not being smart enough, and indications of "giving up" on the subject due to teacher practices, provided the following statement in his reflection:

Daniel (NAFS): "College algebra has definitely opened my eyes towards college life and growing into adulthood. I know now that I need to pay closer attention to my classes and prioritize my schooling more."

Daniel's sentiments show a gained acknowledgement of accountability to his own schooling and working collectively in groups to gain a deeper understanding of concepts by helping his peers. He did not indicate feelings of isolation based on teaching practices as he did in his autobiography but indicated that he needed to place more effort (engagement) in his own learning, suggesting that POGIL activities may have helped him feel less isolated with more opportunities to seek help.

Adam, who had initially thought mathematics was boring in his autobiography, indicated a positive shift in his thoughts of mathematics. He provided the following statement in his reflection:

Adam (NAFS): "[…], the POGIL activities were a success. Working through the lesson with a group of peers honestly did help me understand the material a bit more. Putting the concepts in our own line of thinking helps because when I put it in my own words/thoughts I tend to remember it more. "

Adam indicated that truly understanding the problem goes beyond simply getting the answer correct. He mentioned that if a person understands a topic, they need ability to explain why a problem is done correctly in their own words. Adam did not use the term "bored" throughout his reflection and mentioned that comradery with peers helped further his understanding of the topic.

Emmanuel's reflection, who stated in his autobiography that he had enjoyed mathematics until sixth grade and experienced negative teacher practices, indicated that he was not completely invested in the POGIL instructional process provided the following quote in his reflection:

Emmanuel: "I never have experienced a class like this one and I honestly have mixed emotions in respect of it. There is a lot of benefits but also some downs. I think the engaging aspect of it helps and being able to understand math in your own way is a better way to approach the given problem… I love the idea of being able to make your own definitions and own steps that will help you in the future, sadly there is always a side effect. If you have an idea and you think it is right and end up following through that idea for the rest of the activity and turns out that everything is wrong. I feel like being thought [taught, sic] is better for the safety of the students."

Emmanuel's reflection suggested that his mindset remained fixed throughout the semester. Although Emmanuel acknowledged the benefits of learning through student-centered instruction, he did not feel as if making mistakes were opportunities for learning. Emmanuel's reflection ended with the statement that "being thought [taught, sic] is better for the safety of the students", indicated that he was not able to see the benefits of learning from his and his group's mistakes and suggests he may prefer direct instruction, e.g., lectures, overactive learning modes of instruction.

Grant, who displayed a high level of confidence in his own abilities but placed blame of small "failures" on his teacher practices in his autobiography, indicated in his reflection that his ideas of how math is taught has changed. Grant provided the following quote in his reflection:

Grant: "It is good for everyone because everyone learns math at a different pace. The POGIL activity is set up so students can learn the content by themselves at their own pace in a fun way. Also, if they need help with a problem or so they can easily raise their hand and multiple people are there to help them."

Through Grant's reflection, he displayed an increased interest in the subject, a realization that learning may be paced differently for everyone, and that with a support system, including peers, instructors, and Tas, any questions can be answered individually to increase understanding.

4.2.4.1 Impact of COVID-19 and Online Learning on Mathematics Attitudes

Some students' post course reflections mention of COVID-19 and online learning as an influential aspect of their feelings of mathematics throughout the semester. The following sentiments referenced online learning specifically in post course reflections:

Adam (NAFS)**:** "I honestly thought my opinion on mathematics wouldn't change all that much during the semester, however I was proven wrong. I actually ended up disliking mathematics more, or at least I dislike algebra more. This was not due to you two [instructors], you two were very helpful and helped me understand some concepts more. It also wasn't due to the POGIL activities, those also tended to help me more. To be honest, the only reason I dislike algebra more is because of having to do it online."

Adam (PAFS) mentioned that he did not think his views on mathematics would change but specifically indicated his attitude on mathematics decreased purely based on the classroom format, in which most class meetings, non-POGIL days, were held virtually and not based on instruction or POGIL activities.

Emmanuel (NAFS)**:** "I think I liked it [POGIL] though and I always loved Math, but somehow my grade for this semester will not back that up because of the anxiety of doing online tests and doing most of this course, as other courses, online."

Emmanuel, who based on survey responses fell into the NAFS group, showed indications of positive attitudes towards mathematics with his statements of liking math but also had indications of negative emotions such as anxiety stemming from the online format of Algebra as well as other classes had played a key role in his grades for the term.

Anna, PAFS, also mentioned the online/hybrid format, and viewed POGIL activities as a reprieve to the online learning environment:

Anna (PAFS): "With online learning, I thought the POGIL activities were beneficial. It helped me look forward to Mondays because I knew I would be able to see my friends and be able to learn in person."

Anna's (PAFS) attitude toward mathematics also did not change but remained positive throughout the semester. She viewed her POGIL days as a reprieve from online learning and an opportunity to gain content knowledge and build friendships.

Overall, student autobiographies and post-course reflections suggest positive shifts in attitudes toward mathematics using active learning instructional methodologies and group work. The qualitative analysis supported survey trends of increased student interest in mathematics assignments and helped to explain the increased feelings of dread, anxiety, and fear with the completion of assignments due to the online components of the course. Qualitative results did not coincide with the slight decreases in enthusiasm about attending "live" synchronous class meetings, decreases confidence in their abilities to learn, or decreased feelings of being "good" at mathematics seen in survey trends for PAFS or NAFS. Themes from post course reflections indicate that students began to take control of their own learning and became more engaged in their coursework. This suggests that POGIL instruction can potentially improve student attitudes and their own confidence of learning, especially in a non-COVID classroom.

4.3 IQ3 Results: To What Extent Does the Use of Student-centered Learning Instructional Techniques Improve Student Engagement?

4.3.1 Quantitative Survey Results

IQ3 was structured to examine the influence of active learning on student engagement withing college algebra classrooms. Using both quantitative approaches to assess changes in self-reported survey responses and qualitative analysis of classroom observations and field notes, I was able to gain insight into the students' reported willingness to engage as well as student interactions within the focus Cohort A. According to survey data, as previously presented, no questions showed a statistically significant ($p < 0.05$) difference at the two time points using paired t-tests on survey responses (see Appendix G.3) on the influence of POGIL activities on student engagement. While not statistically significant, student responses indicated that students experienced:

- an increase in interest in assignments
- no change in willingness to engage
- a decrease in the ability to concentrate
- a decrease in the likelihood of checking work or seeking help

Classroom observations and notes were analyzed to help to explain and triangulate these trends seen within survey responses to gain additional understanding and clarify students' survey responses.

4.3.2 Qualitative Results Overview

Qualitative data sources coincided with trends seen in the summary above throughout the semester (discussed in more detail in the following paragraphs) for interest in assignments, willingness to engage, and ability to concentrate. However, classroom observations and analytic memos indicated an increase wiliness to check work and seek help, specifically in Cohort A. Students' camaraderie with peers and excitement for social interactions during the COVID-19 pandemic further explained students' increased interest in assignments in Cohort A. For Cohort A, students who were initially reluctant to work with group members continued to not participate in classroom discussions or exhibited poor attendance throughout the semester. Those who were willing to participate continued to do so, engaging in POGIL activities, as indicated in classroom observations and my analytic journals. This may explain the lack of willingness to engage results that was found on the survey. Decreased concentration was likely partially contributed to zoom burnout, students stress of transitioning to new instructional methods, and impacts of the COVID-19 pandemic. Throughout the semester, students continuously reached out for help during "live" in-person instruction or attended office hours and review sessions outside of class meeting times.

Qualitative data of focus Cohort A supported the lack of changes seen in survey responses throughout the semester. Based on survey responses, students who initially reported they were willing to engage continued to actively participate based on classroom observations. Based on survey responses, students who were unwilling to participate continued to choose not to participate in group work or stopped attending class altogether throughout the semester, regardless of changes in groupings to encourage collaborations and constant encouragement of instructors and TAs in the classroom to work collectively based on classroom observations. However, I did find differences in engagement based on being live in-person versus live via Zoom through analysis of my observational field notes of each cohort. For those who attended in-person POGIL meetings (and were present in class), POGIL activity completion was a collaborative process in which students worked with peers. However, those who attended zoom POGIL meetings (and were present in class), once placed in breakout rooms, tended to work independently (cameras off and muted).

4.3.3 Results of Field Notes and Classroom Observations

I recorded classroom observations for Cohort A during "live" classes for one month (four in-person meetings). During these class observation days, groups were observed, and video recordings were collected to capture interactions of POGIL group work (for Cohort A). During these meetings, my observations focused on group interactions, participation of students, and questions asked within the classroom while my co-instructor took the lead on classroom instruction. Classroom conversations were annotated and examined for engagement themes such as student-student interactions, student-teacher interaction, asking for help, active participation, and attendance.

My primary noticing regarding student engagement was that students who were reluctant to work with group members would simply not participate in classroom discussions or exhibited poor attendance throughout the semester. Initially, students were very hesitant to try something new. The POGIL instructional technique was not something the majority had been exposed to before their interactions in this course. A learning curve was needed to allow students to get comfortable interacting with their peers and instructors, as indicated by classroom observations. Once students became more comfortable with the process, knowing it was "okay not to know the answers," seeking help from others, and keeping an open mind, they became more willing to actively engage in their own learning and work with others in their groups. Throughout the semester, students in Cohort A began to understand that through their own mistakes, they gained content knowledge and a greater understanding of concepts of algebra. Throughout the semester, students also started to become more interactive with their groups, the instructor, and TAs during in-class meetings as their comfort increased. Autobiographies and reflections for insight into the student's past experiences and reasons they initially choose not to ask questions based on past classroom experiences (See IQ2 Results).

While formal classroom observations only were taken for Cohort A, classroom analytic memos were recorded for each class meeting. For these memos, I noted any "struggling" students or students/POGIL groups who were not actively participating in POGIL group work. My field notes allowed me and my co-instructor to "flag" groups that needed more support in their learning or assistance in proper POGIL implementation. These analytic notes further supported the cohort effect mentioned previously and differences in engagement between those in attendance in-person and those who attended virtually using zoom (discussed below).

4.3.4 Student-centered Instruction with POGIL

Classroom observations and field notes of Cohort A supported that the use of student-centered, active learning instructional activities improved student engagement, group work, and communication in "live" in-person class meetings if the student was willing to participate. Seven groups were created in Cohort A. Each student was given the job of presenter, recorder, or manager. Of the seven groups designed, the majority actively participated and collaborated during class time. During the 50-minute sessions, students helped each other understand content from activities by communicating their own understandings. I found that students were often excited to explain to other group members. I offer an example below of student interactions while completing a group activity involving Symmetry and Even & Odd functions:

"…Are you working ahead?"- Recorder

"What number are you on?" - Manager

"Seven" – Presenter

"Oh, I'm not on seven, can we work together to get on the same page?"- Recorder

"Ok"- Presenter

* Some time spent working

"Did you end up with the origin? – Recorder

"YES! – Presenter

Throughout this small sample of narrative as well as visual observations of group dynamics of each student in this group, students were actively collaborating and attempting to maintain a pace for everyone in the group. Members actively communicated when they needed their group members to slow down or needed extra time to catch up. This narrative also demonstrated active collaboration to see if the group had a consensus on the correct answers and displayed an improvement in morale when they received confirmation that they were completing the task correctly from the instructor.

The collaborative nature of the classroom structure also allowed TAs and instructors to help identify struggling students who may need additional help and support in their learnings and build stronger rapport with students. Students also seemed more comfortable, based on classroom observation, despite reporting otherwise on surveys, to ask for help. This was noticeable based on classroom observation and memos, which showed a more significant proportion of students attending office hours or reaching out for assistance during "live" classroom sessions than seen in the previous semester. During in-person meetings with Cohort A, instructors and TAs walked around the room to ensure students had opportunities to reach out with questions without the "fear" of embarrassment, the judgement of peers, or pressures of having to call attention to themselves when asking for help. It was very rare to have time when a group was not being helped directly by an instructor or TA. Students often arrived at class early and stayed after to work with their group and ask questions to the instructors.

Classroom observations of Cohort A often indicated students' conversations with their groups, instructors, and TAs when they felt confused. One example was recorded when completing an activity on quadratic graphing functions when a student made the following statement:

"Can we take a step back, can we think of these steps in words, and stop working out of order?"- Recorder

"Step 1: Constant term…"

Students within their groups became comfortable enough to stop and ask when they needed help or clarification. Since the recorder was responsible for submitting their group's consensus for the day, he wanted to ensure he had gotten everything written down correctly and receive appropriate feedback on the group's submission.

Another group example in which students who were not sure if they were on the right track, reached out for help is below. Students were completing an activity involving solving equations and inequalities with absolute values:

"We got "a" but are confused with "b" - Presenter (explaining solving for slope (a) and intercept (b) of a line.)

"You got "a" right"- Instructor after looking over the group work

"We got it!"- Presenter *Students proceed to high-five each other in excitement

"Now for "b," I personally would start by distributing the negative."- Instructor

"It's the same thing!"-Presenter

"Now we are looking for *x*; what do you think we need to do next?"-Instructor.

"Move to the other side and factor?"- Presenter.

"Guys, I got it! I'll show you"-Presenter speaking to other group members.

As evident in this example, based on the POGIL activity, the students were able to determine the method and solve with little intervention of the instructor as indicated by classroom observations; yet the support of someone being there helped the students gain confidence in their own abilities. The individuals within this group showed their willingness to explain the method of solving equations to their group members and increased confidence to complete the task with a small amount of confirmation that they were on the right track from the instruction. These trends coincide with trends in the quantitative results. Not seeing changes in engagement via survey data is not necessarily purely negative. Students who reported they were initially willing to participate in classroom and group activities actively continued to do so. Those who were not likely to engage and ask for help were likely those students who gave up on the course and had poor attendance throughout the semester.

5.0 Learning & Actions

5.1 Discussion

5.1.1 Effect of Survey Response Rates on Student Attitudes and Engagement

The differences in response rates between cohorts may help to partially explain why statistically significant changes were not found on survey items regarding mathematics attitudes (IQ2) and student engagement (IQ3). Larger samples increase the power of statistical tests to determine if a difference exists. Although trends in data showed that Cohort C was answering survey questions in a different direction than Cohorts A and C, due to limited sample size and low response rates, it is possible that the ANOVA test did not have enough power to detect a difference as statistically significant. Overall, based on self-reported Likert results, although not statistically significant, student feelings towards math decreased on most items except interest in mathematics (IQR2). Survey results and classroom observation results corresponded to the influence of POGIL activities on student engagement (IQR3), suggesting no significant difference in the level of student engagement throughout the semester. However, qualitative responses showed that the use of active learning positively affected student interest in mathematics. Decreases in attitudes corresponding to exams, overall opinions on math, and engagement could be partially contributed to the course content (with increasing difficulty as the term progressed) as well as the influence of burnout introduced by the COVID-19 pandemic.

5.1.2 Effect of POGIL Instruction on Student Achievement (IQ1), Attitudes About Mathematics (IQ2), and Engagement (IQ3)

Leung et al., 2006 suggested that classroom structure and instructional methodology may have strong relationships with student mathematics achievement (Leung et al., 2006). This project introduced a complete course redesign that incorporated student-centered active instructional learning methodology (POGIL) into a college algebra classroom, which had traditionally been lecture-based. This instructional method focuses on gaining content knowledge in mathematics and important process skills such as communication, critical thinking, group work, and collaboration (Moog, 2008).

Although previous studies such as Bénéteau et al. (2017) showed a significant decrease in Drop, Fail, Withdraw (DFW) rates in introductory mathematics classrooms, this study did not show an influence of POGIL instruction on student achievement, with POGIL implementation one day a week, in my classroom. Some contributing factors to these results are explained in more detail later in the paper but focus on student buy-in and accountability, the effect of the COVID-19 pandemic, and revisions of the POGIL activities created.

Qualitative results showed a positive influence of POGIL instruction on students' overall mathematics attitudes and engagement in my college algebra classrooms during its first implementation during the COVID-19 pandemic. Engagement was found to be a mediating factor to achievement goals learning and identified as a targeted concept that allows students to increase their own learning (Putwain et.al., 2018; Rodriguez et. al., 2019). Through our development of structured, scaffolded activities (Yildirim et al., 2010) that follow the learning cycle. These activities were used during live meetings as a method to create active learning and student engagement using visual mathematics in a group setting (Mazziotti, 2019). This builds upon

Mindset Mathematics introduced by Boaler, et.al and ‘mathematics in the making’ introduced by Boyd the focus on these processes skills in addition to allow students to build confidence in understanding through collaborative group work and use of productive struggle (Boaler, et al., 2018; Boyd, 2015) and ultimately increased students active participation in my classroom as well changed views on mathematics among the focus students of Cohort A.

5.2 Implications and Next Steps

During the completion of this project, I had learned a lot about the process of transforming an Algebra classroom. The following section will discuss some helpful information for those who potentially implement a similar student-centered instructional method into their own classrooms as well as some lessons learned throughout one PDSA cycle. My study results help to further understand the complex interactions of student attitudes, engagement, and achievement in college mathematics classrooms. Students within my focus cohort, indicated that POGIL was beneficial to their algebra learning if they were willing to participate. Using qualitative results, I identified the importance of buy-in, effects of the COVID pandemic, need to promote student accountability, and issues in timing which can inform future PDSA cycles.

5.2.1 Importance of Buy-in During the Implementation of Active Learning Instruction

Buy-in for POGIL instructional method is crucial for its success. This comes from both the instructor as well as the student. Throughout this study, it was evident that if a student, or anyone else involved in the process, was resistant to changing their ways of thinking, POGIL instructional design would not work. Cohorts, in which students were receptive to changing the way they had traditionally learned, gained a lot of helpful content knowledge and life skills from participating in group work throughout the semester. However, those who would not even attempt to make a change struggled and simply refused to participate during live classes—opting to work independently.

Students and instructors are often reluctant to change due to a variety of potential reasons. Just like the results of IQ3 showed; people are not happy when uncomfortable, and this holds for both faculty members and students. Change often involves more effort on each stakeholder when new instructional techniques or changes are made to courses. People become fearful of the unknowns that could be introduced when trying something new. From the student standpoint, it is often difficult for students to keep an open mind with topics with which they traditionally have had difficulties. Active learning places more responsibility on the students to take charge of their learning. Sometimes it is difficult for students to want to put more work into a subject, such as College Algebra, in which a lot have already had bad experiences and do not necessarily see the benefit in terms of their own life experiences or goals (Fung, 2018). Based on the results of this project, the importance of student buy-in was necessary for the success of the instructional method.

As a faculty member with the belief that active learning is a way to increase both student learning and engagement, it is often a significant hurdle to find a way to get students to believe in the process and in their abilities to learn. Adjustment time is needed to get students to become comfortable with the instructor and others within the classroom. It is important to stress that mistakes should be taken as opportunities for learning and that they should not fear getting concepts right away. Autobiographies and reflections from this study indicated that most students had shared experiences, both good and bad, in previous courses that framed their thinking on mathematics. By learning student stories and creating a comfortable environment, students begin to buy in to the method, often finding that "something new" may help them to understand concepts but forcing them to learn the material in a way that they had not tried before.

5.2.2 Influence of COVID-19 and Online Learning

Amid the COVID-19 pandemic, online instruction became standard for some cohorts. Overall, in-person activities seemed to improve student engagement (IQ3) when students could interact face-to-face in the classroom. However, increased engagement was not often seen in the virtual environment, even with the ability to use additional technology such as screen sharing. Students within the virtual environment were placed into Zoom breakout rooms in which faculty and TAs would cycle through during their live meeting days. I noticed that most groups in the virtual environment spent their time within the breakout rooms working independently. For some groups in the virtual POGIL environment, students chose to work with groups with cameras off. They lacked the same relationship building and interactions seen in the in-person setting.

Those who opted to attend live in the virtual POGIL format were more reluctant to talk to or work with others, even in smaller breakout rooms. It was also difficult to ensure students worked diligently during the entire scheduled time and difficult to monitor student interactions, even with multiple check-ins throughout the 50-minute scheduled class time. As part of the University policy, students were also not required to make use of video cameras when attending classes virtually which prevented some of the ability to get familiar with other students or to see whom they were speaking to within the breakout room settings. Students did not choose to turn on cameras, share screens, or unmute despite instructors "popping" into breakout rooms on a regular basis to check progress and answer questions.

5.2.3 Additional Roles to Increase Student Accountability

For the initial implementation of POGIL instructional methods, it became apparent that student collaboration would need to be increased in future iterations. This would allow students to gain a further sense of accountability for their group and group work. From this study, POGIL methodology does not seem as effective when working independently and seemed to be overwhelming to the students who chose not to actively participate with their group members. Initially only three roles were used (manager, recorder, and presenter) with the thought that groups of three would work in both the online and in-person settings, due to restrictions on classroom occupancy as well as social distancing. For future semesters, the additional role of "reflector" will be included to gain more in depth understanding of group dynamics and student's participation from the student's viewpoint (IQ3). Reflectors will be responsible in the future to report if their group is having issues with members who are not contributing and act as a representative between groups and faculty.

In the online format, it was difficult to monitor group breakout rooms or ensure groups work collaboratively on activities, even with two faculty members, TAs, and the consequence of students losing participation points. During in-person instruction, more research is needed to determine methods to promote individuals to work within their groups more efficiently (using complex instruction). It was also difficult to ensure all group members were present. During this semester, when all group members were not present, pairs or single individuals were allowed to combine to allow for additional collaboration. This allowed for more collaboration throughout the semester but a noticeable discomfort when meeting and working with new people.

An additional role would add a person to each group. This would allow students to not only become more accountable for reporting their duties and group interactions but could also increase the student's awareness of whether they are actively participating, increase self-reflection on their interactions in the classroom, and allow groups to be more consistent throughout the semester.

5.2.4 Timing of Activities and Revisions

After activity development and implementation in the classroom, timing issues of the course and activities became apparent. Learning through active group work takes more time than traditional lectures to cover content in a lecture format, especially in an online learning environment. An adjustment period was needed to allow the students to get comfortable with others in their groups and the class structure. Within a few weeks, those who were willing to give POGIL instructional methods a chance began to get into a flow and work with more diligence and vigor to complete tasks collectively as a group. As a result of these factors and student recommendations, we will revise activities to fit the semester timeline during future semesters to better fit the semester timeline during future semesters better.

5.3 Future PDSA Cycles

Improvement science methodologies test "small tests of change." During the implementation of this project, knowledge was gained on the structure of active learning POGIL instruction in algebra classrooms. The COVID-19 pandemic operating procedures on campus, limits on classroom capacities, and social distancing prevented the ability to fully implement POGIL active learning for all class meetings and all content covered during the semester or for an accurate comparison to "traditional" in-person classroom instruction. Cohorts only experienced one POGIL activity per week; therefore, results may not be representative or display to influence of POGIL instructional methodology in traditional, in-person settings. POGIL breakout rooms on zoom did not show the engagement or group work seen for “in-person” cohorts. For future semesters, the revised activities will be compiled into a physical book for each student, and all content instruction will be done using the POGIL methodology. This will allow for examining POGIL active learning instruction on mathematics attitudes, engagement, and achievement in more traditional classroom settings.

Qualitative data analysis of autobiographies and self-evaluations in post-course reflections also provided great insight for future iterations of activity facilitation. Their feedback offered suggestions of what activities they enjoyed, ways in which group work had influenced learning, as well as influenced learning, and areas of improvement. In addition, based on student feedback and classroom observations, a group reflector role will be added to facilitate group interactions and increase student accountability in working with groups. Reflector reports will be graded using a rubric targeting active engagement and participation. Students also provided helpful feedback on the logistics of changing groups. Initially, groups were randomly assigned at the beginning of the semester, and students began to build relationships and a level of comfort with those initial individuals. A change in group members often decreased the number of interactions with students' peers. When given the option to select group members, students usually migrated back to their original groupings.

5.4 Reflections

Improvement science methodologies are helpful in creating small tests of change to examine minor scale influences on educational research outcomes. For this project, the introduction of a new active learning instructional technique into college algebra classrooms acted as a potential way to influence student achievement, attitudes, and engagement positively. During the design of this study I, as well as most others, did not expect the implementation to occur during a worldwide pandemic in which a "small test of change" would also coincide with a complete restructure of classroom dynamics. To maintain some source of "normalcy," students had the ability to attend class and participate in POGIL activities one day a week; but it was apparent based on classroom interactions that students and myself became exhausted from being in the online environment. Yet, the days in which students and I had the ability to be "in-person" provided critical interactions with peers, which gave students and me something to look forward to.

The new use of POGIL methodology also allowed me to grow as an instructor. Not only did it allow me to learn more about the instructional method, the analysis, and data collection for this project allowed me to gain more understanding about students' past experiences in mathematics through their autobiography assignments and post-course reflections. POGIL instruction helped to build relationships and open discussion within the classroom. Students' group work allowed me to provide more individualized instruction to students in my classrooms, which helped me to more quickly identify if students were struggling. This type of learning was not only beneficial to students, but it allowed me to better understand what topics students have difficulties with and the types of questions that come up. These difficulties and questions often go unasked during a typical college algebra lecture.

5.5 Study Limitations

The semester in which data was collected (Fall 2020) occurred during the COVID-19 pandemic. During this time, student class sizes were limited; therefore, students did not have the opportunity for face-to-face instruction or use of POGIL activities for all content in Algebra. The cohort case study focused only on 21 students exposed to POGIL instructional techniques for one lesson per week, and inferences may not be extended to other cohorts or additional POGIL activities. The comparisons made during the study only allowed for the examination of POGIL instructional methods in contrast to online asynchronous lectures in content retention but do not necessarily give a comparison to traditional in-person learning. Future implementation, with students exclusively using POGIL instructional techniques, can be used to get a better idea of the effect of POGIL on student mathematics attitudes, engagement, and achievement.

Due to the limitations of the implementation plan during the COVID-19 pandemic, a full understanding of the effects of student-centered, active POGIL learning could not be assessed completely. While changes in student self-reported mathematics attitudes and engagements did not provide statistically significant results, the positive trends from qualitative data showed that implementing in more traditional, non-pandemic environments may aid in addressing mathematics achievement in subsequent semesters. The additional understandings from this study will help frame future study areas. Based on study results, additional analyses could be done to examine the "cohort effect" observed based on overall assessment scores in the class by further examining student placement scores for each cohort. Additional data analysis could be done in the future, focusing on course autobiographies, reflections, and other factors to identify why Cohort B had a more significant fail rate, less participation, less attendance, and lower scores on formal assessments. Additionally, POGIL activities will need to be modified for future implementation in college algebra courses to consider issues with timing, and student accountabilities, and to incorporate student suggestions.

5.6 Conclusion

Throughout this study, I gained more understanding about the interactions of active learning instructional techniques and student learning outcomes—mathematics attitudes, engagement, and successful introductory course completion. Using POGIL and group work in college algebra classrooms allowed me to provide students with more individualized learning opportunities. Eventually, the experience I gained will allow for the expansion of POGIL from one lesson a week to one that can be used in each class meeting during traditional, in-person instruction. This will allow me to continue to examine how the use of POGIL in conventional classroom settings can influence student achievement, attitudes, and engagement to begin to lessen the overwhelming failure and withdrawal rate in introductory college algebra courses at my place of practice.

Appendix A Example PSDA Cycle

Tester:	**Victoria Causer**	Date:	**Fall 2020**
Change Idea:	**POGIL instructional activities used in place of traditional lecture**		
Goal of the Test	**Determine the effect (and extent) of different instructional methods on students' math content knowledge retention and students' mathematics identities.**		

1. PLAN	
Questions:	Predictions:
To what extent does the use of POGIL in algebra classrooms increase student math identities?	☐ **Active learning will promote student's confidence and math understandings.** ☐ **Student mathematics identify will increase as they gain confidence in their own abilities.** ☐ **Active learning will promote collaborations and engagement amongst students.**
To what extent does use of active learning instructional influence student retention of math content knowledge on summative assessments?	☐ **Retention of content knowledge will be higher for those who are exposed to POGIL instructional activities.**

2. DO:

Summer 2020- Faculty attends workshops to learn about POGIL basics, facilitation, and activity writing.

Fall 2020- Students divided into 3 sections based on in person meeting days (M, W, or F).
During in person meetings (once per week) students introduced to POGIL activities for topics content, remaining sessions asynchronous (online)

3. STUDY

What were the results/ What *will* you learn:

- ☐ **Student Autobiography's will provide insight to student mathematics identities**
- ☐ **Post refection's will allow to inform changes in mindsets over the course of the semester.**
- ☐ **Student surveys will allow for student feedback on POGIL activities and instructional preferences.**
- ☐ **Classroom observations will examine changes in classroom engagement**
- ☐ **Overall content knowledge retention will be evaluated using summative assessment result comparisons**

4. ACT

Revise and reflect based on student feedback and assessment results to better or restructure activities. Reimplement in future with extension to additional topics.

Appendix B Mathematical Autobiography Prompt

The purpose of this assignment is to have you reflect on your experiences with mathematics. This will set the stage for all the (possibly different) ways you will experience mathematics in this class. The autobiography will also help us know how you feel about mathematics, what you have experienced in mathematics classes, and will us tailor the course for you. The audience is your professors, and in some sense you.

Assignment:

Write a one-two page double spaced mathematical autobiography. (Times New Roman, 12 pt. font, 1-inch margin)

You should include some of your early experiences, include some experiences with teachers (in any grade), both good and bad experiences and how your attitude towards mathematics has changed over the years (if it has). This may help to explain why you enjoy math or don't, what is scary for you about math class, or what makes math enjoyable… please feel free to include some information about your experiences with mathematics classes and teachers in college (if applicable). Conclude with an explanation of what you believe mathematics is and how you would define mathematics to someone who doesn't know anything about it.

Appendix C Short Survey Questions

Short Survey Questions: Rate the following on a scale of 1 to 5.

1: Strongly disagree

2. Disagree

3. Neutral

4. Agree

5. Strongly agree

1. I feel I am learning from the POGIL activities.
2. I am becoming more comfortable with the class structure.
3. POGIL activities make mathematics concepts clear.
4. My POGIL group is working well together.
5. I am contributing to the group an appropriate amount.
6. I feel I am learning from interacting with my group members.
7. I am willing to seek help when I need it.
8. I like mathematics.
9. I like coming to my "live" math class.
10. My feelings towards math are changing.
11. What do you like or dislike about POGIL activities?
12. Comment with anything we should know about your group or group members.
13. How does working with your group on POGIL activities influence your confidence to complete individual assignments?

Appendix D Long Survey Questions

Long Survey Questions: Rate the following on a scale of 1 to 5.

1: Strongly disagree

2. Disagree

3. Neutral

4. Agree

5. Strongly agree

1. POGIL activities helped me to learn new mathematical content.
2. POGIL activities make mathematics concepts clear.
3. Online lectures made mathematics concepts more clear.
4. POGIL activity concepts were difficult to grasp
5. Online activity concepts were difficult to grasp
6. POGIL activities helped me to gain confidence doing mathematics.
7. I retained information from Lecture Videos
8. I retained information using POGIL activities
9. My POGIL group is working well together.
10. I am contributing to the group an appropriate amount.
11. I feel I am learning from interacting with my group members.
12. I am willing to seek help when I need it.
13. POGIL activities made me more willing to engage with my peers

14. When other students are distracting me in math class, I often find a way to keep concentrating on my work.
15. When I’m working on a math problem, I think about whether I understand what I’m doing.
16. When I finish my math work, I check it to make sure it’s done correctly
17. I like coming to my "live" math class.
18. I like mathematics.
19. People are born with fixed mathematical intelligence and cannot change this intelligence level throughout their lives.
20. In general, I find math assignments very interesting
21. I am good at learning something new concepts in mathematics
22. My goal is to learn as much as possible.
23. You have a certain amount of mathematical intelligence and there is no way to change this.
24. Taking math tests scare me.
25. I dread having to do math.
26. It is very important for me to get good grades in math.
27. In general, topics I learn in math are useful.
28. I am good at math.
29. In general, I find math assignments very boring.
30. When I am taking a math test, I usually feel anxious.
31. My feelings towards math are changing.
32. POGIL activities help my math understanding

Appendix E Post Course Reflection Prompt

The purpose of this assignment is to have you reflect on your experiences with mathematics in this course. The reflection will help us know how your views on mathematics have changed based on the use of POGIL instructional techniques throughout the semester.

Assignment:

Write a one-page double spaced reflection on your experiences in mathematics class this semester. (Times New Roman, 12 pt. font, 1-inch margin)

You should include information on how you liked or did not like the use of POGIL activities, if the POGIL activities helped or did not help clarify algebra topics, any adjustments you needed to make during the use of POGIL instructional techniques, and if/how your views on mathematics changed at all from your initial autobiography statements though out the semester.

Appendix F Survey Results

Appendix F.1 Numeric Summaries of Survey Questions Regarding the Use of POGIL Activities and Student Achievement Self-Reported Content Retention

		Cohort A (n_M=20, $n_F = 20$)		Cohort B (n_M=12, n_F =9)		Cohort C (n_M=22, $n_F = 18$)	
Survey Question		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Q21: POGIL activities helped me to learn new mathematical content.	M	3.45	1.05	3.46	1.19	3.32	0.95
	F	3.30	1.03	3.89	0.93	3.11	1.37
Overall Change		-0.15		+0.43		-0.21	
Q22: POGIL activities make mathematics concepts clear.	S2	3.85	1.04	3.25	1.06	3.44	0.96
	M	3.63	0.96	3.29	1.38	3.05	1.04
	S3	3.44	0.527	3.40	0.89	2.86	1.345
	F	3.30	1.08	3.78	0.97	2.83	1.38
Overall Change		-0.55		+0.53		-0.61	
Q23: Online lectures made mathematics concepts more clear	M	2.68	1.25	2.64	1.69	3.09	1.27
	F	2.60	1.10	3.33	1.32	2.89	1.37
Overall Change		-0.08		+0.69		-0.20	
Q24: POGIL	M	2.32	1.06	2.71	1.20	2.64	1.09
	F	2.30	0.98	2.33	1	2.94	1.26

activity concepts were difficult to grasp							
Overall Change		**-0.02**		**-0.38**		**+0.30**	
Q25: Online activity concepts were difficult to grasp	M	3.11	1.24	3.43	1.28	2.55	1.14
	F	3.00	1.49	2.78	0.67	2.94	1.26
Overall Change		**-0.11**		**-0.65**		**+0.39**	
Q26: I retained informat ion from Lecture Videos	M	2.95	0.91	3.00	1.30	3.00	0.88
	F	2.40	0.94	3.33	1.32	3.17	1.34
Overall Change		**-0.55**		**+0.33**		**+0.17**	
Q27: I retained informat ion using POGIL activities	M	3.53	0.96	3.21	1.12	3.18	0.91
	F	3.35	1.31	3.33	1.00	2.89	1.57
Overall Change		**-0.18**		**-0.12**		**-0.29**	
Q28: I feel I am learning from the POGIL activities .	S2	3.95	0.89	3.33	1.07	3.44	1.15
	S3	3.67	0.50	4.20	0.45	3.00	1.16
Overall Change		**-0.28**		**+0.87**		**-0.44**	

Appendix F.2 Numeric Summaries of Survey Questions Regarding the Use of POGIL Activities and Student Attitudes in Mathematics

Question:	n	Midterm Avg.	Midterm Std. Dev.	Final Avg.	Final Std. Dev.	Change	p-value
Q1: POGIL activities helped me to gain confidence doing mathematics	45	3.11	1.09	2.98	1.22	-0.133	0.382
Q2: I like coming to my "live" math class.	45	3.91	1	3.76	1.21	-0.156	0.368
Q3: I like mathematics.	45	3.02	1.36	2.89	1.34	-0.133	0.309
Q4: In general, I find math assignments very interesting	45	2.44	1.03	2.62	1.23	0.178	0.209
Q5: I am good at learning something new concepts in mathematics	45	2.82	1.05	2.67	1.04	-0.156	0.291
Q6: You have a certain amount of mathematical intelligence and there is no way to change this.	45	1.96	0.9	2.22	1.17	0.267	0.110
Q7: Taking math tests scare me.	45	3.96	1.19	4.16	0.95	0.200	0.173
Q8: I dread having to do math.	45	3.16	1.45	3.2	1.38	0.044	0.785
Q9: It is very important for me to get good grades in math.	45	4.33	0.83	4.33	0.77	0.000	1.000
Q10: In general, topics I learn in math are useful.	45	3.09	1.1	3.09	1.12	0.000	1.000
Q11: I am good at math.	45	2.82	1.11	2.71	1.14	-0.111	0.441
Q12: In general, I find math assignments very boring.	45	2.96	1.04	2.91	1.26	-0.044	0.767
Q13: When I am taking a math test, I usually feel anxious.	45	4.11	1.11	4.22	0.95	0.111	0.481
Q14: My goal is to learn as much as possible.	45	4.18	0.86	4.07	1.05	-0.111	0.481
Q15: My feelings towards math are changing.	45	2.73	0.96	2.84	1.07	0.111	0.514

Appendix F.3 Numeric Summaries of Survey Questions Regarding the Use of POGIL Activities and Student Engagement

Question:	n	Midterm Avg.	Midterm Std. Dev.	Final Avg.	Final Std. Dev.	Change	p-value
Q16: POGIL activities made me more willing to engage with my peers	45	3.73	0.96	3.73	1.14	0.000	1.000
Q17: When other students are distracting me in math class, I often find a way to keep concentrating on my work.	45	3.78	0.95	3.71	1.08	-0.067	0.673
Q18: When I finish my math work, I check it to make sure it's done correctly	45	3.67	1.04	3.6	1.1	-0.067	0.673
Q19: In general, I find math assignments very boring.	45	2.96	1.04	2.91	1.26	-0.044	0.824
Q20: I am willing to seek help when I need it.	45	4	1.15	3.82	1.05	-0.178	0.290

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