This paper articulates a particular model of flipped classroom implementation in large undergraduate calculus courses. It examines the impact of the model on students’ experience and learning. Our initial findings indicate that students can be sceptical about the pedagogy when first exposed to it; however when the instructor stays committed to the method, their students’ view turned much more positive at semester end. While implementation fidelity matters, we also argue for the importance of instructors’ judgement of effectiveness and sensitivity to context. Our results of the impact on learning achievement are mixed at the current stage of our experiment. Our goal is to systematically explore, test, and adjust our model over time so that it would have wide appeal and applicability beyond our classrooms and institution.

INTRODUCTION

The idea of the flipped classroom is to use technology to shift lectures outside the classroom, reserving class time for homework, practice with concepts and other learning activities (Strayer, 2007). Despite a great deal of media attention to the flipped classroom in recent years, research regarding the specifics of this pedagogical approach is only beginning to be published (Davies, Dean, & Ball, 2013). In particular, much of the research to date focuses on showing that the method has worked (Crouch & Mazur, 2001; Lage, Platt, & Treglia, 2010). In contrast, this paper describes a particular model of flipped classroom implementation and investigates the specific ways in which it has or has not worked for students in order to determine how the model can be improved so that sustained pedagogical changes can be brought to these and other large introductory courses covering different subject matters at our and other institutions.

We studied three first-year calculus courses conducted by experienced senior mathematics instructors. These were: Calculus I (C-I) and Calculus II (C-II) taught by one instructor, and Calculus I with Review (C-I-R) by another, with class sizes of 346, 246, and 224 students respectively. C-I was conducted as part of the second round of implementation in fall 2013, while the other two courses were part of the first round in fall 2012. C-I-R is designed for students with no previous calculus experience. C-I, covering exactly the same content as C-I-R, is for students who took
calculus in high school. C-II takes in the students who succeeded C-I-R or C-I. These courses work together to serve the requirements of various Science and Applied Science majors.

THEORETICAL FRAMEWORK

Although flipped (or inverted) classroom pedagogy is not a recent invention, it has become increasingly popular over the past few years as a blended learning approach, supported by consumer video technologies and motivated in part by efforts to improve STEM education (Berrett, 2012; Davies, Dean & Ball, 2013).

Applications of the flipped classroom idea are differentiated by how they deliver lectures outside the classroom, and how learning activities are designed and executed inside the classroom. Our approach is informed by research on STEM education using active learning, peer instruction and just-in-time teaching (Crouch & Mazur, 2001; Hake, 1998; Simkins & Maier, 2010). Hake’s investigation (1998) on using Socratic method and interactive engagement to replace conventional lecture classes is one of the most influential studies in physics education. Hake's findings, based on Force Concept Inventory (FCI) performance data from over six thousand students in high schools and colleges across the United States, are extraordinary. They show that learning gain is independent of the pre-test score on FCI, and largely independent of instructor and text. It is, however, strongly dependent on the instructional methods used. Classes that used interactive engagement show learning gain more than twice that of the conventional lecture classes. Consistent with Hake’s study, studies of the Calculus Concept Inventory by Epstein (2007) find that traditional instruction has remarkably little effect on basic conceptual understanding.

In addition, studies on the use of peer instruction in both physics and mathematics and in team-based learning across many disciplines and subject matters also consistently show the dramatic effects of these techniques on improved conceptual understanding, problem solving skills and social skills (Crouch & Mazur, 2001; Ferreira, Nicola, & Figueiredo, 2011; Michaelsen, Knight, & Fink, 2004). Peer instruction prompts learners to verbalize their thoughts, benefiting both capable learners and those less so. Explaining their understanding to the others and listening to the perspectives of others opens up opportunities for all learners to improve their conceptual understanding. The theoretical basis for this phenomenon is explained by Gadamer’s notion of “fusion of horizons” through dialogue (Gadamer, Marshall & Weinsheimer, 2004), and is reflected in Vygotsky’s (1978) concept of the zone of proximal development, defined as the difference between what a learner can do without help and what she can do with help from an adult or in collaboration with abler peers (p. 86).
Just-in-time teaching is a pedagogical strategy that uses feedback from work that students do at home and in class in preparation for the classroom meeting. Its goals are to increase learning during classroom time, enhance student motivation, encourage students to prepare for class, and allow the instructor to fine tune the classroom activities to best meet students’ needs (Simkins & Maier, 2010). Smith, Wood, Krauter & Knight’s study (2011) found that the combination of peer discussion followed by instructor explanation improved average student performance substantially when compared with either method alone.

Drawing on the results of these studies, we designed our model to combine the use of video lectures, i>Clickers (a classroom response system), peer instruction, and just-in-time teaching.

**INSTRUCTIONAL PROCEDURES**

The following steps, repeated weekly, were refined based on instructors’ reflections, classroom observations, and student feedback from the first round of flipped classrooms. They reflect the latest iteration of our instructional practice.

Instead of flipping all classes all at once, we chose to flip only about one-third of regular lecture classes for each of the three courses. This gave us eight flipped classes for C-I-R and C-II offered in fall 2012 and nine classes for C-I offered in fall 2013. This decision allowed our team time to reflect on our experiment, make necessary adjustments, and prepare instructional materials for the flipped classes before and during the course delivery. More importantly, we felt both instructors and students needed a trial period to adjust to the new pedagogy.

**Step 1:** Students take the traditional 50-minute lecture classes on Monday. After class, students are required to watch an assigned recorded video lecture before attending the flipped class on Wednesday. Each instructor-made video is about 40-minutes long, divided into segments of about 10 minutes each.

**Step 2:** Immediately after watching the video, students take an online quiz testing their basic understanding of the materials they just viewed. They receive instant feedback on their performance. Individual scores are aggregated for each quiz item and for the whole quiz. Before the flipped class on Wednesday, the instructor reviews the quiz results to identify areas of weakness and strength in students’ understanding, and prepares a set of 12 to 24 clicker questions with a range of difficulty levels that specifically address problem areas.

**Step 3:** In Wednesday’s class, the instructor conducts peer instruction and just-in-time teaching, beginning with posting an easy question as a warm-up exercise; this often receives more than 90% correct answers. He then quickly moves on to more challenging questions. Each question is first answered by students individually
using their clickers. The instructor reveals the poll result on screen after a minute or two. If a great majority of the students answer it correctly, the instructor moves on to the next question; otherwise, the students are asked to talk to their neighbors and attempt to convince each other their choice of answer. Once they have had a chance to debate and discuss their answers, they vote again. This peer-instruction process often lasts two to three minutes, at which point the instructor stops the poll and reveals the second voting results. While students attempt to determine the answers to clicker questions, whether individually or with their peers, the instructor walks around the classroom, monitoring students’ work and answering any questions they may have. The instructor uses the poll results to assess students' understanding, spending more or less time on each problem accordingly. If the second vote results show students are still having trouble solving a problem, the instructor reveals a follow-up question selected from his prepared set for students to try again. This process continues until students have achieved a satisfactory level of understanding (more than 90% answering correctly), at which point the instructor moves on to the next concept.

Step 4: Before Friday’s class, students are require to complete a) a graded online assignment and b) a non-graded paper-based problem set chosen by the instructor from the textbook. These exercises are designed to reinforce the materials taught since the Friday last week.

Step 5: On Friday, students take a quiz which consists of two items randomly selected by the instructor from their non-graded homework assignment. This in-class quiz completes the weekly instructional cycle.

METHODOLOGY

Our overarching methodology is design-based research (Bell, 2004), whose goal is to improve, not to prove. For these reasons, we used a mixed-methods approach to our data collection. Data were collected from student questionnaires on their perceptions of the flipped classroom experience (at the middle and end of the semester), student performance scores (in-class clicker questions, weekly quizzes and weekly online homework assignments) and achievement scores (two mid-terms and the final exam). Qualitative data were also collected from student interviews during the semester, and extensive classroom observations throughout the semester to provide in-depth and contextual understanding of our experiment.

RESULTS AND DISCUSSION

At the time of writing this paper, we have not yet completed our data analysis. Comprehensive results will follow. Only selected summary results are reported here.
Students’ experiences

Students’ experiences are investigated primarily through questionnaire and supplemented with one-on-one and group interviews and classroom observations. Questionnaire data were collected anonymously (with a unique ID assigned to each respondent) twice during the semester, one after three flipped classes during week six of the semester, and one after all flipped classes during week twelve of the semester.

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<td>C-I-R</td>
<td>C-II</td>
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<td>91 (41%)</td>
<td>83 (34%)</td>
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Table 1: Number of survey responses and response rates of the three courses

Video lecture watching behaviours: Overall 80% of respondents from the three courses spent the expected amount of time watching the video lectures (at least half an hour per week) before the weekly flipped class over the course of the semester. A significant portion of respondents (68% for C-I-R, 78% for C-II, 73% for C-I) said they took notes when watching videos. About one-third of the respondents said they at least sometimes review the videos after class. About 60% of respondents said they watched the videos again during exam periods. While 80% of the respondents said they watched the videos on their own, close to half of the respondents from each course (46% for C-I-R, 49% for C-II, 44% for C-I) said they discuss the video with classmates after watching. Compared to respondents from C-I-R, students from C-I and C-II spent more time watching videos before class and were more likely to review them during exam periods.

Perceived benefits of the video lectures: Overall, the respondents from all three courses agreed that the video lectures helped them better prepare for class (72%), learn at their own pace (78%), answer clickers questions in class (65%), prepare for exams (59%) and learn better in general (63%). A significantly higher percentage of the respondents from both C-I and C-II believed so for each of the following categories: better prepare for class (20%-29% higher), learn at their own pace (20%-21% higher), and learn better in general (14%-26% higher).

Student perceptions of peer instruction: Respondents were generally positive about peer instruction. Aggregated mid-term data from the three courses indicated most agreed that working in small groups helps them better understand the subject matter (63%), hearing other students’ explanation enhances understanding (58%), and having to explain their own answers to their peers helps them learn better (68%). Perceptions were initially similar across all three courses. At course end opinions among respondents from C-I-R had changed little, but those in C-I and C-II had become more enthusiastic.
Students’ perception of clicker questions: At mid-term, about 40% of the respondents from C-I-R agreed that with the statements “It is valuable to answer a clicker question individually first and then discuss with their peers” and “Doing so makes them think more deeply about the question.” Their opinions changed little by course end (47% agreed with both statements). Respondents from C-I and C-II were significantly more positive: 63% (C-I) and 73% (C-II) agreed with the first statement and 66% (C-I) and 65% (C-II) with the second mid-term; by course end about three quarters of the respondents from both courses agreed with both statements.

Students’ overall evaluation of their flipped classroom experience: Respondents were asked to rate the statement “The flipped classroom helps me learn better than the traditional lecture class” on a scale of 1 (strongly disagree) to 5 (strongly agree). While C-I-R respondents’ collective view stayed unchanged over time, with 24% agreeing at mid-term, compared to 28% at course end, the views of C-I and C-II respondents improved significantly over time: 42% (C-I) and 44% (C-II) agreed at mid term – by the end of the course, the percentages rose to 66% for both courses.

In summary, the survey results show that by many measures, compared to C-I-R respondents, C-I and C-II respondents were more positive about their flipped classroom experience at mid-term, even more so by course end. Our classroom observations were that students from C-I-R were less enthusiastic about the clicker questions or peer instruction when the methods were first introduced. The instructor responded to students’ hesitation with more demonstration and lecturing. This seemed to have re-established the old norm and expectations of a conventional lecture class. The class remained lukewarm to the new pedagogy throughout the term. In contrast, the instructor of C-I and C-II stayed committed to the flipped pedagogy. The attitude of these students towards the flipped classroom was much more positive at course end than at the beginning of the course.

While the results indicate that implementation fidelity matters; in-depth discussions with the C-I-R instructor revealed a more complex story. As an experienced instructor and teaching award-winner he felt deeply about the importance of being sensitive to students’ reactions and needs in class. For most students, this was their first experience of university learning; he felt that he needed to help them overcome the initial fear of learning calculus. Adhering strictly to the planned instructional procedures conflicted with his professional judgment based on the context. “I am not just teaching calculus, I am also teaching and caring for a person,” reflected the instructor. In his critical analysis of the idea of evident-based practice, Gert Biesta (2007) argues that education is an open and recursive process and a thoroughly moral and political practice. “What works” (i.e., a particular intervention) may not always be desirable (p. 9). Evidence-based practice must not prevent the educator from making professional decisions as to what is desirable in a particular context.
Learning achievement

Results in this section are preliminary. Detailed statistical analysis comparing grade distributions of the flipped courses with the same courses offered in lecture mode will follow.

Compared to previous three offerings of the same courses by the same instructors, no statistical significant difference in student performance scores (final exam and two mid terms) were observed for C-I-R and C-II during the first iteration of our experiment in fall 2012. Many psychological, behavioural and situational factors could explain this. Weekly calculus workshops were cancelled or abbreviated due to a prolonged TA strike.

By the same measures (and the same exams), the level of C-I student performance increased significantly and consistently (by more than 10%) during the second iteration of our experiment. Although calculations of effect size are yet to be conducted, the observed results in C-I was unprecedented. Many factors could contribute to this change. We hypothesize that major factors could include: more streamlined and refined instructional procedures (described above), increased frequency of the formative assessment, and improved instructor fluency with conducting flipped classes (the C-I instructor had experience from the first round).

These results are suggestive but inconclusive at this stage. We plan to continue observing, reflecting on and tweaking our instructional intervention so that sustained improvement in learning gain may be brought about across instructors and over time.

CONCLUSION

Our study indicates that while students generally recognize the benefits of the video lectures, their views of the value of the flipped classes can be mixed. When first exposed, they can be sceptical or even negative about the flipped classroom. If instructors stay on course, students are likely to be more positive about their experience and more convinced of its value at semester end. This must not, however, be permitted to overrule the expertise and judgment of instructors. For our study, the impact on learning achievement is inconclusive at the current stage; however, we remain cautiously optimistic about future results as we move into the next iteration of our experiment.

References


