Fostering Success in Introductory Calculus through Peer-Led Team Learning (PLTL)

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Introduction

As the analytical foundation of engineering, Calculus 1 is a key building block of the first-year engineering curriculum. It is also, unfortunately, a stumbling block for many students for a variety of reasons: weak preparation in high school math courses; lack of self-confidence; and difficulty building a new peer study/support group in the new college environment, among others [1,2]. D or F grades in calculus can be a significant barrier to progression in an engineering curriculum [1,3]. Interventions in Calculus 1 that foster both better course mastery and improved habits and connections to resources that support STEM success more broadly thus have the potential to significantly improve retention and success in engineering programs.

The NSF-sponsored Urban STEM Collaboratory project, a joint initiative at three partner urban universities (Indiana University-Purdue University Indianapolis (IUPUI), University of Memphis, and University of Colorado Denver), provides scholarship support and interventions for academic success and retention to students with demonstrated financial need majoring in engineering, math, and computer science. All three campuses employ a cohort model and provide targeted support in Calculus, community-building summer bridge activities prior to the start of the first semester, and additional opportunities during the academic year to strengthen peer connections within the cohort. At IUPUI, we adapted the Peer-Led Team Learning (PLTL) model that has long been successfully implemented in introductory Chemistry, and more recently in sophomore-level engineering classes, and piloted PLTL recitation sections of Calculus 1 specifically for our Urban STEM scholars.

Peer-Led Team Learning differs from other recitation section models in several key factors. The section is led by Peer Mentors rather than by an instructor or TA, with a ratio of about 10 students per Peer Mentor. Peer Mentors are students who successfully completed the class recently (typically within the last 1-3 semesters). Rather than demonstrating how to solve problems while students passively watch, the mentors engage students in active team-based problem-solving activities – typically a mix of foundational and more challenging problems – and offer hints and guidance on approaches rather than direct solutions. Peer Mentors receive training in how to guide students through the problem-solving process and help them self-discover the approachess that work best for them. It has been shown to improve grades and decrease DFW rates in large introductory Chemistry classes [4, 5]. Perhaps more importantly, these gains persist even among students who are less quantitatively prepared than their peers [6] as well as among students from underrepresented groups [7].

Project Approach

Recruiting Students to Each Cohort

For the Urban STEM program at IUPUI, two cohorts of freshman-level students (Fall 2019, Fall 2020) were recruited. Due to the focus on PLTL in Calculus 1 as a primary academic intervention, selected students needed to be ready to enter Calculus 1 in their first semester of the

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program. We recruited these students both from incoming direct admit calculus-ready first-time engineering freshmen and from continuing, calculus-ready pre-engineering, pre-mathematics, and pre-computer science students in University College (UC). Engineering-interested pre-majors at IUPUI are most frequently admitted to UC because they do not meet the direct admission criterion of Calculus 1 readiness. We were particularly interested to include UC students in these cohorts both because these students on average tend to be more ethnically diverse and to show higher financial need compared to direct admits; and because the additional support in Calculus 1 through PLTL could be particularly impactful for students who entered college with weaker mathematics backgrounds. In addition to readiness for Calculus 1, students recruited to each cohort needed to demonstrate financial need as determined by the Free Application for Federal Student Aid (FAFSA); other selection criteria are described in [8]. We aimed for cohorts of 25 with diversity of sex, ethnicity, first-time freshmen vs continuing students, and status as a first-generation student. Our first cohort (entering Fall 2019) met these targets; but due to impacts of COVID, our second cohort (entering Fall 2020) ended up being both smaller and less diverse, with a much smaller proportion of UC students [8].

Incorporating Peer-Led Team Learning in Calculus 1 Recitations

MATH 16500 Analytical Geometry & Calculus 1, the introductory calculus course required for Engineering, Computer Science, and Mathematics students, includes an optional recitation component. Standard recitations meet weekly for 75 minutes and build on material from the lectures with a combination of group activities (in about 1/3 of the weekly sessions) and working problems from the current chapter in a more traditional recitation style led by the TA for the other 2/3 of sessions. In the PLTL sections, the standard chapter problems were replaced with small-group problem-solving and analysis activities prompting students to consider problems in non-routine ways – such as considering both functional and graphical approaches or considering the effect of parameter changes in the limit – with the goal of stimulating thoughtful discussion and development of deeper insights among group members.

Comparison Groups

In Fall 2019 and Fall 2020, two recitation sections were designated for special populations. The Urban STEM cohort were assigned to a special recitation section that included PLTL. These students also participated together in their own section of the First Year Seminar (FYS), a course supporting student success in the transition to college and providing additional opportunities for community-building. Thus, the Urban STEM cohort functioned as a learning community (LC) by taking these two courses together as a small cohort. A second recitation section was reserved for students participating (by self-selection) in the Success in Engineering LC. These students also participated together in their own FYS section, but their math recitation followed the structure of the standard recitation sections without PLTL. We compare student outcomes among four separate groups of students in this Calculus 1 class: Urban STEM students in the PLTL section ("PLTL"); students in the Success in Engineering learning community ("other LC"); students in a regular recitation section that was not part of one of these two special communities ("other recitation"); and those not enrolled in a recitation ("no recitation").

Results and Discussion

Enrollment and DFW rates by section type

Table 1 shows enrollments in each section type in both 2019 and 2020, broken down according to sex and ethnicity. In 2019 the PLTL section had a more even distribution by sex compared to the course overall and compared to the other section types, while in 2020 the percentage of women in the PLTL section (20.0%) was just under the course overall (22.7%) but higher than the other recitations. Because the Urban STEM cohort included only students with demonstrated financial need based on FAFSA, international students (Intr) were not eligible to join this cohort. In Fall 2019, the PLTL section was more ethnically diverse than the overall course, which in turn was more diverse than the other recitation sections. The Fall 2020 Urban STEM cohort was much less ethnically diverse, but still exceeded the other recitation sections in representation of Black/African American students and those of 2 or more races. Neither the PLTL section nor the other LC included any students identifying as Hispanic/Latino in Fall 2020, although they were well-represented in the other recitation sections.

Table 1. Fall enrollment in each section type by sex and ethnicity in 2019 and 2020.

Semester	Sex/Ethnicity[1]	PLTL	Other LC	Other recitation	No recitation	Course total
Fall 2019	**Section total**	N=25	N=25	N=81	N=249	N=380
	F	32.0%	12.0%	27.2%	24.1%	24.5%
	M	68.0%	88.0%	72.8%	75.9%	75.5%
	As	16.0%	0	4.9%	9.2%	8.2%
	B/AA	12.0%	4.0%	2.5%	6.8%	6.1%
	Hisp/Lat	24.0%	4.0%	7.4%	10.8%	10.5%
	Intr	0	0	0	10.8%	7.1%
	2 or more	0	4.0%	4.9%	4.4%	4.2%
	Wh	48.0%	88.0%	80.2%	57.4%	63.7%
Fall 2020	**Section total**	N=20	N=23	N=50	N=303	N=396
	F	20.0%	4.4%	18.0%	25.1%	22.7%
	M	80.0%	95.6%	82.0%	74.9%	77.3%
	As	5.0%	8.7%	10.0%	8.9%	8.8%
	B/AA	5.0%	0	4.0%	7.9%	6.8%
	Hisp/Lat	0	0	16.0%	10.2%	9.8%
	Intr	0	4.3%	4.0%	10.2%	8.6%
	2 or more	15.0%	0	6.0%	5.9%	6.1%
	Wh	75.0%	87.0%	60.0%	56.4%	59.6%

[1]F=Female; M=Male; As=Asian; B/AA=Black/African American; Hisp/Lat=Hispanic/Latino; Intr=International; 2 or more=2 or more races; Wh=White.

In Fall 2019 (green bars, Figure 1), the Urban STEM PLTL section performed significantly better than any other section type, including the other learning community, with a DFW rate of

0% – that is, every student in the PLTL section passed Calculus 1 with a grade of C- or higher. Students in other recitation sections (with or without learning community) fared better than students not enrolled in a recitation section, with DFW rates of 20.0% in the other learning community and 21.0% in other recitations, compared to 33.3% in students not participating in recitations.

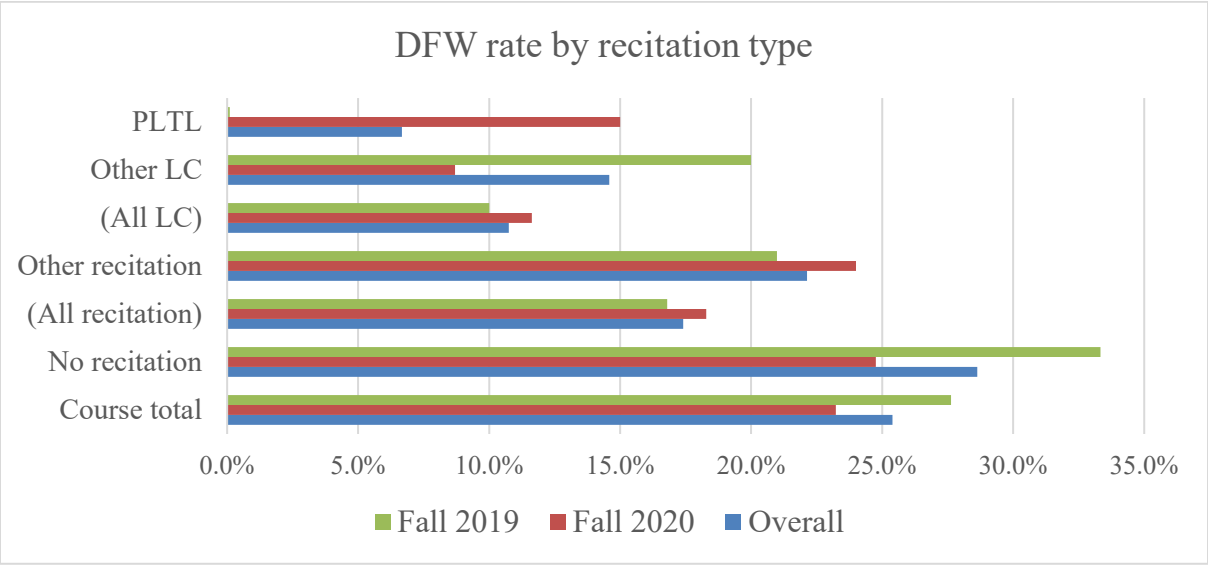

Figure 1. DFW rate by recitation section type and year.

In Fall 2020, pandemic-induced social distancing requirements limited in-person lecture attendance to one-third of enrolled students each day, with the rest joining via Zoom. Recitation sections were held in large rooms to ensure a six-foot distance was maintained between students, making it difficult to engage in group problem-solving and community building. In acknowledgment of these and other pandemic-related challenges, instructors were strongly encouraged to extend grace to students needing extra time to complete assignments. This grace was likely a major contributing factor to the overall lower course DFW rate (23.2%) in Fall 2020 (red bars, Figure 1) compared to previous semesters. Participation in a LC-linked recitation (PLTL or other LC) was associated with a lower DFW rate (11.6%) compared to other sections. However, the PLTL section (DFW rate of 15.0%) fared worse than the other LC (8.7%). Interestingly, there was not a substantial difference (Figure 1) between DFW rates in non-LC recitation sections (24.0%) and sections with no recitation (24.8%) in the pandemic semester.

Combining data across both semesters (blue bars, Figure 1), participation in the PLTL sections resulted in the overall lowest DFW rate (6.7%) followed by the other LC-related recitation (14.6%). Participation in regular recitations was also associated with a lower DFW rate (22.1%) than not participating in any recitation (28.6%).

Comparing PLTL to other Learning Community-linked Recitations

Overall, participation in a recitation linked to a LC was associated with lower DFW rates. To consider how PLTL may contribute to student success beyond simply the community-building

aspect of a LC, we look more closely at individual course grades between the PLTL section and the recitation linked to the other LC, including an analysis of DFW rates by sex and ethnicity.

Remarkably, for the PLTL sections there were no F grades in either semester. In Fall 2020 the PLTL DFW rate of 15.0% comprised two D grades and one W. In contrast, the other LC-linked recitation section had one D grade (4.0%), three F grades (12.0%), and one W (4.0%) in Fall 2019. Like the PLTL section, the other LC had two D grades in Fall 2020 (8.7%) but no F or W grades. The course overall had 7.1% D, 12.9% F, and 7.6% W grades in Fall 2019; and 6.1% D, 12.7% F, and 4.5% W grades in Fall 2020.

Furthermore, despite a population that was overall more diverse in terms of both sex and ethnicity than the other LC, all students with D, F, or W grades in the PLTL sections were White and male. Put another way, underrepresented students made up a significant proportion of the students involved in the PLTL sections, and all of them passed Calculus 1 with grades of C- or higher despite demonstrated financial need. In the other LC, the student who withdrew in Fall 2019 was a white female, and all other students receiving D or F grades were white males; however those sections contained only three women and three (male) ethnically underrepresented students in Fall 2019 and only one woman and no ethnically underrepresented students in Fall 2020, and students were not required to show financial need.

Further supporting this premise that PLTL reduces equity gaps, DFW rates by sex and by ethnicity for non-LC recitation sections, sections with no recitation, and the course overall (Figure 2) show markedly higher DFW rates for female and non-white students compared to the PLTL section, which had a 0% DFW rate across all these categories. Notably, DFW rates for Black/African American (B/AA) students hover around 50% in non-LC sections regardless of whether these students participate in a recitation or not. Hispanic/Latino (Hisp/Lat) students, in contrast, fare better in sections with a recitation (average DFW of 14.3% across both years) compared to sections without a recitation (average of 34.5% across both years).

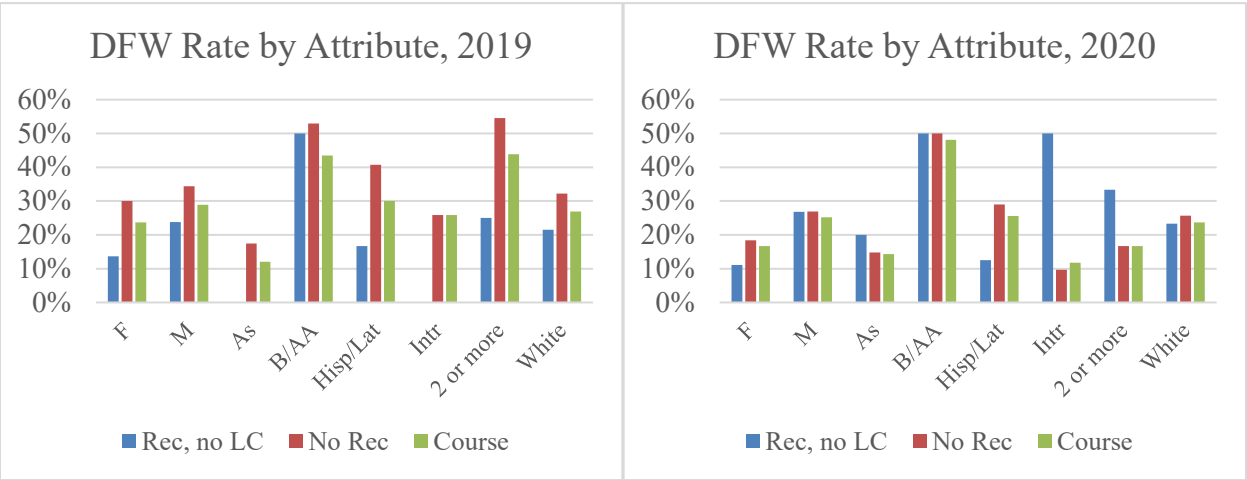

Figure 2. DFW rates by sex and ethnicity for non-LC recitation sections, sections with no recitation ("No Rec"), and the course overall. No international students (Intr) enrolled in a

recitation in 2019. Both LC recitation sections had DFW rates of 0% in all non-white ethnicities, and the PLTL section also had a DFW rate of 0% among female students.

Given the effectiveness of both PLTL and the non-PLTL LC in reducing DFW rates, helping students build community seems to be a major factor in their success. PLTL adds an extra dimension of community-building in the context of regular team-based mathematical problem solving that also supports deeper engagement with course content. The course instructor observed that the 2019 cohort of PLTL students, compared to others in the class, more proactively formed calculus study groups with each other. The challenges of the pandemic in 2020 reduced opportunities for in-person community building; the 2020 cohort of PLTL students did not gel as effectively as the 2019 cohort, likely a factor in the increase in DFW rates in the PLTL section that semester.

Our results suggest that PLTL in Calculus 1 strongly supports student success, with particularly strong gains for students typically underrepresented in engineering. While the focus on developing problem-solving skills and engagement with course content is important, intentional community-building to foster peer connections that lead to mutual academic support appears to be a crucial aspect of these gains. Thus, linking PLTL to a LC or incorporating intentional community-building directly into early PLTL sessons will help maximize achievement gains.

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