The flipped classroom in engineering education: A survey of the research

Barbara Kerr
Teaching Commons
York University
Toronto, Canada
kerrb@yorku.ca

Abstract—The flipped, or inverted, classroom model is increasingly being utilized in higher education. However, the use of the flipped classroom has received less attention in engineering subjects and currently only limited research exists. The purpose of this study is to identify empirical studies that have investigated the impact of using a flipped classroom model in undergraduate engineering education. The search for empirical articles included electronic databases for engineering education such as IEEExplore, Inspec and ERIC. The following keywords were used during this search: flipped classroom, engineering education. A total of 24 studies were included in the review. Most studies reported high student satisfaction and increased performance in a flipped classroom environment.

Keywords—engineering education, flipped classroom

I. INTRODUCTION

The flipped classroom is a pedagogical model whereby the typical lecture and homework components of a course are reversed. The content heavy lecture is usually replaced by direct computer-based individual instruction such as online videos, and the face to face classroom time is spent on interactive group learning activities, discussion of difficult concepts and problem solving.

In 1998, Walvoord and Anderson proposed a model where students would gain their first exposure learning prior to class and then focus on the processing, or higher cognitive thinking, part of learning in class by engaging in activities such as problem solving [1]. Lage, Platt, and Treglia portrayed a similar approach, which they called the inverted classroom, and described its application in an introductory economics course in 2000 [1]. In 2001, Mazur and Crouch described a modified form of the flipped classroom that they named peer instruction. This model also requires that students gain first exposure prior to class, and uses assignments to help ensure that students come to class prepared. Then class time is structured around alternating mini-lectures and conceptual questions. All students must answer the conceptual question, often via handheld personal response systems, that allows the instructor to determine how well the students have understood the concepts. If a large proportion of the class answers incorrectly, then students reconsider the question in small groups while instructor circulates. After discussion, students answer the conceptual question again. Mazur and his colleagues published results suggesting that the peer instruction method results in significant learning gains when compared to traditional instruction [1].

A growing number of higher education instructors have begun using the flipped classroom in their classroom. Nevertheless, the use of the flipped classroom has received less attention in engineering subjects [2]. The need for engineering graduates to be able to solve real-world problems and work in teams suggests the merit in flipping the classroom. However, currently, limited research exists on the impact of the flipped classroom model in engineering education [3].

Although flipped classrooms can have many advantages, some issues, such as student resistance to this model and the time required on the part of the instructor to integrate out-of-class and in-class elements, have been identified; thus leading some instructors to question the value of changing to a flipped classroom. The purpose of this study is to identify empirical studies that have investigated the impact of using a flipped classroom model in engineering education with respect to anticipated benefits such as increased student learning and course satisfaction, and under which conditions or context were such gains observed. The following sections will first outline the methodology used to identify potential studies, the criteria for inclusion and exclusion, a brief description of the findings of the included studies, implications for practice and research, and finally conclusions.

II. METHODOLOGY

This review was guided by the question: What research evidence do we have on engineering students’ learning experience in a flipped classroom in terms especially with respect to performance and satisfaction? The search for empirical articles included significant electronic databases for engineering education such as IEEExplore, Inspec and ERIC. The following keywords were used during this search: flipped classroom, engineering education. Due to resource limitations, the search was restricted to English language publications.

A search of the literature through March 2015 yielded 141 studies. To be included in the review the abstracts were examined to ensure that the study involved a de facto flipped class. To meet this criterion, the out of class activities had to include an online component such as video lectures or the use of MOOC content. The in class activities had to be primarily...
interactive learning activities. However, short reviews of the online material at the beginning of the class did not lead to exclusion from this study. Furthermore, the classes had to include undergraduate engineering students, and the reporting of empirical data. This resulted in the immediate exclusion of 58 articles for a variety of reasons, such as they were a work-in-progress without any results reported, the classes were entirely online, they were reports of workshops on how to design flipped classrooms, or they were theoretical discussions. The full-text of the remaining 83 studies was reviewed using the same criteria, which resulted in the exclusion of a further 59 studies.

Of the remaining 24 studies, a spreadsheet was created listing such features as: type of course, level of course, in-class activities, out-of-class activities, research question or focus, measurement instruments, and findings. However, not all included studies reported on these features.

III. FINDINGS

The studies included in this review were published from 2009 to 2014. Not all studies reported the course level but reviewed studies included first year, second year, third year and fourth year of a program. The studies also included a range of subjects such as architectural engineering, circuits, computer science, mathematics, robotics and systems design. Three of the studies made use of existing MOOCs to provide students with material to review before class, and two studies used pencasts. The remaining studies produced their own online videos.

Student surveys were the most common research method, but control groups, focus groups and observation were also employed. The majority of studies looked at student perceptions of their flipped class experience and comparisons of student performance in the flipped classroom model with the traditional face to face classroom approach. The results of these surveys are briefly described in the remainder of this section.

A. Student perceptions of flipped classroom experience

Thirteen of the studies examined student perceptions of their flipped classroom experience with five of these also looking at student performance. Overall, these studies reported at least a moderate level of student satisfaction with a flipped classroom format and in several studies; students reported high levels of satisfaction with the flipped class model [4] – [8].

For example, in a software engineering course where one module had been flipped, 85.8% of the students found this way of learning to be interesting [4]. In another study [5] in a large systems design course, students felt strongly that compared to other courses, the flipped classroom format provided more face-to-face interaction and they received more feedback from instructors and peers. In a senior Robotics and Control course the majority of students stated that they would like to see more flipped classes and they would recommend the flipped Robotics and Control course to other students [6]. In a differential equations course, 65% of the students reported that the flipped classroom course design and instruction met or exceeded their expectations [7]. Finally, in a Sustainable engineering course, students scored the class environment above average compared to other courses [8].

However, other studies found that students had a more mixed response to the flipped classroom format. In a large sophomore introductory multivariable calculus course, 77% of the Mechatronics engineering students reported that they preferred the flipped classroom format while only 45% of the Control engineering students preferred the flipped classroom [9]. In an architectural engineering course [10] students indicated that active learning and the additional project time available in class had improved their understanding; however they also said that they would prefer that only about half of the classes be flipped and some use of traditional lectures be maintained. Similarly, in a junior level industrial engineering course [11], students indicated that they preferred attending lectures face-to-face, however, they also preferred using class time for problem solving and hands on activities, stating that having more time to work in groups in class was a beneficial use of class time. The authors [11] found significant correlations with students’ responses to the study survey questions with the results of the Soloman and Felder’s Index of Learning Styles Questionnaire. The seemingly contradictory responses from the student satisfaction survey may be a reflection of differing learning styles.

Finally, in a three year project to implement a flipped classroom model, where feedback from the first year pilot was used to improve subsequent offerings, researchers [12] found that by the third year, students were demonstrating more of an acceptance in learning with online videos with 56% of them stating a preference for using online videos rather than having a formal lecture. Flexibility of use and access was cited as the main benefit for using online videos. Students’ responses to the limitations of the online videos were less consistent yielding a variety of answers. For example, some students stated that they found the organization of the video lectures problematic while others said that the organization was clear. On the other hand, the majority of students found the in-class group activities to be a good way to develop skills and prepare for their future professions.

B. Student performance

Nine studies examined the effect of the flipped classroom format on student performance with one study specifically looking at performance and retention.

In the first study, two of three sections of an introductory computing class for engineers followed a flipped classroom model. Summative assessments showed that students in both flipped sections of the course attained higher average scores than students in the section that followed the traditional model; however students did not positively value the course [13].

In another study [14] that included a control group, students in the flipped section benefitted as a whole. However, what is most interesting in this study is that the middle and bottom thirds of the class benefitted even more. Thus, in the flipped section there was a much smaller difference between the highest and lowest performing groups. Similarly, in an Electronics and Circuits course, student pass rates in a flipped classroom increased to 91% as compared to a 59% pass rate.
from the previous year’s traditional face-to-face lecture class. Likewise, in a Circuits 1 flipped course [15] 83% of the students received a grade of “C” or better compared to the previous semester’s passing rate of 56%, there was a reduction in standard deviation and student retention was vastly improved. Student responses to Likert scale survey suggest that students strongly favoured the flipped classroom approach. In an Introduction to Circuit Analysis course that merged content from MOOC with in-class team-based learning and hands-on instruction, researchers [16] found student pass rates jumped from 91% compared to 59% in previous year’s face-to-face class. Using online pencast lectures in a flipped Engineering Thermodynamics course, researchers [17] found students performed better on homework and the final examination compared to students in a traditional class taught by the same instructor.

In a flipped sophomore level engineering probability and statistics class, compared to previous year’s traditional offering taught by same instructor, the same material was covered in less time and test scores on a common (identical) final exam increased [18]. Similarly, in a first year Digital Circuits class, researchers [19] found an increase in course content covered and mean student grade increased. Furthermore, the distribution range between minimum and maximum grade was reduced significantly in the flipped classroom.

In a first year engineering dynamics course, compared to previous year’s traditional offering taught by same instructor, the flipped class the gain coefficient was significantly higher [20]. In a senior level signal processing class, in the flipped class, 90% of class had final exam scores exceeding 70/100 while only 55% of previous face-to-face class exceeded 70/100 [21].

C. Student perpceptions and peformance

Five studies looked at student perceptions of the flipped classroom experience and compared student performance with more traditional face-to-face offerings of a course. Overall, students indicated equal or greater satisfaction with the flipped classroom, although they also suggested course improvements. The results of these studies also suggest greater learning gains in learning with the flipped classroom model.

For example, in one of the most extensive studies in this review, in a senior level Mechanical Engineering control systems class researchers [2] used a control treatment experiment to compare the effectiveness of a flipped classroom with a traditional classroom in three areas: 1) content coverage; 2) student performance on traditional quizzes and exam problems; and 3) student observations and perceptions. They found that the flipped classroom format allowed the instructor to cover more material. This does not appear to be due to students spending more time on this particular course because students actually reported spending significantly fewer hours per week studying; although the authors [2] note that the students may not have considered watching videos as time spent studying. In the flipped classroom, students performed as well or better on quiz and exam questions and on open-ended design problems. In terms of student perceptions and observations, students in the flipped classroom noted that the new format was initially frustrating and required self-discipline and an adjustment to their study habits, which the majority felt they had achieved by week four of the course. The end of course departmental assessment indicated a similar rating of teaching from students in both types of classes. However, students in the flipped classroom gave a higher rating when asked about the appropriateness of the assessment methods although there was no difference in the way the two courses were assessed. The authors [2] suggest that the flipped classroom students may have felt more confident in their abilities at the time they took the quizzes and exams and thus felt the assessments were a good reflection of their skills.

In a third year electronics and electrical engineering course in Technical Communications, students’ subjective degrees of achievement increased [22]. In a comparison of a comparable previous year’s mid-term examination, more students in the flipped classroom scored above 80 points and fewer students scored less than sixty points. It should be noted that students also indicated that in this case, they spent considerably more time preparing for this course compared to all other courses in the department. Similarly, in a junior level signals and systems class for electrical and computer engineering students, survey results [23] indicated that students felt strongly positive about flipped classroom; the quality of videos was regarded as quite high and the duration of each video was about right; clicker quizzes provided moderate motivation to watch videos but in-class summaries and problems were significant in helping students learn. Comparison with previous offerings’ mid-term examinations showed that students in the flipped course averaged 4-5 points higher. The author [23] pointed out that the mid-term examinations assessed only problem-solving and students in the flipped classroom scored lower on final Concept Inventory exam.

In a cost estimating course [24], student survey results indicate high satisfaction with their flipped class experience and student examination scores show a slight improvement from previous offerings.

Finally, a study involving a Computer Science Operating Systems course, looked at how students’ self-regulated learning affects their learning satisfaction and performance in a flipped classroom [25]. The results of a web-based questionnaire indicated that self-monitoring and planning along with self-reinforcement and persistence was found to positively correlate with both learning satisfaction and performance.

IV. IMPLICATIONS FOR PRACTICE

A. Provide scaffolding

While the flipped classroom format can encourage skills that are useful for students’ future careers, such as self-regulation and life-long learning, consider scaffolding this move away from a traditional teacher-centered environment. For example, assign credit for documenting the work spent outside of class [17], have a short “check-in” and mini-lecture at the start of class [12], provide a rubric-oriented check-off process for task completion [12] and have students complete a short concept test based on the online video lectures before coming to class [9].
B. Online videos

Lectures can be replaced by online videos using a variety of screen capture technologies or by the use of MOOCs. The length of the videos should be shorter than a traditional lecture for example 15-20 minutes [23], 15-30 minutes [22], or 20 minutes [10].

V. IMPLICATIONS FOR RESEARCH

A. Class size

Not all studies reported class size so at this point it is difficult to draw conclusions on the impact of class size. In the successful implementation of a flipped class in Thermodynamics, the author [17] cautioned that this was with a small (< 20 students) class and may not translate to larger classes. In fact, another author [9] noted that with class sizes between 45 to 75 students, it was challenging to have all students involved in class activities at one time. Further research may indicate possible strategies for the in-class portion of the flipped classroom

B. Type of course

According to the surveyed research, the flipped classroom has been successfully implemented in a variety of engineering courses, such as Thermodynamics and Circuits. However, there is still not sufficient data to draw conclusions regarding which instructional designs work best with different subjects.

VI. CONCLUSIONS

Although many studies are still relying on surveys of student perceptions of the flipped classroom experience, a few are reporting research methodologies that include discourse analysis, quasi–experimental designs, mixed methods, and so on. The use of more robust research designs is adding evidence of the potential effectiveness of the flipped classroom approach in engineering education. In addition to student perceptions, studies are also looking at performance on exams and concept inventories, and retention rates. Nevertheless, many studies do not include reports of statistical analysis of the data; nor is there sufficient data on the context and instructional design of the studies.

Overall, based on this short review, positive gains in problem-solving skills, conceptual understanding, student retention, and satisfaction with flipped classes are being reported. The context and instructional design of the course are important factors in students’ experience and performance. Flipped classrooms are being implemented for a wide variety of engineering subjects, and at all levels from first-year to final year. Studies need to continue to provide details regarding the integration of out-of-class and in-class activities so that there is more information regarding good practices and guidelines for flipped classes in engineering education.

REFERENCES


