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Student-Faculty Connection and STEM identity in the Flipped Classroom

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Abstract

Students who arrive at college intending to major in a STEM discipline are often required to complete a college-level precalculus course, despite evidence that these courses are not always successful in preparing students for calculus. The implementation of evidence-based teaching strategies, such as the flipped classroom, provides an avenue for improving the effectiveness of precalculus. This quasi-experimental study explores the effect of a flipped precalculus classroom on students' degree of connection with their instructor and other students, together with their sense of motivation and enjoyment of mathematics, which we treat as an indicator of a developing STEM identity. Validated survey inventories are used to investigate differences in these affective outcomes between three sections of precalculus, two taught using flipped instruction and a control section in which the instructor delivers traditional lectures. The flipped students report significantly greater interactions with their instructor and peers, but indicate that they feel less connected with their instructor. Attitudes towards mathematics are found to decrease slightly through the semester in both instructional approaches.

Keywords: Flipped instruction, precalculus, undergraduate mathematics, student identity, student-faculty connection

Introduction

The traditional image of a college mathematics classroom involves an instructor at the front of the room delivering course content and offering insights, while students passively take notes, perhaps asking an occasional question. Students are then expected to explore and apply the ideas outside of class. The flipped classroom aims to reverse this paradigm, shifting content delivery out of the classroom and creating space during class for students to engage in more cognitively demanding tasks with the support of the instructor and their peers [1], [2]. The college-level precalculus course serves as an important early gateway to a range of STEM majors, and yet is "notoriously ineffective" at preparing students for calculus [3]. Innovative teaching methods, like flipped learning, may be especially beneficial for student success at such a key moment in the curriculum.

Previous studies of flipped learning in introductory-level mathematics classes below calculus - especially college algebra and precalculus - paint a mixed picture of their effectiveness in improving students' affective outcomes and content knowledge [4]. Studies generally report improvements in content knowledge compared to more traditional lecture courses [5], [6], although some observe no statistically significant difference between the two instructional approaches [7]. The effects of flipped learning on student affect are also mixed. Zack et al. studied flipped and lecture courses in a variety of freshmen-level mathematics classes, finding that many students disliked the flipped structure, and their attitudes towards mathematics tended to become more negative compared to the lecture course [7]. In contrast, others found that attitudes towards mathematics improved relative to the lecture course [5], [6]. These disparities are perhaps not surprising, given the variety of ways in which the flipped classroom can be implemented, the different constructs used to measure student affect, and the small sample size of many of these studies. In a national study of calculus students, Sonnert et al. found that “ambitious pedagogy” - which would include flipped learning - leads to a small decrease in attitudes towards mathematics [8].

The flipped classroom naturally creates opportunities for increased interactions, both amongst students, and between the students and instructor. Such interactions can have significant positive benefits for students. Kuh and Hu observed that frequent student-faculty interactions that have “an intellectual or substantive focus” are strongly correlated with student satisfaction and improved learning outcomes [9]. Early experiences that create opportunities for interaction between and among students - including living-learning communities, freshman seminars and study abroad programs - have lasting effects which include improved resilience and retention [10], [11]. Lundberg and Schreiner found that the quality of student-faculty interaction predicts learning outcomes more reliably than a student’s background, and that the effect may be especially powerful for students from under-represented groups [12].

The importance of the relationships between students and faculty in the classroom is further highlighted by Jensen et al., who found that students in both traditional and flipped classes preferred in-class activities over out-of-class activities [13]. That is, students demonstrated a strong preference for the tasks undertaken in the presence of their peers and instructor, rather than a preference for a specific type of task, even when those tasks were switched in the flipped paradigm. Furthermore, Komarraju et al. find that students’ feeling of being respected by their professor has a positive impact on their self-confidence and motivation [14]. Regular student-student interaction in the classroom can also help students become more connected to the college community, which is associated with multiple positive outcomes [11]. The lasting effects of focused and frequent student-faculty and student-student interactions suggest that the benefits of the flipped classroom extend beyond improved content knowledge in a particular course.

Student and faculty connections and interaction are also central to students’ development of a STEM identity. The model of science identity developed by Carlone & Johnson contains three elements: identifying, and being recognized by others, as a “science person”; a sense of scientific competence; and the public performance of one’s science identity [15]. Hazari et al. added a fourth component: interest in one’s chosen scientific discipline [16]. All of these elements are likely influenced by substantive interactions with faculty and like-minded students. Evidence suggests that STEM identity is correlated with persistence and success in STEM disciplines, and a students’ development of a STEM identity is likely encouraged by meaningful relationships with STEM faculty and students with similar interests [17], [18].

This paper investigates students’ experiences in a flipped precalculus course, in contrast to the experiences of those in a more traditional lecture course. Our fundamental research questions are, firstly, does the flipped classroom increase students’ perceptions of their connection with faculty and other students, compared to the traditionally taught course? And secondly, does flipped pedagogy result in an increase in STEM identity for these students? In an attempt to answer these questions we use survey instruments to compare the flipped and lecture students' perceived connection to their instructor, interactions with the instructor and their peers, as well as the enjoyment of mathematics as an indicator of a developing STEM identity.

Method

This study used a quasi-experimental design in which students self-selected into one of three precalculus sections in a single semester, with no advance information about the teaching approach to be used in each section. The same instructor taught all three sections, with one taught in a traditional "interactive lecture" format, while the other two sections were flipped. Each section began with 21 enrolled students, and met three times a week for 50 minutes during the semester. All students completed a weekly quiz over the previous week's material, three mid-semester tests and a final comprehensive exam; tests and quizzes were essentially identical between the three sections. Students in the lecture section were assigned online homework through WeBWorK [19], and the first 5-10 minutes of each class was spent addressing students' questions on the homework. The instructor then lectured on new material while encouraging student interaction, and provided occasional opportunities for students to apply ideas.

The two flipped sections shared a common structure, which was developed in light of the evidence-based design principles for flipped mathematics courses presented by Lo, Hew & Chen [4]. The instructor created a total of 31 video lectures which were posted on YouTube and accessed through the Learning Management System (LMS). The mean length of the videos was 16 and a half minutes, with a standard deviation of almost 3 minutes; the shortest video was 10 minutes, the longest a little over 23 minutes. Before each class students were expected to watch the day's video, take notes, complete one or two exercises that provided immediate application of the ideas from the video, and then answer a brief pre-class quiz. The quiz was designed to encourage students to reflect on the videos, make connections with previous knowledge, and share points of confusion. During the first 10-15 minutes of the flipped classes the instructor reviewed the pre-class homework and addressed issues raised in the pre-class quiz, together with any other questions. The remainder of the 50 minutes was devoted to group work on more challenging problems.

The online videos had significant overlap with the in-class lectures, although the lecture class received many more examples worked by the instructor at the board. These additional examples formed the basis of the in-class activities in the flipped sections, which were worked by students in groups of three or four. While the mathematical material was as close as possible between the two approaches, the ownership of mathematical ideas differed. The lecture section was largely focused on the instructor as expert, while the flipped classes were encouraged to take ownership and engage in mathematical sense-making with guidance from the instructor as needed.

Connection between students and faculty was measured using the validated, six-item "student perception of student-faculty relationship" (CON) subscale developed by Micari & Pazos [20]; see Table 1. Students completed the survey in the last week of the course, indicating agreement with the individual items on a five-point Likert scale, from "strongly disagree" to "strongly agree". Micari & Pazos found high reliability between subscale items, with a Cronbach alpha of 0.92. Interaction between student and professor, and between students, was also measured by asking students to directly compare their interactions in precalculus with interactions in their other classes [20]. Students rated their agreement with the following statements: "I discussed course material with MY PROFESSOR IN THIS CLASS more than with my professors in other classes" (INTERACT_PROF) and "I discussed course material with OTHER STUDENTS IN THIS CLASS more than with the students in my other classes" (INTERACT_STUDENT). Agreement was indicated on a five-point Likert scale from "strongly disagree" to "strongly agree". No validation was performed on these two items.

To investigate STEM identity among freshmen we follow Trujillo & Tanner and focus on interest in STEM, which is likely the primary component of STEM identity during its early development [21]. Interest was evaluated using students' self-reported motivation and enjoyment in completing mathematical activities. The motivation and enjoyment subscales of the validated Attitudes Towards Mathematics Inventory (ATMI) contain multiple questions related to student interest, including "the challenge of mathematics appeals to me", "mathematics is a very interesting subject" and "I really like mathematics" [22]. We implemented the shortened version of this instrument (sATMI) developed by Lim & Chapman, who used factor analysis to demonstrate that the motivation and enjoyment subscales in the ATMI are highly correlated [23].

The validated sATMI uses five items from the full enjoyment subscale of the ATMI to measure both enjoyment of, and motivation for, mathematical tasks. We expect this subscale to be closely correlated with interest in mathematics. We investigated changes in students' motivation and enjoyment of mathematics as an indicator of developing STEM identity using a pre-post application of the enjoyment (ENJ) subscale of the sATMI in both flipped and lecture classes. Students indicated their level of agreement with each of the five statements (see Table 2) on a five-point Likert scale, from "strongly disagree" to "strongly agree". A similar selection of items from the ATMI were used by Zack et al., although they did not use the full subscale [7].

Results

All three course sections consisted of 21 students at the end of the first week of classes. Only those students who answered all survey items and provided their informed consent are included in this analysis, resulting in 15 students in the lecture section and a combined 33 students in the two flipped sections. Since the classroom intervention applied in flipped classes was consistent between the two sections, we group those students together in our analysis.

Wilcoxon Rank Sums and various t-tests were applied to these data. The Wilcoxon Rank Sum test was applied to individual instrument items and t-tests were applied to totals across subscales, consistent with the recommendations of Lovelace et al. [24]. For the ENJ items of the sATMI survey data, where there is a pre and post measurement, the data were treated as matched pairs and the analysis was performed on the pre-post differences. Then either a Wilcoxon or t-test was applied, depending on whether the measurement was a single item or a subscale mean. We deem differences to be significant at the 0.05 level.

The SAT Mathematics subscore was used to compare the control (lecture) and intervention (flipped)

Item	Survey statement	Lecture	Flipped	Δ
CON1	My professor is the kind of professional I would like to emulate, regardless of the career I end up pursuing.	4.27	3.79	−0.48
CON2	I feel comfortable asking my professor questions in class.	4.27	4.21	−0.06
CON3	In general, my professor respects the academic abilities of the students in the class.	4.47	4.36	−0.11
CON4	I see my professor as a role model	4.13	3.58	−0.55
CON5	I feel comfortable going to my professor's office hours	4.13	3.79	−0.34
CON6	My professor respects me as a person.	4.40	4.55	+0.15
CON	Subscale mean	4.28	4.05	−0.23

Table 1: Item descriptions and means for the connecting with the professor (CON) subscale [20], with $n = 15$ for the lecture (control) and $n = 33$ for flipped (intervention). Δ is the change from control to intervention.

groups. ACT Mathematics and Pre-2016 SAT Mathematics subscores were converted to their equivalent post-2016 SAT Mathematics subscores using the College Board's concordance tables. When multiple scores were available, the maximum was used. The mean SAT for the control group was 558.1 with standard deviation 52.6, while the intervention group had mean 560.9 with standard deviation 67.6. The differences in both mean (t-test; $p = 0.875$) and variance (f-test; $p = 0.301$) are not statistically significant. The pre application of the ENJ subscale provides further insight, with mean 3.39 in the lecture section and 3.26 in the flipped section. These differences are also not statistically significant ($p = 0.601$). The gender make-up of the groups does differ. The control group is 47% female, the intervention group is 76% female, while the university's overall student population is 63% female. The consistency of the SAT and ENJ pre tests between groups provides evidence that the two groups of students initially have similar academic and attitudinal profiles.

The flipped class reported spending more time interacting with the professor and other students than in their other classes, with a mean response of 3.85 for INTERACT_PROF and 4.33 for INTERACT_STUDENTS, compared to 3.40 and 2.87, respectively, in the lecture class. These data support the hypotheses that meaningful interactions with faculty and other students were more frequent in the flipped classes than the lecture class; $p = 0.055$ for interaction with professor and $p < 0.001$ for interactions with other students.

Consistent with Micari and Pazos [20], we find that the six items in the CON subscale demonstrate a high reliability coefficient, with Cronbach alpha 0.86 for all students, indicating that the six Likert items measure a related construct. The CON subscale shows the flipped students reporting a lower perceived degree of connection with the professor than the lecture students. The lecture students CON subscale mean was 4.28 with standard deviation 0.569, while the flipped

Item	Survey statement	Lecture			Flipped		
		Pre	Post	Δ_L	Pre	Post	Δ_F
ENJ2	I have usually enjoyed studying mathematics in school	3.33	3.40	+0.07	3.52	3.42	−0.09
ENJ4	I like to solve new problems in mathematics	3.73	3.67	−0.07	3.30	3.30	+0.00
ENJ6	I really like mathematics	3.53	3.20	−0.33	3.39	3.12	−0.27
ENJ7	I am happier in a mathematics class than in any other class	2.73	2.47	−0.27	2.64	2.39	−0.24
ENJ8	Mathematics is a very interesting subject	3.60	3.53	−0.07	3.45	3.39	−0.06
ENJ	Subscale Mean	3.39	3.25	−0.13	3.26	3.13	−0.13

Table 2: ENJ subscale items and means with $n = 15$ for the lecture and $n = 33$ for flipped. Survey item labels correspond to ATMI items [22], and Δ_L, Δ_F are the pre-post change for the control and intervention groups.

mean was 4.05 with standard deviation 0.578. The differences are not statistically significant. Two of the six individual items in the connection scale showed significant differences at the 0.05 level, CON1 ($p = 0.050$) and CON4 ($p = 0.046$).

Table 2 shows the mean values of the five items of the ENJ subscale from pre and post surveys, together with the total subscale ENJ, obtained by taking the mean of each students' responses to the five items. The subscale shows a high degree of reliability with a Cronbach alpha of 0.89 for both pre and post items. Most of the individual ENJ items decreased pre to post, but the only significant change was ENJ6 in the flipped class, with $p = 0.033$. The corresponding pre-post change for ENJ6 in the lecture class was not significant at the 0.05 level, with $p = 0.072$.

The mean of the total enjoyment subscale (ENJ) for the pre survey in the lecture class was 3.39, with standard deviation 0.75, and 3.26 with standard deviation 0.81 for the flipped sections. The differences are not significant ($p = 0.601$ for mean). There is a reduction in the mean of ENJ of 0.13 for both the flipped and lecture classes from pre to post, but neither change is statistically significant ($p = 0.082$ flipped, $p = 0.284$ lecture). The difference between the means of ENJ on the post surveys, 3.25 with standard deviation 0.81 for lecture and 3.13 with standard deviation 0.75 for flipped, are also not significant ($p = 0.617$).

Discussion

In comparison to the lecture section, students in the flipped sections were significantly more likely to agree that they interacted with both the professor and other students more than in their other classes. This was especially true for interaction with other students. This finding is consistent with our expectations for the flipped classroom, the benefits of which are likely due to the time spent engaging actively with the course material in conjunction with the instructor and other students [4].

Students in the flipped sections reported lower feelings of connection with the professor (CON subscale) than lecture students, despite the fact that the flipped students interacted more frequently with the professor. Although the overall subscale differences were not significant, two of the six items were, and all but one of the individual items showed a lower degree of connection for the flipped sections. The items that were significantly lower in the flipped sections were "my professor is the kind of professional I would like to emulate, regardless of the career I end up pursuing" and "I see my professor as a role model".

These results are interesting in light of the instructor's perception of a greater sense of connection with students in the flipped sections. The comparative lack of connection reported by the flipped students may be influenced by the types of student-faculty interaction in the two pedagogies. The frequent and direct student-faculty interactions in the flipped section may allow students to form a more complete picture of the professor, not simply seeing their instructor as a somewhat removed expert at the front of the room. By acting as a "guide on the side", the professor inhabits the stereotypical role of "expert" far less than freshmen students may expect, leading to a reduction in their view of the instructor as a professional role model. This interpretation is consistent with the only statement that was agreed with more strongly in the flipped section (although not at the level of significance): "my professor respects me as a person" (CON6).

The reduced connection indicated by the flipped students may also be related to the greater discomfort they experience, compared to the lecture class, due to the regular challenges of active learning, and the more explicit expectation that students take ownership of their own understanding. Students are likely to enjoy the experience less in the moment, and assign part of the blame for their discomfort to the instructor. This is a common experience in active learning courses, although the time spend struggling with ideas in collaboration with peers and the instructor has both immediate and long term benefits [25]. Sonnert et al. observed that "ambitious pedagogy" correlates with decreases in attitudes towards mathematics [8], and this may lead to a corresponding decrease in attitudes towards the instructor.

We found that students' assessment of their enjoyment of mathematics was only slightly better than neutral at the beginning of the semester, and decreased by a small amount for both the control (lecture) and intervention (flipped) groups. Most of the observed changes were not significant. The only significant reduction was in the flipped classes' agreement with the statement "I really like mathematics". Although this may suggest a more substantial reduction in attitudes in the flipped class, we are unable to conclude that there is a meaningful overall difference between pedagogies. The general trend of reduction across almost all attitudinal items in both implementations suggests that any effect is due to the course, rather than a particular teaching strategy. The largest reductions in attitudes towards mathematics in both the control and intervention sections occurred in response to the items "I really like mathematics" and "I am happier in a mathematics class than any other class", which are perhaps particularly focused on the current classroom experience, rather than the past ("I have usually enjoyed studying mathematics in school") or more abstract statements ("Mathematics is a very interesting subject" and "I like to solve new problems in mathematics").

While we are unable to draw conclusions regarding the effect of flipped learning on students' STEM identity, our results suggest that the precalculus course itself leads to an overall reduction in mathematical enjoyment and motivation, which may be associated with a corresponding threat to students' STEM identity. This may be particularly impactful for freshmen students, although we expect it to be more impactful for students who intend to major in STEM disciplines that are heavily dependent on mathematics.

Conclusion

This study provides support for the hypothesis that students in a flipped precalculus class experience greater interaction with both the professor and other students than students in a lecture course. While these interactions may be supportive of students' developing STEM identity, the relatively lower degree of connection with the instructor reported in the flipped classes raises questions about the nature of student-faculty interactions in a flipped classroom that merit further study. The overall reduction in student enjoyment of mathematics through the semester, which appears to be related to precalculus rather than pedagogy, is also concerning. While consistent with other findings [3], [8], these concerns encourage us to continue to explore ways to help students effectively prepare for calculus.

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