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Analyzing the effects of a flipped classroom pedagogy on freshmen and sophomore STEM courses

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***Abstract*— This Research-to-Practice paper, a work-in-progress, describes work supported by the First in the World program at three different universities in California. A consortium of three California State Universities (CSUs)— San José State University, California State University- Los Angeles, and Cal Poly Pomona -- have a four-year grant from the U.S Department of Education First-in-the-World (FITW) program. Surveys of students revealed that a major challenge to success is course bottlenecks – impasses where they cannot enroll in a course they need to make progress toward their degrees or when they cannot successfully complete a course and move forward. All three campuses have large numbers of high-need and under-represented students (URM) and URM students are over-represented among students who receive low grades in bottleneck courses. To address course bottlenecks, the flipped classroom approach has been implemented in seven gateway STEM courses collaboratively across the partner campuses. This paper targets faculty and administrators interested in promoting and implementing the flipped classroom pedagogy at their institutions. It provides a brief overview of the target courses and the impact of the curricular changes thus far. In addition, a description of the in-depth Calculus study of the flipped classroom approach across the three campuses is discussed.**

Keywords— underrepresented students, active learning, flipped classroom

I. Introduction

This paper reports on a collaborative project of three California State University (CSU) campuses—San José State University (SJSU), California State University- Los Angeles (CSULA), and Cal Poly Pomona (CPP)—to improve the retention rates and success of students in gateway STEM courses. The CSU is the largest and most diverse university systems in the country. This project builds upon the collaborative environment in the CSU by engaging faculty from three different campuses in a rigorous collaboration and evaluation of pedagogy in STEM education. This project incorporates a flipped classroom approach in high-failure undergraduate gateway STEM courses at these three CSUs and evaluates if the teaching style is effective at decreasing failure rates of students.

San José State University, located in San José, California, is the oldest campus in the CSU system. The university offers bachelors and masters degrees in 134 areas of study and two doctorates to more than 32,000 undergraduate and graduate students in seven colleges. The Davidson College of Engineering and College of Science prepare students for graduate training and a global and Silicon Valley workforce.

CSULA in Los Angeles, California was founded in 1947 and focuses on providing excellent education to its eight colleges. CSULA has one of the most diverse student populations of any college or university in the nation. Building on this diversity, CSULA graduates constitute a major leadership force in Los Angeles.

CPP, located in Pomona, California is one of only seven polytechnic universities in the nation; its College of Engineering graduates 1 of every 14 engineers in the state. Enrolling 24,000 students, the university's focus on "learn by doing" is evident in curricular designs that blend theory and practice. Students are afforded multiple opportunities to collaborate with faculty on research projects.

There are many commonalities among our three institutions. All three are designated Hispanic-serving institutions (HSI) and Asian American Native American Pacific Islander serving institutions (AANAPISI). At each institution, many students are first generation, under-represented minorities (URM) and/or low income. 64% of SJSU students, 80.8% of CSULA students, and 66% of CPP students qualify for some kind of financial aid (loans, grants, scholarship, etc.) and 38% of SJSU students, 75% of CSULA students, and 44% of CPP students receive Pell grants. Figure 1 summarizes the undergraduate student ethnicity as of Fall 2014 for STEM majors in our three universities.

This project targets undergraduate gateway STEM courses with high failure rates. Recent reports highlight the need for curricular reforms that promote problem solving, collaboration, and "deep learning" [1]. Active learning approaches have proven to be especially crucial for learning experiences of high-needs students [2]. High-need students are those at risk of educational failure or otherwise in need of special assistance and support, such as adult learners, working students, part-time students, students from low-income backgrounds, students of color, first-generation students, students with disabilities, and students who are English learners [3]. The vast majority of students at SJSU, CSULA, and CPP fall into one or more of these categories. This project utilized the definition of active learning proposed by Freeman et al. [4], "Active learning engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert." Active learning increases academic self-confidence, motivation to persist in

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academic pathways, motivation to complete one's academic study, and likelihood of pursuing advanced study [5]. Significant research shows student learning can be improved when instructors move from a teacher-centered approach to a student-centered, interactive approach [6].

	SJSU		CSULA		CPP	
	HC	**%Total**	**HC**	**%Total**	**HC**	**%Total**
AmInd	4	0.1%	16	.4%	17	0.2%
Black	111	2.6%	149	3.4%	275	2.9%
Asian	1,715	40.3%	828	18.6%	2,428	25.9%
Pac Isl	33	0.1%	7	.1%	21	0.2%
Hispanic	837	19.6%	2,526	56.9%	3,261	34.8%
White	901	21.1%	374	8.4%	2,136	22.8%
Foreign	309	7.3%	297	6.7%	444	4.7%
Other	350	8.2%	246	5.5%	802	8.5%
Total	**4,260**		**4,443**		**9,149**	

Figure 1. Demographic information for SJSU, CSULA, and CPP shows that all three universities have large minority populations

This project focuses on one active learning technique, the flipped classroom. In a flipped classroom, the standard teacher-centered lecture is replaced with a student-focused approach that involves strategies implemented outside the classroom [7]. Students use online resources to learn the material before class, allowing them to learn at their own pace and be better prepared for in-class work [8]. Classroom time is reserved for active learning including problem-based learning and practice activities [9]. Although the flipped classroom has been implemented in different ways, the idea is to move a student's acquisition of basic knowledge out of the classroom and use class time for higher-level activities that build upon basic knowledge [10]. This approach is shown to have a positive effect on student learning outcomes, especially in regards to STEM courses, which are rated as some of the most challenging and alienating university classes [11].

This project implements the flipped classroom across STEM courses at three large CSUs. The project builds upon extensive cross-field research, proven models for increasing student engagement and participation in STEM courses, and assesses the effectiveness of these strategies. In addition to the curricular development, the project investigates the use of Faculty Learning Communities to support faculty in curricular development and build a culture of change to expand the use of active learning strategies in STEM classes.

II. Faculty Learning Communities

Wright and Sunal [12] found that a key factor in educational innovation is for faculty to be willing participants in innovations. Despite being subject experts, few university faculty have formal training in pedagogy [13]. Several recent reports [14] highlight the need for curricular reforms to provide undergraduate education that engages both students and instructors in activities that promote problem solving, collaboration, and "deep learning" [15].

Guiding principles for faculty development are based upon the social-cognition model and supported by the science of learning perspective as described in several National Research Council publications, including *How People Learn: Brain, Mind, Experience, and School* [16]. The curricular revision in this project linked faculty across the three CSU campuses in order to generate new thinking about models of instruction [17]. In Year 1, core faculty responsible for converting the targeted courses and project leadership from all three campuses attended an intensive three-day workshop. During the workshop, core faculty met with the PI and the campus leads to clarify the project goals, timelines, and responsibilities for their course redesign.

Each campus has a Faculty Learning Community (FLC) to facilitate collaboration on this project. In addition, cross-campus disciplinary FLCs were developed so faculty in each discipline could collaborate. FLCs provide an arena in which colleagues have the time and opportunities to reflect on their teaching, their discipline, their institution, and themselves. FLCs inspire faculty to think beyond their discipline and into the realm of intellectual and interpersonal connections [18]. These FLCs are aligned with the project's social-cognition theory of change; FLCs foster constructive interactions and allow faculty to explore their mental models about teaching. According to Senge [19], an individual's mental models or cognitive frameworks shape and frame behavior and "limit us to familiar ways of thinking and acting." The FLCs were designed to foster faculty leadership and empower faculty to be change agents in their departments, at their institutions, and among STEM faculty across the CSU [20]. Each campus has a FLC coordinator to facilitate FLC activities. Faculty on each campus meet face-to-face and digitally to discuss progress in their curricular development, explore new ideas, and increase knowledge of active learning. The design of this project facilitates cross-institutional collaboration and development of both discipline-focused and campus-centered FLCs.

Coordinated FLC activities have included collaborative sessions where faculty learn about new developments in flipped learning, reflect on their current flipping challenges, provide feedback to colleagues on flipped materials, and engage in development of tools that support flipping efforts. Participants in these activities may be all grant faculty across the campuses, grant faculty on only one campus, or discipline faculty across the campuses. Activities that require coordination across the campuses are handled through a variety of online tools. Project faculty communicate in their discipline-focused FLCs through phone calls, email, video conferences, message boards, and chat rooms. The types of communication tools used for each disciplinary FLC have varied; what are consistent across all disciplinary FLCs are regular communication and a sense of community among the members. FLC activities and sessions remain appropriately fluid in response to faculty needs.

III. Flipped Classroom Curriculum Development

Courses for this project were chosen based on high levels of students who received grades lower than a "C" as of Fall

2014. Research at SJSU has [21] showed that students who received a grade below a C in a freshmen or sophomore STEM class rarely passed the subsequent class in the sequence. In addition, it is well established that many engineering students, for example, are "lost" before engineering faculty interact with them because they become discouraged in preparatory courses [22]. This project targeted freshmen and sophomore gateway STEM courses.

Curricular development for this project was phased in over three years. In Year 1 (2016-2017), faculty from the three CSUs implemented the flipped classroom approach in two classes: Calculus I and General Physics I. In Year 2 (2017-2018), Computer Science I and Introduction to Circuits were flipped. In Year 3 (2018-2019), the flipped classroom will be implemented in three final courses: General Physics II, Discrete Math, and Statics.

Calculus I and General (Calculus-based) Physics I were chosen as the first courses to be flipped because of the literature from CSU and other institutions on flipping these courses. General Physics I was identified by the CSU as one of the CSU's 22 high demand-low success courses [23]. In the CSU, 1/5 of the students in the 22 high demand-low success courses received grades lower than a C. In response, the CSU created a Physics eAcademy focused on teaching Physics in a flipped classroom model [24]. This initiative served as a foundation for development of General Physics I in FITW.

In 1998, Richard Hake collected data on 2,084 students from 14 introductory physics courses taught by traditional instruction methods and compared these results to classes using active learning for 4,458 students in 48 courses [25]. His research showed an increase in learning nearly two standard deviations higher when using interactive engagement methods. Hake's research is supported by research by ENGAGE that shows that faculty-student interactions increase student retention rates in STEM courses [26].

Calculus I was chosen as a first-year course for the grant because of promising literature that suggests flipping Calculus can lead to increased student learning gains. According to the College Board [27], Calculus is an impediment to student success in STEM careers. In Fall 2010, 325,000 students enrolled nationwide in a university Calculus I course; of this number, 27% received a D or F or withdrew. The numbers of students unsuccessful in Calculus I at some project campuses is higher than the nationwide numbers. Since Calculus I is often the first mathematics class for STEM students, this course was deemed very important to serve as a foundation for student retention and success in subsequent courses.

IV. Results of the Flipped Classroom Project

Preliminary results presented here are not evaluated based on any demographic, student preparedness, or student performance outside of the given class. Such detailed analyses are reserved for the in-depth Calculus study and presentation/publication by the faculty teaching the course. Results from the first term of Year 1 courses (Calculus I and Physics I) were presented at the 2017 ASEE Annual Conference and Exposition [28].

In an additional term of Calculus I and Physics I at CSULA, results continued to show positive impact of using the flipped model. Calculus I was taught in 16 sections (size range: 17-26), with one section being in the flipped model (size: 23). A comparison of grades showed that 65.2% of students in the flipped section received a passing grade of "C" or better, as compared to only 62.9% of students in the traditional section. The GPA of the class in the flipped section was 2.23, compared to the other sections with GPAs ranging from 1.33-3.0. Students in the flipped class did achieve a grade of "C-" or better at a far greater percentage than students in the traditional classes (78.3% versus 64.4%). Physics I at CSULA had similar positive results across four Physics I sections (Size Range: 26-72), with one section using the flipped model (Size: 49). In the flipped section, 93.9% of students received a grade of "C" or better as compared to 76% in the traditional sections. The GPA for the flipped section was 2.93, the highest among all sections (GPA Range: 1.98-2.93; 1.98-2.54 for traditional sections).

Initial preliminary results for Year 2 courses reflect the first semester of instruction in Fall 2017 using the flipped classroom approach. Introduction to Circuits courses across the three campuses have historically had among the highest failure rates. While content in Circuits is similar across campuses, variation in other structural changes in the courses and class size make cross-campus comparisons difficult. Introduction to Programming has even greater variation across the campuses, including programming language used, departmental ownership of the courses, class size, and term offerings. In addition to the change in pedagogy to the flipped classroom, CSULA transitioned from a quarter system to a semester system during the evaluation semester, which could have an influence on flipping a course for both the instructors and students. Data collection will continue in Spring 2018 and after to enable greater inference on the effectiveness of the flipped classroom in all courses across all project campuses.

Results show that flipping the classroom generally has a positive impact on passing rates when comparing similar classes. All sections of Circuits at SJSU had a significant number of structural and curricular changes in addition to utilizing the flipped classroom and other active learning pedagogy. Results show that those structural changes, combined with the curricular changes, saw nearly 10% more students receiving A's or B's when compared to sections of similar size in previous semesters taught by the same instructors. At CSULA, two flipped sections were offered in Fall 2017, though they varied considerably in size (Sizes: 35 and 83), making evaluation challenging. In order to evaluate the effect of the flipped classroom, three sections of similar size (Size: 28-35) taught by the same instructor in a previous semester were compared to the smaller flipped section in Fall 2017. When comparing the Circuits sections of similar size, the flipped section shows positive results, with a higher percentage of students passing the course (62.9% versus 60.5%) and having higher achievement at all grade levels (A-B-C). Circuits at CPP was taught in four

sections (Size: 29-32), with one using flipped classroom pedagogy. The flipped classroom resulted in 11.3% more students passing the course with a C or better and no students receiving an F or withdrawing from the course.

Introduction to Programming varies in content, the department in which the course is housed, and the grading structure on the three campuses; this contributes to challenges in evaluating the effectiveness of the flipped approach. Introduction to Programming (CS 46A) at SJSU is housed in the Computer Science Department. The course was taught in the flipped classroom pedagogy only in Summer 2017, with a second offering planned for Summer 2018. Results between the Summer 2017 offering and an academic year offering by a different instructor show that the flipped classroom section was less successful than the academic year section despite being smaller (Size: 25 compared to 80). Only 64% of students received a C or better in the summer flipped section, compared to 70% in the traditional academic year section. Grant personnel are awating additional data from a second summer session, as well as evaluating potential variables that may have contributed to the lower results, including faculty evaluations and student preparedness for the course.

Introduction to Programming (EE 2450) is housed in the Electrical Engineering department at CSULA. CSULA has a large number of students, approximately 20-30%, who take the course as Credit/No Credit, which does not enable a strong comparison to the other campuses nor does it enable a full evaulation of student success because lower grades are not reported. The course was taught with three sections using traditional instruction (Size: 22-26) and one section using the flipped classroom (Size: 30). Initial results for the flipped section show reduced success in the course (70% versus 77.5%). A large number of students received a grade of "No Credit" (NC) in the flipped section (N = 9), which was relatively high when compared to the students who received "NC" other sections (N = 3, 5, and 6).

Introduction to Programming at CPP is taught in two different departments: the Computer Science Department (CS 141) and the Electrical and Computer Engineering department (ECE 114). In Fall 2017, three sections of CS 141 were offered, two using traditional pedagogy (Size: 34-36) and one with the flipped classroom (Size: 37). Students were significantly more successful in the flipped section, with 94.6% of students passing the course with a C or better compared to 84.1% in the traditional sections. Students also had higher achievement in the flipped section, with over 51% receiving a grade of "A/A-" compared to only 29% in the traditional sections. In Fall 2017, five sections of ECE 114 were offered, with one section taught with the flipped classroom. The traditional class sections ranged in size from 14 to 27, while the flipped classroom was 26. While students passed the course in similar percentages in both the traditional and flipped sections (95.7% versus 96.2%), nearly 12% more students earned an A or a B in the flipped section.

V. Calculus Impact Study

The external evaluator for this project is conducting a summative evaluation of the flipped classroom model. Calculus I is the focus of the summative evaluation because it will have benefitted from two years of development. The evaluation will specifically address: Does being in a class using the flipped model improve student outcomes in calculus? What implementation factors moderate the effectiveness of the flipped approach? Here "effectiveness" is measured by student performance outcomes in calculus, both in terms of grades and a study-specific pre- and post-test.

The design is a randomized controlled trial. Participating instructors agree that their course sections will be randomly assigned, each semester, to use instruction as they normally would teach (control condition) or use a flipped approach (treatment condition). Instructors teaching a control section can do whatever they normally would, but not to use "flipped" techniques. For treatment sections, instructors use flipping in the class. Instructors can elect to participate by teaching one or two sections. Instructors who agree to teach two sections of the course agree that they will teach one section as control and one as treatment. They track their activities in a journal so that their work can be reviewed by the evaluator who can then consider any overlapping that may have occurred.

Ideally, instructors participate for 2 academic terms (Spring 2018 and Fall 2018 for SJSU and CSULA). Since CPP is converting from a quarter structure to a semester structure in Fall 2018, the Calculus study for CPP will be Fall 2018 and Spring 2019. Campus FLC coordinators will work with a local campus Calculus 1 faculty leader to offer eight hours of "Do the Flip!" training for calculus instructors. The time was spread across several meetings in Fall 2017 for those who began to flip classes in Spring 2018. There will be another workshop in summer 2018 for those calculus instructors who will be new to flipping in Fall 2018.

VI. Conclusions

The three universities have worked collaboratively to improve instruction methods used in seven gateway STEM courses identified to have high failure rates across the campuses. The flipped classroom model is being phased in over three years on the campuses through collaborative efforts by faculty to develop materials to support knowledge acquisition outside of class time and engage students in higher-order applications such as problem solving and peer instruction during class time. Results show increased pass rates for students in most flipped classroom sections when compared to sections taught with traditional methods. The final draft of this paper will include preliminary results on the multi-campus Calculus study.

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