Active Learning and Flipped Classrooms in Introductory Mathematics

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Introduction

Lecturing has been the primary method of instruction since universities were first founded over 900 years ago (Freemen et al., 2014, p. 8410). In today's age of rapidly advancing technology, however, there has been a growing concern amongst educators that this approach engages students at an insufficient level. From these concerns stems a vast archive of research on *active learning*, approaches to education that involve students directly in the learning process rather than treating them as passive observers. Active learning in mathematics often appears in the form of in-class problem solving, group discussions, and clicker questions, though newer techniques such as peer instruction (PI) and just-in-time teaching (JiTT) have also gained popularity.

Over the course of the last decade, proponents of active learning have advocated its benefits in numerous comparison and case studies. Their findings point to three key success of active learning: improved performance and reduced failure rates, greater levels of peer interaction, and better attitudes toward learning. These outcomes have been confirmed in large scale studies as well. In a meta-analysis of 225 post-secondary STEM courses, Freeman et al. (2014) observed that on average, students experience higher performance levels and lower failure rates when exposed to active learning. This is consistent with the findings of Watkins & Mazur (2009), who state that the use of PI in introductory undergraduate courses can lead to significantly higher retention rates in STEM disciplines.

Due to the mounting evidence in support of its effectiveness, active learning techniques are becoming more prevalent in undergraduate education (Berrett, 2012). In some cases, instructors have elected to replace their lectures with these methods. Their students acquire knowledge through reading textbooks or watching videos outside of class, and class time is reserved for activities that deepen that knowledge (Love, Hodge, Grandgenett, & Swift, 2014). This model, known as the *flipped classroom*, has become a popular approach to instruction in recent years.

Although many of the benefits that surface in active learning environments have also been documented in flipped classroom studies, some authors (e.g., Jensen, Kummer, & d M Godoy, 2015; Strayer, 2012; Zack, Fuselier, Graham-Squire, Lamb, & O'Hara, 2015) warn that flipping should be approached with caution. Zack et al. (2015) advise that students in flipped classrooms can be resistant to taking ownership of their learning and may develop more negative attitudes toward technology (p. 808-809). Furthermore, students in flipped settings who do not prepare adequately before class receive little to no benefit under this model. Flipping also comes at a substantial cost to instructors, as preparing, editing, and uploading video content can occupy a considerable amount of time (Jungić, Kaur, Mulholland, & Xin, 2015).

By comparing two sections of a general biology course, Jensen et al. (2015) weighed the benefits of the flipped model against its criticisms. While one section of the course was flipped and the other was not, both sections included substantial active learning components. The authors found no statistical difference in student performance between the two conditions, and the only variance in attitudes was a more negative view of technology appearing in the flipped section. This suggests that in the presence of active learning, the flipped model does not contribute to better attitudes or higher learning gains (p. 9). For this reason, and in view of the concerns described above, some educators have raised support for a more blended approach (Strayer, 2012, p. 192; Wilson, 2013, p 197; Zack et al., 2015, p. 809).

The Impact of Active Learning in STEM Classrooms

In today's post-secondary institutions, the university lecture persists as the most ubiquitous form of instruction. Sahin, Cavlazoglu, & Zeytuncu (2015) suggest that this may be problematic, as the current generation of students has an approach to learning that differs dramatically from generations past. The authors add that "effective teachers have to master a variety of teaching techniques and strategies to establish and maintain student interest" (p. 142). This perspective is far from unique; Berrett (2012) warns that "professors can no longer simply pump out information and take it on faith that students understand it," and Mazur (as quoted by Berrett, 2012) advises that "simply transmitting information should not be the focus of teaching, helping students to assimilate that information should." These are but some of many calls from educators to upgrade or, in some cases, replace the traditional lecture with a method of instruction that better suits the 21^{st} century classroom.

While the lecture approach has faced criticism, research conducted in recent years suggests that students experience better educational gains when they actively engage in the learning process (Lucas, 2009, p. 220). In accordance with this, Mazur (as quoted by Berrett, 2012) explains that "once you engage students' minds, there's an eagerness to learn, to be right, to master." These findings have led to a growing interest in *active learning*, approaches to education that seek to engage students in the learning process directly. Techniques can range from in-class problem solving and group discussions, to more modern methods such as peer instruction (PI) and just-in-time teaching (JiTT).

Studies on active learning document various educational benefits. These include increased student performance and reduced failure rates, higher levels of peer interaction, and improvements in students' attitudes toward learning. Concerning undergraduate mathematics, these benefits are best exemplified in studies conducted by Lucas (2009), Freeman et al. (2014), and Watkins & Mazur (2013).

Lucas (2009) introduced active learning to his Calculus II course through the use of peer instruction. This method begins with students responding to a question either electronically via clickers or with a raised hand. If too few correct responses are received, the students discuss the question in small groups. Following the discussion period, students attempt to reach a consensus through a re-voting period. The instructor then briefly explains the solution to the problem, and the class moves on to the next question (Watkins & Mazur, 2013, p. 37). As Jungić et al. describe, "Students are calculating, gesturing, arguing, helping each other, teaching each other, and most importantly, learning from each other" (2015, p. 4).

Lucas observed that the use of PI was beneficial in engaging his more passive students, hypothesizing that the lively atmosphere created during group discussions made learning an active and fun process. Students were able to benefit by seeing multiple approaches to a single problem, and ultimately found greater value in learning from their peers (p. 224). Students felt safe to make mistakes, and the class experienced a stronger sense of community overall. Lucas also noted that responses collected during the voting phase served as fast and accurate predictors of student performance throughout the semester (pp. 228-230).

Some of the strongest evidence supporting the claim that student performance in STEM fields is augmented in the presence of active learning comes from Freeman et al. (2014). In a large-scale meta-analysis of 225 STEM classrooms, the authors found that, on average, examination scores for students exposed to active learning were approximately 6% higher than those taught via traditional lectures. Moreover, it was observed that failure rates were about 1.5 times lower in active learning classrooms (p.8410). The authors remark that the positive outcomes observed in the presence of active learning were found across all STEM fields and in all class sizes, though the effects were most prominent in classes of 50 students or fewer (p. 8411).

Watkins & Mazur (2013) described similar findings. Citing Seymour & Hewitt (1997), the authors explain that over 90% of students who switch out of science programs, in addition to over three quarters of those remaining, are concerned with the quality of instruction. These students include the lack of professor-student interaction, “coldness” of the classroom, and overall dullness of presentations as evidence of poor teaching (p. 36). To test whether such grievances were as prevalent in active learning environments, the authors analyzed data from various sections of an introductory physics course at Harvard University over a 7-year period. One of these sections was lecture-based, and others were taught using PI.

Their study indicated that the proportion of students in the traditionally-taught section who switched out of STEM programs was twice that of students in the PI-based sections (p. 38). One explanation for this disparity is that the presence of PI helped to mitigate some of the criticisms of STEM teaching described by Seymour & Hewitt. In particular, the higher level of peer interaction generated in PI classrooms may reduce the “coldness” and increase the “openness” of the learning environment. Additionally, instructors using PI are afforded better opportunities to listen and participate in class discussions, thereby increasing the degree of professor-student interaction. The authors conclude that the use of an interactive teaching pedagogy can lead to excitement towards course’s teaching and/or content that may ultimately affirm a student’s decision to pursue a STEM degree (p. 39).

The Flipped Model

In view of the benefits that active learning promotes in STEM education, it may be unsurprising to learn that these teaching methods are gaining popularity in post-secondary institutions. Some instructors have even adopted teaching models that replace their lecturing component with alternative methods built around active learning. In these so-called *flipped classrooms,* students are introduced to course content before class in the form of instructional videos, pre-recorded lectures, or textbook readings. The in-class portion of learning is then devoted to applying that knowledge via problem solving, peer interaction, or other methods of active learning (Jensen et al., 2015).

The flipped model operates under the assumption that students require less instructional support when learning definitions, basic facts, or routine procedures, but conversely may need assistance and feedback when engaged in activities that demand a greater level of proficiency. This arises from the observation that content traditionally covered in lectures often promotes learning in the lower ranks of Bloom's taxonomy (*remember, understand,* and sometimes *apply*), while much of the learning a student encounters outside of class, and without the support of their peers or instructor, belongs in the higher tiers (*analyze, synthesize,* and *evaluate/create*). The flipped model aims to provide students with increased exposure to their instructor and peers during activities that require more complex thinking and reasoning skills. (McGivney-Burelle & Xue, 2013, p. 478).

Interest in the flipped model stems partially from the rising popularity of video-based education. Video learning sites such as Khan Academy and MOOCs have directed considerable attention to the use of video content both inside and outside the classroom in order to promote flexible learning. Furthermore, the increasing availability of technology in today's society provides a means for instructors to produce and upload video lectures at a relatively low cost (Jungić et al., 2015, p. 2).

Economic reality is another factor at play. Although smaller class sizes allow for greater levels of faculty-student interaction, stringent budgetary constraints make large, lecture-based classes an economically efficient option. The flipped model offers institutions a cost-effective alternative: by replacing lectures with in-class learning activities, instructors can use their time and expertise more effectively while allocating a higher degree of personal attention to each student (Berrett, 2012).

Advantages of the Flipped Model

With growing interest in the flipped model comes a vast collection of research assessing its effectiveness. Many of these studies report benefits to flipping that parallel those detected in other active learning models, such as increased student performance and improved attitudes toward learning. Additional gains specific to flipped learning, such as the ability to view video content at one's own pace, are also frequently cited. These benefits can be seen in the following three studies, each of which illustrate the advantages flipping poses in undergraduate mathematics.

While teaching back-to-back sections of a Calculus II course, Xue (2013) elected to flip the *Applications of Integration* unit in one section, while retaining a traditional lecture-based approach in the other. Students in the flipped section were expected to watch short videos--each approximately 15 minutes in length--before each class, as well as complete 1-2 question readiness quizzes designed to measure their out-of-class preparation. Class time for the flipped section was devoted almost entirely to problem solving in small groups, while students who were taught traditionally spent class time taking notes and listening to lectures.

It is important to note that students in both sections performed similarly on assessments administered before the flip, including online homework assignments and the first midterm exam. After the flip, however, a distinct performance disparity was detected. The flipped section obtained a mean score on the second midterm exam five points above that of the traditional section. A comparison of median values yielded similar findings, with the flipped class seven points ahead. Furthermore, the average score on the online homework assignment pertaining to the *Applications of Integration* unit was four points higher in the flipped class (pp. 481-482).

To identify students' perceptions of flipped learning, the instructor administered a short survey at the end of the unit. Results indicated that students preferred learning from videos, rating their helpfulness at 4.06/5. Students frequently cited the opportunity to review content before exams; the ability to pause, re-watch, and take notes at one's own pace; and the chance to see the big ideas of each section before attending class (p. 482). Interviews conducted in a small-scale focus group also revealed that some students felt more comfortable asking questions during class, and found the videos to be "a stress-free visual method of learning". Overall, students reported a strong preference for the flipped model (pp. 483-484).

Sahin et al. (2015) documented analogous findings in a first-year Calculus II course for engineers. The authors noted that although any calculus course requires familiarity with high school mathematics, their students frequently demonstrated a lack of understanding of requisite material. In order to facilitate greater achievement in calculus through changes in preparation habits, the instructors applied the flipped model to three of their course's ten sections. During the flipped units, students viewed video lectures before attending class, and used class time to work on problem sets. Note-taking and listening to lectures monopolized class time during non-flipped units.

Survey results obtained after flipped classroom implementations indicated that changes to preparation practices did indeed occur. While 41% of students reported that they did not engage in pre-class preparation during the traditionally taught units, this number was reduced to just 22% during flipped instruction. Responses also suggest that students found value in video learning, with 81% agreeing that the video lessons improved their confidence, and 83% agreeing that the videos helped them to perform better during the flipped units (pp. 147-148). A comparison of quiz scores from flipped and non-flipped units showed a statistically significant increase in grades when the flipped model was implemented (p. 146). The authors conclude that the flipped classroom can be effective in courses that require a degree of background knowledge by fostering improved preparation habits and interactions with instructors and peers (p. 149).

A third study corroborating these findings comes from Jungić et al. (2015), who utilized a flipped pedagogy roughly once weekly in their first year calculus courses. Students prepared for flipped classes by watching pre-recorded video lessons, reading the textbook, and completing an online quiz designed to assess their readiness. In class, instructors used clicker questions and peer instruction to reinforce the material from the videos and pre-readings. Clicker questions were chosen based on students' quiz responses. Students' in-class performance on initial questions would dictate which problems instructors posed subsequently. This method, known as *just-in-time teaching*, allows instructors to focus the in-class learning on the topics that require the most attention.

Students were surveyed at two points during the term in order to generate feedback on the flipped model. Akin to the findings from the studies examined above, responses indicated that the videos helped students to prepare for clicker questions, study for exams, and improve their learning overall. The ability to access the videos at any time and learn at one's own pace were aspects that students found especially favorable. As in Lucas' 2009 study, survey results demonstrated that students were able to see greater value in learning from their peers. Statements such as "Working in pairs or small groups in class helps me to learn better." and "Hearing other students explain their understanding of a problem helps me to learn better." received consistently high ratings from students in all sections (p. 6).

Jungić et al. explain that the advantages of the flipped model extend to instructors as well. In particular, the active learning style allows instructors to better engage with their large classes, and in addition, the pre-class quizzes and in-class clicker questions provided substantial insight into student performance. The authors state that they "have [a] finger on the pulse of the student and are able to address misconceptions immediately as they arise" (p. 6).

Criticisms, Dangers, and Drawbacks of Flipped Learning

Despite the many advantages that have been detailed in flipped classroom studies, this model is not without its flaws. Authors regularly cite the multitude of costs that flipping imposes on both instructors and students. For instance, flipping can be very labor-intensive for instructors that lack adequate teaching support, particularly if the instructor intends to create video content for every lesson (Berrett, 2012). Furthermore, studies regularly report that flipped classrooms can be met with resistance from students accustomed to more traditional methods of instruction. As a result, this model may become a hindrance to learning, leading students to experience negative views toward technology and lower opinions of the course and instructor (Berrett, 2012; Zack et al., 2015, pp. 808-809).

In fact, one does not have to look far to find criticisms of flipped learning; shortcomings of this model are detailed in two of the three studies presented in the preceding section. McGivney-Burelle & Xue explain that students sometimes forgot to watch the videos before attending class, and consequently found it challenging to engage in the learning process. Additionally, students who did watch the videos were dissatisfied that they were unable ask the instructor questions as they arose (2013, p. 484). The study of Jungić et al. revealed that creating regular video content can be extremely time consuming for instructors. The authors estimate that every 30 minutes of video content equates to roughly 3-4 hours of recording, editing, and uploading (2015, p. 3).

Negative outcomes of the flipped model and dangers in its implementation become even more apparent in classrooms where a higher proportion of the course is flipped. In a 2012 comparison study of two sections of introductory statistics, Strayer taught one section of the course using a lecture-based approach, and the other entirely using the flipped model. Students in the flipped class used ALEKS (Assessment and Learning in Knowledge Space), an online artificial intelligence learning system, to facilitate online homework assignments and content acquisition outside of class. Instead of a classroom, students from the flipped section met in a computer laboratory. There they completed various activities designed to complement the material they were learning in ALEKS by applying it in different contexts.

Researchers collected qualitative data from both sections through focus groups that met at the end of the semester. Responses indicated that too much variability in the flipped section created an environment where students did not know what to expect (2012, p. 181). In reference to the in-class activities, one student in the flipped section stated that "… neither [you nor your partner] know what you're doing. And then it becomes you just sit there for like 20 minutes" (p. 182). This outlook contrasts heavily with perceptions from the lecture-based section. As one student from non-flipped class described, "You always know what to expect from [the instructor]. There is structure in the class" (p. 184). Strayer's experience shows that without proper routine, students in flipped classrooms can feel lost and perceive learning as unstructured.

In addition to the detriments introduced by a lack regularity in the classroom, Strayer observed that students in the flipped section sometimes experienced difficulty in synthesizing ideas presented by ALEKS with those exposed in class. This was likely due to the fact that certain concepts were explained differently by ALEKS than during in-class discussions. While viewing mathematics from various perspectives may help more advanced learners to strengthen their understanding, Strayer acknowledges that the two ill-connected learning platforms made it difficult for his students to link ideas and see the big picture (p. 185). In light of the drawbacks that the flipped model can impose on less experienced learners, Strayer suggests that an introductory course may not be the best setting for flipped instruction (p. 191).

Zack et al. adopted a similar outlook on the flipped model after implementing its use in four introductory mathematics courses: calculus I, pre-calculus, business calculus, and finite mathematics. Each instructor involved in the study taught two sections of their course, one using a traditional lecture-based approach, and the other using the flipped model exclusively. Students in flipped sections were provided with video lectures to view outside of class, and instructors administered short assignments due before each lesson to ensure that the videos were being watched.

In-class learning was conducted similarly in each of the four flipped sections. Students began by asking questions related to the pre-assignment, and the majority of class time was reserved for working on online homework problems, participating in activities focused on the day's material, or completing a quiz. Regardless of the course, students learning under the flipped model spent the entire class period actively working on problems (2015, p. 805).

Data collected from students in mid-term and end-term surveys pointed to a strong opposition to the flipped style of learning, particularly in the flipped pre-calculus class. Students indicated that the interaction with their instructors was ineffective, and explained that "they felt like they did not have a teacher", or that "their teacher did not actually teach" (p. 807). The activities and general atmosphere in the flipped classroom were not seen as beneficial to the learning process. Overall, while 45% of students reported a preference for the flipped model in the mid-term survey, this number was reduced to 36% at the end of the semester (p. 806). In addition to the model's poor reception, a statistical analysis indicated no significant difference between student performance in the flipped and non-flipped sections of each course (p. 805-806).

Reflecting on their experience with the flipped classroom, the authors state that flipping may not be an ideal teaching model for first-year students. This is supported by the fact that the greatest disapproval for the flipped model occurred in the pre-calculus course, the only one of the four in which first-year students comprised 100% of the class. The authors explain that the transition from high school to university requires many adjustments already, and hence a radically different teaching style may be overwhelming to first-years students (p. 807). Furthermore, students in lower-level courses may be more resistant to taking ownership of their learning, and consequently may neglect to watch the videos before attending class. The authors recommend that in future implementations of flipped learning, in-class activities should be structured so as not to exclude these students.

The common concern voiced by Strayer (2012) and Zack et al. (2015) is that a fully flipped classroom may not be the best learning environment for non-advanced students. The stark contrast between these findings and the successes of McGivney-Burelle & Xue (2013), Sahin et al. (2015), and Jungić et al. (2015) may be explained by the degree to which each class was flipped. This observation has led some researchers to recommend a more blended approach. By reserving some class time for short lectures, review, or instructor-led discussions, studies have reported that students can receive the best of both models (Love et al., 2014; Wilson, 2013). In particular, learners can experience many of the performance and social gains from the flipped model while still retaining the direction, support, and familiar structure of traditional learning.

Flipping vs. Active Learning

Lucas' 2009 study of peer instruction in first-year calculus, the findings of Watkins & Mazur (2013) on retention rates in introductory physics, and the meta-analysis of active learning in STEM education by Freeman et al. (2014) provide substantial evidence in support of the following claim: active teaching pedagogies in STEM classrooms can promote both qualitative and quantitative gains to learning. However, studies suggest that the flipped classroom has significant drawbacks. Creating and editing video content requires a considerable time commitment from instructors, and students in flipped classrooms may actively resist becoming self-sufficient learners (Zack et al., 2015). In light of these findings, it becomes interesting to ask whether the flipped classroom exhibits greater educational benefits over non-flipped models that incorporate regular active learning.

This question was investigated by Jensen et al. (2015) in a comparison study of two sections of a general biology course. While one section was flipped and the other was not, active learning methods were regularly integrated into each section. Content was presented to the non-flipped section through in-class instruction, after which students engaged in group work and whole-class discussions to build their conceptual understanding. Concept application for non-flipped learners took place after class in the form of online homework assignments. In contrast, the flipped section was introduced to course content through short video clips and pre-class online homework assignments, while in-class learning was devoted to group work and class discussions designed around concept application.

To ensure as much homogeneity between the two sections as possible, all students were exposed to the same active learning materials, just via different learning platforms (p. 3). Specifically, the pre-class online homework administered to students in the flipped section was identical to the in-class activity completed in the non-flipped section. Both sections were assessed using identical quizzes and unit exams, as well as a common final exam. As the authors note, "neither section was exposed to more content material, more application practice, or more assessment than the other" (p. 4). Furthermore, data collected through testing at the outset of the study indicated that prior biology knowledge and scientific reasoning skills were equivalent across both sections (p. 6).

A statistical analysis of the scores on unit tests and final exam revealed that students in both conditions performed equally well. In addition, students from both sections achieved equivalent scores on the 40 low-level final exam questions (ranked at the *remember* or *understand* levels of Bloom's taxonomy), as well as on the 40 high-level final exam questions (ranked at *apply* level or above) (pp. 6-7). Students' perceptions of the two learning styles were collected through an attitude survey at the end of the term. While views of the overall structure of the course and the usefulness of in-class and out-of-class learning activities were equivalent across both sections, students in the flipped section exhibited a more negative attitude toward the use of technology-facilitated activities. Responses also indicated that both the flipped and non-flipped sections regarded the active, hands-on learning as the most enjoyable aspect of the course (pp. 7-8).

This evidence demonstrates that the flipped classroom does not lead to greater performance benefits or improved attitudes towards learning over the non-flipped classroom when both adopt pedagogies of active learning. Jensen et al. propose that any learning gains experienced in either section were "more likely a result of the active-learning style" rather than the instructor's role in content delivery versus concept application. They suggest the possibility that "the flip [was] simply being used to facilitate the shift from more passive, traditionalist teaching to active-learning approaches" (p. 9). Thus, it may also be possible that some studies accounting the benefits to flipping may, in actuality, be reporting the gains from active learning that naturally arise in flipped classrooms. The authors conclude that "if active learning is not being used or is being used very rarely, the flipped classroom may be a viable way to facilitate the use of such approaches, if the cost of implementation is not too great" (p. 10).

Conclusion

In today's technology-driven society, it is no surprise that the current generation of students exhibits an approach to learning that differs significantly from those that came before (Sahin et al., 2015, p. 142). This realization has generated concern amongst educators that modern learners do not receive the engagement they require through the teaching techniques of the past. As a result, considerable attention has been directed to student engagement and active learning methods, and a wealth of research has been amassed attesting to their effectiveness. Amidst the many gains that arise in active learning environments, three key benefits stand out in the literature: improved performance and reduced failure rates, higher levels of peer interaction, and better attitudes toward learning.

These successes, together with the increasing availability of technology, have motivated some instructors to promote a higher degree of active learning in their courses by way of a flipped classroom. Numerous studies on the flipped model report educational benefits that mirror those seen in the presence of active learning. Furthermore, many authors also find that students strongly favor the use of video learning, commonly citing features such as the ability to learn at one's own pace and the opportunity to review content before exams (McGivney-Burelle & Xue, 2013, Sahin et al., 2015, and Jungić et al., 2015). Instructors have also noted that the flipped model helps them to better engage with their learners and correct misconceptions as they arise (Jungić et al., 2015).

This, however, is but one side of the coin. Studies on flipped learning routinely warn that that this model can impart a significant time commitment on instructors, particularly when regular video content is being created for the course. Strayer's implementation of flipped learning in introductory statistics demonstrates that too much varied activity can leave students feeling lost, and improper integration of in-class activities with out-of-class learning can impose difficulty on students when synthesizing course content (2012). In addition, Zack et al. (2015) note that flipped classrooms may receive significant pushback from students who are unwilling to take ownership of their learning. Both studies advise that a fully flipped classroom may not be an appropriate teaching model for students who are still adjusting to post-secondary education.

In light of these findings, it becomes important for instructors to know whether the benefits of flipping outweigh its risks and drawbacks. Jensen et al. (2015) provide evidence to the negative in their comparison study of two sections of a general biology course. Their results indicate that the flipped classroom does not lead to better performance or improved attitudes to learning over a non-flipped classroom when both incorporate pedagogies of active learning. The authors conjecture that the benefits observed in either section likely reflect the presence of active learning, rather than the flipping itself.

It is evident from this analysis that active learning plays an important role in post-secondary education, with students receiving both quantitative and qualitative gains when they actively engage in the learning process. In learning environments that incorporate little to no active learning, the flipped classroom may be a viable way to increase engagement and student participation. Instructors, however, must understand that this model can impress heavy costs on both themselves and the students, and should be not be implemented carelessly. As some researchers advocate, a blended approach to learning may provide a safe, yet effective alternative to the flipped model.

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