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Shifting Pre-Calculus from a Gatekeeper to a Gateway Course

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Abstract

The national need to transform STEM education is paramount, as evidenced by the persistent gap in STEM degree attainment between whites and minorities, which continues to be a wide chasm in spite of greater numbers of minority students entering into STEM studies as compared to ten years ago. This gap may be attributed in part to the systemic problem of a growing number of minority undergraduate students who are unable to continue their STEM studies because of their inability to pass pre-calculus, the gateway to calculus, which is a requirement for all STEM majors. This paper presents preliminary findings from a project funded by the U.S. Department of Education to increase the number and proportion of Latinx, particularly Latinas, who successfully complete pre-calculus and persist to completion of a STEM degree. The focus of this project is a 5-hour, pre-calculus course at a public, 4-year institution, consisting of four hours of classroom lecture and two hours of workshop facilitated by learning assistants (LAs). To increase the success rate of students in pre-calculus, the project aims to create theory-informed communities of learners that promote active, collaborative learning using evidence-based practices, such as cooperative learning and the use of metacognitive strategies. Extant research suggests LAs can be instrumental in fostering student learning, especially when they have a basic understanding of a sociocultural theory of learning. In this project, the LAs undergo an intense professional development workshop to understand cooperative learning and the importance of social settings to promote learning. The LAs are supported throughout the semester with the assistance of a faculty member who is certified in cooperative learning methods. When communities of learners are developed, students become producers and disseminators of knowledge rather than solely consumers of knowledge.

Background

A 2016 Harvard Business School report found a faltering United States economy and a need for reform [1]. One principal reason for this faltering economy is the United States' inability to develop qualified science and engineering (S&E) human capital, in particular women and minorities. However, diversity in the S&E workforce has not improved over the last decade [2]; and, given Hispanics aged 21 years and older represent 15% of the U.S. population, a mere 6% of the S&E workforce are Hispanic [2].

The Bureau of Labor Statistics has projected that total employment in S&E jobs will increase at a faster rate (1.1% compound annual growth rate) from 2016 to 2026 than employment in all occupations (0.7%) [3]. Equal representation of women and minorities in the workforce is desired for a society whose demographic profile leans towards people of color. "Organizations with homogeneous workforce are unlikely to operate effectively in an environment that is constantly changing and diverse" [2]. Thus, U.S. universities and colleges have potential to promote a heterogeneous STEM workforce by supporting the persistence and graduation rates of students from underrepresented groups. This can be accomplished in part by focusing on a gateway course to a STEM degree: pre-calculus.

Cooper and Woodward [4] identify this two course as gatekeeper, as it is the first college-level courses in mathematics after possible completion of one or more developmental courses. Colleges around the country have attempted a variety of approaches to support students in matriculating to higher level mathematical courses. These include the use of problem-based learning in pre-calculus [5, 6]; creation of communities of learners [7, 8]; and integration of peer leaders [9, 10, 11] and graduate teaching assistants (TAs) [12]. These studies have had mixed results. Several studies found that cooperative learning coupled with problem-based learning promoted positive attitudes towards learning along with significant improvement in grades and retention [8, 13]. Studies integrating undergraduate peer leaders to support learners did not statistically find a significant increase in student performance [10]; however, statistical significance was demonstrated when the peer leaders were graduate Teaching Assistants (TAs) [12]. These studies suggest that developing a community of learners with expert tutors (e.g., graduate-level TAs) improves student outcomes in STEM. Thus, this study focused on increasing the capacity of graduate-level TAs, as well as advanced undergraduate TAs, to foster student learning through the development of math learning communities in pre-calculus.

Theoretical Framework

The conceptual framework framing this project is a sociocultural theory of learning, which posits learning as a social and cultural phenomenon rather than strictly an individual phenomenon that takes place within a learner's mind. Grounded in the work of Russian psychologists and philosophers Lev Vygotsky, Alexander Luria, and Alexie Leont'ev [14, 15, 16], a sociocultural approach focuses on social interaction, authentic engagement, and the learning environment. Each of these scholars theorized human learning and behavior resulted from the mediation of cultural artifacts, activities, and concepts [16, 17, 18]. Vygotsky hypothesized that learners internalized the societal tools of activities, then externalized them to create new tools for the realization of a goal [15, 17, 19]. He further posited that learners have the ability to utilize a tool or assistance from someone more expert to perform a more difficult activity then they could do alone, and thus improve their cognitive skills. Vygotsky coined this as the Zone of Proximal Development, or ZPD (see Figure 1) [17, 18, 24].

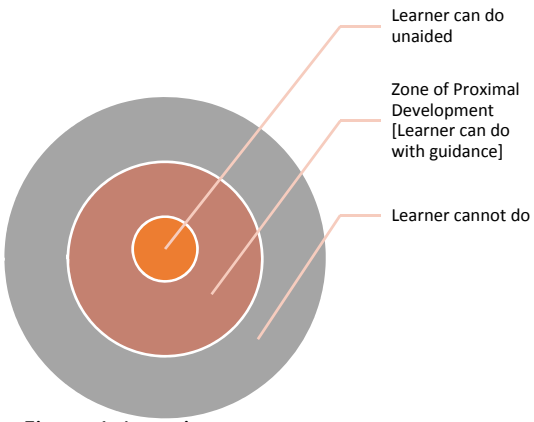

Figure 1. Learning zones

The principal characteristics of a sociocultural model include: the importance of authentic activities to promote learning; the importance of the collaborative construction of knowledge; the need for coaching and scaffolding at critical moments; and the importance of reflection to encourage metacognition [20, 21]. Thus, the intervention under study focused on the development of learning communities through the practice of cooperative learning. This serves to promote social interaction and authentic engagement, which in turn fosters student learning.

Studies have found that learning communities and cooperative learning support academic success [21, 22], especially for students from minority

backgrounds [23]. While the range and type of learning communities may vary [24, 25], most learning communities embody several vital characteristics, including the use of smaller groups among faculty and students; the bringing together of faculty and students in more meaningful ways; curriculum integration; emphasis on the development of academic and social support networks; and a focus on learning outcomes [26]. Learning communities help foster increased student engagement, defined by Astin [27] as "the amount of physical and psychological energy that the student devotes to the academic experience" (p. 518).

Description of Intervention

This project builds on a previous grant-funded project aimed at small cohorts of entering engineering and computer science students enrolled in an introductory course into these disciplines. Informed by the same theoretical framework as previously described, the project goal was to build communities of learners who could support each other beyond the introductory course. Evaluators, who are the same evaluators for the current project, continue to track these cohorts of undergraduate students beyond the intervention semester, and is finding them passing in higher rates and with higher grades during their subsequent semester in Calculus I, as compared to non-intervention students. This finding was statistically significant (p=093). Based on what was learned, the current project was designed to scale what was learned in the previous study with an aim of increasing programmatic impact.

Approximately 40% of students enrolling as STEM majors are required to take pre-calculus, as determined by placement tests. Thus, pre-calculus serves as the gateway to calculus, which is a requirement for STEM majors. As such, the study focused on an intervention designed to increase the success rate of STEM majors through development of theory-informed learning communities in the required 2-hour pre-calculus workshops. Specifically, for the first year of intervention, the number of participants was 1,015 followed by the spring semester with 317 (Note: several sections of pre-calculus are online or held in the evenings; these sections do not require workshop.)

The pre-calculus course sections are each accompanied by a 2-hour workshop with four hours of lecture. The workshop consists of 45-90 students, and led by 3-5 graduate and advanced undergraduates. The purpose of each workshop is to provide pre-calculus students with reinforcement of key concepts.

Qualitative baseline data was collected prior to the study intervention to understand the landscape of the workshop prior to the implementation of the intervention and to also assist with the intervention design (see the Methods and Data Sources section for details). While students were told they could work together, students worked individually or in student-initiated small groups throughout the entire class period to complete worksheets. The workshop itself was loosely structured: in some cases, TAs circulated the room seeing if students needed assistanc. In most instances, TAs tended to wait for students to approach them for assistance. One key feature of some sections of the workshop was the use of translanguaging practices, where students and/or TAs moved between Spanish and English to ask questions and provide explanations.

During Year Two of the project, the project leadership designed the intervention to create a more social environment with TAs purposefully creating groups of 3-4 students with specific instructions, informed by cooperative learning principles [28] and sociocultural learning theory. To learn these principles, the TAs attended a 4-hour professional development (PD) workshop that incorporated modeling of cooperative learning principles and strategies and a module on cooperative learning that includes face-to-face promotive action, individual accountability, social skills, and positive interdependence. In addition to cooperative learning, other key features of the PD were introductions to learning theory as a sociocultural phenomenon and practices of inclusion. A module on inclusionary practices was introduced to sensitize the TAs to how these practices could be deployed. Sample videos of students engaged in the pre-calculus workshops were shown with prompts for the TAs to decide the kinds of interventions that could be made to promote more inclusion. For example, a group of five students tends to have at least one student who might be left out. TAs could then shift group sizes to groups of three or four. Weekly meetings with the pre-calculus coordinator and education faculty are held throughout each semester with TAs to reinforce the use of cooperative learning strategies through the co-design of activities for the following week. TAs are reminded that these strategies serve to build communities of learners who will support each other throughout the current semester into the following semesters as they matriculate through their coursework.

The intent of the PD is for the TAs to transition into LAs, who are facilitators of student-centered knowledge construction rather than transmitters of knowledge. Additionally, education researchers in collaboration with the project team developed a training toolkit to assist LAs in further developing an understanding of how best to integrate active learning methods.

Research Context

The site of this study is a 4-year, public institution on the U.S. Mexico border with a majority Hispanic population. More than 80% of students enrolled at the university are Hispanic/Latinx, and more than 50% are first-generation college students. The project represents a partnership between education researchers located in the education college and math faculty in the mathematics department, with a focus on improving outcomes in pre-calculus at the university. Based on institutional data, approximately 2,000 students each year are enrolled in pre-calculus at the university, of whom, on average, 35% fail and 10% drop out before completion. When compared to the Progress through Calculus project, the average DFW rate at the study institution is slightly higher than Progress through Calculus, which found 236 institutions reporting a DFW rate of approximately 27% [28]. However, another project, The Common Vision project, reported up to 50% of students in college algebra earned a D, F or W [29]. Thus, the DFW for this institution is comparable to the national percentages reported by the studies mentioned above.

The primary focus of the study was to understand how and to what extent theory-informed learning communities impacted student learning. As such, the intervention focused on teaching assistants (TAs) who could become more effective and transition into Learning Assistants (LAs).

Methods and Data Sources

Qualitative and quantitative methods were employed to understand the effectiveness of the intervention. Of the 140 students surveyed in Year 1 to gather baseline data, 109 (78%) identified as Hispanic/Latino. Twenty-eight (20%) identified Spanish as their primary language; 60 (43%) identified English as their primary language; and 51 (36%) identified both Spanish and English as their primary languages. The top two intended majors were engineering/math (38.5%) and the health professions (38.5%).

The research team chose a qualitative approach because it is a naturalistic, process-oriented way [30] to understand student/TA perspectives and existing teaching/learning practices in the pre-calculus workshops. Data collection is led by a team of four education faculty members and two education doctoral students.

The project includes multiple data Ssources, including:

(a) **Participant observation** – During 2016-2017, the research team conducted more than 45 hours of participant observation in the five sections of the pre-calculus workshop. Members of the research team wrote field notes using an observation protocol focusing on the interactional patterns, tools, and teaching/learning practices in the workshop.
(b) **Focus groups** – In spring 2017, the research team conducted two focus groups: one with pre-calculus TAs and one with representatives from the math department (faculty and pre-calculus program coordinator). The focus groups lasted one hour and involved questions about the logistics and content of pre-calculus workshops from the perspectives of TAs and the math department.
(c) **Questionnaires** – In spring 2017, the research team disseminated questionnaires to pre-calculus students participating in five sections of the workshop. The short questionnaire, which was in English and Spanish, included background questions about the student's ethnicity, primary language, and math level prior to college; Likert-scale questions focused on the perceived utility of workshops; and open-ended questions asking for students' views on the workshop. A total of 140 responses were collected.

Qualitative data continues to be collected and is currently being analyzed to understand how and to what extent learning communities are created, and external evaluators are analyzing institutional research data each semester. The qualitative focus group data and observation data were initially coded using a thematic approach, where primary and secondary themes were identified. Thematic coding was also used to analyze the open-ended responses on the questionnaires regarding student views on the workshop [31]. Preliminary findings are presented in the next section.

Preliminary Findings

A tenet of sociocultural theory is the mediation of tools, such as practice problems and online homework programs, encompassed within the social influences of a community [14, 15, 17]. Thus, the first year of intervention (or Year 2 of the project) revealed an increase in social interactions between the LAs and the students, allowing students to become part of the cultural context of other more knowledgeable learners, LAs. Although delivery of the course was in English, LAs were able to develop a space where learning could occur in Spanish as well. One particular aspect of the workshop is the use of trans-languaging practices where students and/or

teaching assistants moved between Spanish and English to discuss problem solutions and explanations. Evidence of learning communities is emerging as a result of the extended use of collaborative learning practices.

Science and engineering majors who were enrolled in the pre-calculus workshops achieved higher overall grades than their peers who did not attend a section with a workshop. Workshop students' mean grades were 2.68 on a 4-point scale while their peers with no workshop averaged 2.00 ($p = 0.000$). An independent sample t-test revealed the pre-calculus grades following the pedagogical training of TAs for workshops were higher, and that this difference was statistically significant at the 0.05 alpha level ($p=0.018$). See Table 1 for details.

Table 1. Statistical data of pre- and post-intervention.

Condition	Mean of precalculus grade	Std. Deviation	Std. Error Mean
Before pedagogical training (n=2,331)	2.5410	1.37962	.02858
After pedagogical training (n=859)	2.6647	1.28531	.04385

Similarly, the DFW rate, or the proportion of students who enrolled in the course and subsequently withdrew, earned a D, or failed the course, improved from a rate of 28% to a rate of 23%. This difference was also statistically significant, as measured by Chi Square analyses $X2 (1, N = 3477) = 8.488, p < .05$) In other words, more students successfully completed the course following the adjustment to TA workshops via pedagogical training.

Limitations

The pre-calculus course offered at this university is a coordinated course; and, as such, all departmental exams are written by the coordinator. Any differences in the exam from one semester to the other could have an adverse or advantageous effect on passing rates. Further, the LAs are assigned to different workshops; and, thus, may have variability in how effective the strategies are deployed, which may affect how well students engage socially and culturally. Although other variables may have affected the passing rates, the authors of this study are confident that the analysis of subsequent semester data will support the findings of this study.

Conclusion

Moving pre-calculus from a gatekeeper to a gateway course has implications for broad program impact in achieving equity in the workforce and has significant impact for increased throughput to graduation of STEM majors, especially Hispanic women and English Learners (ELs). The

project has potential impact beyond the institution should other institutions choose to adopt this approach to develop learning communities to support students in their trajectory toward a STEM degree.

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