Sense of Belonging in Two First-Semester Calculus Pathways

Casey Griffin
University of Delaware

Retention in Science, Technology, Engineering, and Mathematics (STEM) continues to be a problem in the U.S. Prior research indicates that students leave STEM due to poor instruction and low sense of belonging in introductory STEM courses. Incorporating active learning into these courses, especially Calculus, has potential to support students in developing a greater sense of belonging and staying in STEM. This study investigates students' sense of belonging in two versions of introductory Calculus – a standard course and a non-standard course infused with active learning. Results indicate that students in the two courses recognized differential opportunities to engage in active learning. While there was no significant change in students' sense of belonging over the course of the semester in either course, students in the active learning course reported significantly higher sense of belonging than students in the standard course, both early in the semester and at the end of the semester.

Keywords: undergraduate calculus, active learning, sense of belonging

Problem

The U.S. has a retention problem in undergraduate STEM. Less than half of all STEM-intending students complete a STEM degree, and the students who leave STEM are disproportionately women and students of color (Chen et al., 2013; PCAST, 2012; Seymour & Hunter, 2019). To expand and diversify the pool of STEM graduates, the PCAST's 2012 report called for adoption of empirically validated teaching practices at the undergraduate level, especially in the first two years of STEM coursework. And yet almost 10 years later, we continue to lose students throughout the STEM pipeline.

Students who leave STEM often cite poor instruction in introductory STEM courses as a reason for leaving — citing Calculus in particular (Ellis et al., 2014; Seymour & Hunter, 2019). In fact, students are less tolerant of poor teaching now than they were 20 years ago (Seymour & Hewitt, 1997; Seymour & Hunter, 2019). Students reported "good teaching" as engaging and interactive and "bad teaching" as boring and non-interactive (Seymour & Hunter, 2019).

In addition to concerns about pedagogy, students who leave STEM also report a low sense of belonging in (Rainey et al., 2018; Seymour & Hunter, 2019; Shapiro & Sax, 2011). A student's sense of belonging is their "sense of being accepted, valued, included, and encouraged by others (teachers and peers) in the academic classroom setting and of feeling oneself to be an important part of the life and activity of the class" (Goodenow, 1993, p. 25). Students with low sense of belonging are more likely to leave STEM, and these students are disproportionately women and students of color (Rainey et al., 2018; Seymour & Hunter, 2019).

Calculus can be an especially critical leak in the STEM pipeline. It is required of most STEM majors, and is usually taken in students' first year. Thus, Calculus is often one of students' first experiences with undergraduate STEM coursework. In addition, it is often a prerequisite or corequisite for other STEM courses, and so students who perform poorly may be prevented from taking other courses in their major. Consequently, students' experiences in Calculus can be influential in their decision to persist in STEM (Ellis et al., 2014; Seymour & Hunter, 2019).

Relation to Literature and Conceptual Framework

This study investigates relationships between students' sense of belonging and opportunities to engage in active learning in Calculus. In this section, sense of belonging and active learning are defined and a theoretical argument linking active learning and students' sense of belonging is presented.

Students' Sense of Belonging

Sense of belonging refers to the level at which one feels connected to a particular environment, or feels accepted and appreciated by others in that environment (Rosenberg & McCullough, 1981). According to Strayhorn (2019), sense of belonging is a basic human need and other processes like listening to a lecture and studying for a test cannot be completed until the basic need is met. Thus, sense of belonging can influence how students interact in a classroom. This study adopts Goodenow's (1993) definition of sense of belonging as the "sense of being accepted, valued, included, and encouraged by others (teachers and peers) in the academic classroom setting and of feeling oneself to be an important part of the life and activity of the class" (p. 25).

Researchers have studied students' sense of belonging in math or STEM courses using a range of approaches. For example, Good et al. (2012) developed a Mathematical Sense of Belonging (MSoB) instrument to measure students' sense of belonging in mathematics. A factor analysis revealed five distinct factors contributing to one's sense of belonging: Acceptance (e.g., "I feel like I fit in"), Affect (e.g., "I feel calm"), Desire to Fade (e.g., "I wish I could fade into the background"), Trust (e.g., "I trust my instructors to be committed to helping me learn"), and Membership (e.g., "I feel that I belong to this class"). Rainey et al. (2018) conducted interviews with students to investigate their sense of belonging in STEM. Students' reasons for feeling they did or did not belong were categorized into four central themes: interpersonal relationships, science identity, personal interest, and competence. Lahdenperä et al. (2020) conducted a study in which students completed the MSoB survey and responded to two additional items asking about positive and negative factors contributing to their sense of belonging in math. Based on their analyses, Lahdenperä et al. expanded Rainey et al.'s framework, identifying learning environment as a distinct category influencing students' sense of belonging. Here, learning environment refers to "student perceptions of elements in the teaching practices, such as lectures and small group discussions" (p. 484).

Research indicates that students with a higher sense of belonging are more likely to persist in STEM, and that women and students of color are less likely to develop a strong sense of belonging in STEM than their white male classmates (Rainey et al., 2018; Seymour & Hunter, 2019; Shapiro & Sax, 2011). Good et al. administered their survey to students at a highly selective university and found sense of belonging in math to be a significant predictor of intent to study math in the future. Rainey et al. (2018) found students' sense of competence and ability to form interpersonal relationships to be most influential for students' decisions to persist in STEM.

Active Learning and Its Potential Connection to Sense of Belonging

Active learning can be broadly conceived of as any instruction that engages students in the learning process (Prince, 2004). More specifically, active learning can be defined as engaging students in "the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert" (Bonwell & Eison, 1991, p. iii). Examples of ways instructors can provide active learning opportunities are facilitating whole-class discussions, engaging students in group work, and using student response systems such as clicker polls. Research indicates that students who have opportunities to engage in active learning attain higher levels of achievement, self-efficacy, sense of mastery, and persistence than students who do not have such opportunities (Freeman et al., 2014; Lahdenperä, Postareff, & Rämö, 2017; Michael, 2006; Prince, 2004; Rasmussen et al., 2019; Salomone & Kling, 2017; Watkins & Mazur, 2013).

Instruction that incorporates active learning provides students with a more engaging and interactive learning experience and is linked to higher achievement and self-efficacy, supporting students' sense of competence. Instruction that incorporates active learning provides opportunities for students to interact with their instructors and/or classmates and thus supports students in forming interpersonal relationships. Thus, by bolstering students' sense of competence and ability to form interpersonal relationships, active learning has the potential to sustain or strengthen students' sense of belonging. Specifically, this study hypothesizes that having multiple opportunities to engage in active learning in Calculus will be linked with a greater sense of belonging.

This study examines students' sense of belonging in two versions of Calculus I offered at the same post-secondary institution. One version is a standard large-lecture Calculus course taught primarily by lecture; the other is a non-standard, integrated Calculus course taught using active learning instructional strategies. The purpose of this study is to better understand students' sense of belonging in Calculus, and how it may be related to opportunities to engage in active learning. Specifically, this study addresses the following research questions in the context of these two versions of Calculus: (1) How do students in each course characterize the instruction they experience? (2) To what extent does students' sense of belonging change over the course of a semester?, and (3) How does students' sense of belonging in the two courses compare?

Research Methodology

Setting and Participants

This study was conducted at a mid-sized R1 research university in the mid-Atlantic region of the U.S. during the Fall 2020 semester. The university offers two pathways for Calculus I. One is a standard one-semester Calculus course. Each semester, multiple sections of this course are offered, taught by a mix of permanent and temporary faculty. The course is coordinated in the sense that there is a common textbook (Stewart, Clegg, & Watson, 2021) and common exams. To enroll, students must earn a certain minimum score on the university's math placement test. Students in the course are typically freshmen intending to major in STEM. In the Fall 2020 semester, eight sections were offered, taught by four different instructors, with each section capped at 100 students. Typically, this course is taught in a large auditorium with lecture as the primary means of instruction. However, due to the COVID-19 pandemic, this course was taught in a synchronous virtual format over Zoom during the Fall 2020 semester. For the remainder of this paper, this course will be referred to as C-T.

The second pathway through Calculus I is a two-semester Integrated Precalculus and Calculus course designed to incorporate multiple opportunities for active learning. The first semester of the course, which is the focus of this study, develops differential Calculus, weaving in necessary pre-calculus topics as they arise. The second semester (which is not the focus of this study) develops integral Calculus, again weaving in necessary pre-calculus topics. Each semester, multiple sections of the course are offered, taught by permanent faculty. The course also uses the Stewart et al. textbook, as well as a second textbook designed specifically for integrating calculus and pre-calculus topics. The course is highly coordinated. In addition to common textbooks and exams, the instructors teach from common lesson plans specifying which problems students work on each class, and whether they will be discussed as a whole class or in small groups. To enroll, students must earn a certain minimum score on the math placement test; however, this minimum is lower than that required for C-T. Students are typically freshmen who need Calculus for their intended major but have not mastered all of the pre-calculus prerequisites. In the Fall 2020 semester, two sections were offered, taught by two different instructors, with each section capped at 50 students. Typically, this course is taught in a special classroom in which students sit at circular tables in groups to enable opportunities to work on math problems together during each class session. However, due to the COVID-19 pandemic, this course was taught in a synchronous virtual format over Zoom during the Fall 2020 semester. To maintain opportunities for group work, Zoom's breakout room functionality was used in most class meetings. For the remainder of this paper, this course will be referred to as C-A.

Participants were students enrolled in C-T or C-A in the Fall 2020 semester. Only one C-T instructor (who happens to use some active learning strategies in her lectures, especially student-response polls) was able to have students participate. All 198 students enrolled in her two sections of C-T and all 91 students enrolled in the two sections of C-A received an email inviting them to participate. All participants were asked to complete two surveys, one administered early in the semester and one near the end of the semester. For this study, only students who were freshmen and completed both surveys were considered, resulting in a final sample size of 114 C-T students and 69 C-A students. Table 1 provides the demographic background of the final set of participants. Most C-T students (~90%) reported they had taken Calculus in high school, whereas 60% of C-A students reported they had never taken Calculus before.

Table 1. Student demographics for C-T and C-A.

Characteristic	C-T		C-A	
	n	%	*n*	%
Gender				
Female	44	39	37	54
Male	70	61	31	45
Non-binary/Third Gender	0	0	1	1
Ethnicity				
Hispanic, Latinx, or Spanish	10	9	11	16
Not Hispanic, Latinx, or Spanish	93	82	54	78
Race				
White/Caucasian	79	69	57	83
Black or African American	6	5	8	12
Asian	18	16	5	7
American Indian or Alaskan Native	1	1	2	3
Middle Eastern	0	0	1	1
Other	5	4	2	3

Data Collection

Students from two sections of each course completed two surveys during the 14-week semester. The first survey took place in the third week of the semester, just after the drop/add deadline to attempt to avoid participant mortality. The second survey was distributed in the eleventh week of the semester. The two surveys were nearly identical. The first survey was designed to capture students' early sense of belonging, after just a few weeks of instruction. The second survey was designed to capture students' sense of belonging towards the end of the course, and to collect information about the instructional strategies they had experienced in the course.

The surveys were distributed and completed electronically using Qualtrics, a web-based survey tool. Good et al.'s (2012) MSoB instrument was incorporated into each survey. The MSoB portion consists of 30 Likert items, forming five factors that contribute to students' sense of belonging in a mathematics community. Additionally, students were asked to indicate how often they experienced each of eight instructional strategies, and to identify the three most frequently used strategies. The instructional strategies were chosen based on typical active learning instructional practices (e.g., group work), as well as strategies known to be used in at least one of C-T or C-A. See Table 2 for the full list of instructional strategies. In C-T, 80% (N=158) completed the first survey and 77% (N=153) completed the second survey. In C-A, 94% (N=86) and 88% (N=80) completed the first and second survey, respectively.

Data Analysis

To capture students' perceptions of the instructional strategies used in each course, frequencies were computed to determine the percentage of students who reported experiencing each strategy. These proportions were tested with a two-sample proportion z-test with $p<0.05$ to determine significant differences between strategies used in the two courses. Remaining analyses were conducted using IBM SPSS Statistics 27 software. Mean responses were calculated for overall sense of belonging and for each factor of the MSoB. Dependent samples t-tests were conducted to determine significant differences between responses on the first and second surveys; independent samples t-tests were used to determine differences in mean responses between C-T and C-A students with $p<0.05$. The effect size of each significant difference was calculated using Cohen's (1988) benchmarks for d (≤ 0.20 small effect, 0.50 medium effect, ≥ 0.80 large effect).

Results

Instruction

To determine how students perceived their Calculus instruction, students were presented with eight instructional strategies and asked to identify the three most frequently used. Table 2 presents the percent of students in each course who chose each strategy as frequently used.

Table 2. Percent of C-T and C-A students selecting each instructional strategy as one of the most frequently used.

	C-T	C-A	z	Cohen's d
Students work on math in groups	21%	97%	9.81***	1.84
Students work on math individually	87%	9%	-10.19***	1.79
Instructor asks for student responses	16%	80%	8.40***	1.39
Instructor lectures	86%	45%	-5.73***	0.9
Instructor encourages students to ask questions	45%	48%	0.24	0.06
Instructor encourages students to talk to each other	3%	14%	--	--
Students present their work to the class	4%	3%	--	--
Students answer in-class polls	25%	4%	--	--

Asterisks are used to denote the p-values (* for $p<0.05$, and *** for $p<0.001$ significance levels). Entries with "—" denote tests that could not be conducted due to a small sample size.

C-T students were significantly more likely to report lecture and working individually on math as the predominant strategies. In contrast, C-A students were significantly more likely to report working in groups and being asked to share their responses as the predominant instructional strategies. These data indicate that students perceived very different types of instruction in the two courses, with C-A students reporting more opportunities for active learning.

Sense of Belonging

Students' responses to the MSoB portion of the survey were used to measure their sense of belonging. Table 3a presents the mean scores on each survey for each course. There are two main results. First, there was no significant change in students' sense of belonging or its associated factors between the first and second survey for either course. Second, C-A students reported significantly higher sense of belonging than C-T students, both early in the semester and at the end of the semester, with medium effect sizes. Additionally, C-A students had significantly higher averages on each of the five factors associated with sense of belonging. Table 3b presents the results from the tests for significance and effect size.

Table 3a. Mean scores (and standard deviations) on the MSoB items for C-T and C-A.

	C- T Survey 1	C-T Survey 2	C-A Survey 1	C-A Survey 2
Sense of Belonging	5.95 (1.21)	5.95 (1.34)	6.72 (0.99)	6.86 (1.03)
Acceptance	6.19 (1.24)	6.18 (1.41)	6.96 (1.02)	7.10 (0.98)
Affect	5.75 (1.59)	5.76 (1.60)	6.34 (1.41)	6.53 (1.42)
Desire to Fade (-)	5.52 (1.74)	5.55 (1.66)	6.09 (1.31)	6.25 (1.50)
Trust	6.18 (1.45)	6.23 (1.52)	7.16 (0.98)	7.22 (0.99)
Membership	5.88 (1.64)	5.85 (1.62)	6.95 (1.15)	7.09 (1.12)

Table 2b. Dependent and independent T-test comparisons.

	Dependent Samples *t*-Test				Independent Samples *t*-Test			
	C-T		C-A		Survey 1		Survey 2	
	t(113)	Cohen's *d*	*t*(68)	Cohen's *d*	*t*(181)	Cohen's *d*	*t*(181)	Cohen's *d*
Sense of Belonging	0.08	0.01	2.13*	0.14	4.68***	0.71	5.17***	0.79
Acceptance	-0.09	-0.01	1.88	0.14	4.38***	0.67	5.20***	0.79
Affect	0.09	0.01	1.83	0.14	2.52*	0.39	3.30***	0.50
Desire to Fade (-)	0.26	0.02	1.41	0.11	2.52*	0.38	2.88*	0.44
Trust	0.49	0.04	0.55	0.06	5.45***	0.83	5.31***	0.81
Membership	-0.27	-0.02	1.05	0.12	5.20***	0.79	6.14***	0.94

Asterisks are used to denote the *p*-values (* for $p<0.05$, and *** for $p<0.001$ significance levels).

Discussion

This study examined students' sense of belonging in two different Calculus learning environments at the same institution. Results indicate that there were no significant changes in sense of belonging or its associated factors in either course. However, C-A students consistently reported a higher sense of belonging than C-T students, both early in the semester and at the end of the semester. Several hypotheses and areas for further investigation emerge from these results.

What factors might account for the higher sense of belonging in C-A students? Although the design of this study does not allow for causal claims, several hypotheses emerge. C-A students did report experiencing more frequent use of active learning strategies than the C-T students. Specifically, C-A students reported the two most common instructional strategies were working on math problems in groups and being asked by the instructor to share their thinking. Regular group work ensures students have opportunities to get to know one another and discuss their ideas, thus enabling them to form interpersonal relationships. Having opportunities to share their thinking with the instructor supports their ability to form a relationship with their instructor. Both instructional strategies have the potential to foster a safe learning environment in which students feel accepted and "belonging." In contrast, the two most common instructional strategies reported by C-T students were lecture and working on math individually, suggesting that students had fewer opportunities to form relationships with their peers and their instructor. The smaller class size in C-A may have further enabled students to form relationships with their instructor and their peers. Additionally, the fact that C-A incorporated prerequisite Pre-calculus topics and only covered differential Calculus may have contributed to a higher sense of competence in the C-A students. Further research is needed to tease out the differential effects of instructional and curricular features of the courses. However, the findings do align with Lahdenperä et al.'s (2020) argument that learning environments that enable social interaction support students' sense of belonging in the mathematical community.

The majority of C-T students reported having taken Calculus previously; the majority of C-A students reported never taking Calculus before. Given this, one might assume that C-T students would report a higher sense of competence, and thus sense of belonging in Calculus, than C-A students, at least early in the semester. Interestingly, the results indicate the opposite was true — C-T students reported significantly lower sense of belonging than C-A students, both early in the semester and at the end of the semester. Perhaps having taken Calculus before but needing to take it again in college had a negative impact on C-T students' sense of competence. Similarly, given that C-A students had placed into a "lower" version of Calculus, one might assume they would have a lower sense of belonging, at least early in the semester. Again, the opposite played out. Thus, the findings from this study highlight the importance of considering the learning environment when studying students' sense of belonging.

This paper presents results on all students who completed both surveys. Further research is needed to determine the differential impact of different instructional approaches, including active learning strategies, on women and students of color, as these students disproportionately leave STEM.

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