Higher Education Quality Council of Ontario

An agency of the Government of Ontario

The Effects of the Inverted Classroom Approach: Student Behaviours, Perceptions and Learning Outcomes

Micah Stickel, Qin Liu

University of Toronto

Published by

The Higher Education Quality Council of Ontario

1 Yonge Street, Suite 2402
Toronto, ON Canada, M5E 1E5

Phone: (416) 212-3893
Fax: (416) 212-3899
Web: www.heqco.ca
E-mail: info@heqco.ca

Cite this publication in the following format:

Stickel, M., & Liu, Q. (2015). *The Effects of the Inverted Classroom Approach: Student Behaviours, Perceptions and Learning Outcomes.* Toronto: Higher Education Quality Council of Ontario.

Acknowledgements

The authors are very grateful for the support of Siddarth Hari throughout this project; for his thoughtful contributions to the overall study and survey design and for his logistical management of the research. Heartfelt appreciation is also extended to Monique Herbert, Susan Elgie and Ruth Childs for their very helpful insights early on in the project, and to Olesya Falenchuck for so generously sharing her clear understanding and practical approach to statistical analysis. Finally, we are very thankful to all of the students who supported this research and gave of their time to provide us with insightful feedback and suggestions for continued improvement.

Table of Contents

List of Tables

List of Figures

Executive Summary

Introduction

As we move forward into a new millennium and the landscape of higher education continues to change rapidly, there is a growing interest in using technology to improve the student learning experience. With the developing awareness of the science behind learning, an increasing number of higher education faculty and course instructors are looking for means to use their time with students more effectively, and see technology as a potential part of the solution.

The inverted (or flipped) classroom is a teaching approach in which students are introduced to the fundamental ideas of a course through pre-class activities that often involve the viewing of a short video. This enables the in-class time to be used for learning activities that go beyond traditional lecturing. In many ways, this is akin to the practice of requiring readings before class and using class time for debate and discussion that is common in many humanities and social science courses and seminars. In some sense, the inverted classroom approach is an adaptation of this long-standing instructional method to courses, in such fields as engineering and science, for which readings before class are not typically required or completed. This approach has great potential to create a more student-centred environment that is more conducive to effective learning. It can be used to support a number of fundamental principles of the science of learning that have been well established over the past 100 years. It enables students to engage in more active learning experiences, process the new material in meaningful ways and incorporate these new ideas into their own existing knowledge framework. It allows for enhanced student-faculty interactions and opportunities for prompt formative feedback throughout the learning process. As well, it supports the instructor to scaffold the material appropriately, as there is a greater awareness of how much the students understand prior to and during the in-class experiences. Despite the strong theoretical reasons for use of the inverted classroom approach and growing interest in the approach, empirical studies that systematically investigate the effects of the approach on students' behaviours, perceptions and learning outcomes are not often seen. Therefore, more empirical evidence is needed to support effective implementation of the approach.

Thus the primary purpose of this study was to address the following two research questions:

1) What were the **student behaviours** and **perceptions** associated with the inverted classroom approach?
2) As compared to the traditional teaching approach, what effect did the inverted classroom approach have on **student self-efficacy** and **learning outcomes**?

This study was set in a large engineering physics course, with approximately 300 students, on electric and magnetic fields offered in the second year of the electrical and computer engineering program at the University of Toronto. The course was taught in Winter 2012 using a traditional lecturing approach that was primarily instructor-led but did incorporate the use of a tablet for teaching as a replacement for the blackboard and regular active-learning exercises through in-class response system questions (typically 1 or 2 questions per class). In Winter 2013, the course was taught by the same instructor using the inverted classroom approach, which required students to watch a 20- to 30-minute lesson video before each class. This video provided students with fundamental knowledge, definitions, equations, historical context and basic problem-solving examples. Thus the in-class time was used for more active learning opportunities with short (3- to 10-minute) periods of individual, partner or group exercises, followed by a period of review by the instructor with the entire class.

Research Design and Methods

The study employed a quasi-experimental design that treated the 2012 cohort of students as the control group (the traditional cohort) and the 2013 cohort as the treatment group (the inverted cohort). A total of 12 data sets were collected from the two student cohorts, approximately around the same time for the two years and using the same instruments, except the final exam. The data sets are grouped into the following categories.

1) *Student characteristics*: Prior academic performance and learning style
2) *Student behaviours*: Student lecture attendance, lesson video viewing behaviour, student engagement questions and student-faculty interaction questions in the end-of-term survey and focus groups
3) *Students' perceptions and evaluation of instruction*: Student responses to the instructional approach through questions in the end-of-term survey and focus groups, and the official Faculty course evaluations
4) *Student learning assessments*: Pre- and post-instruction concept inventory tests, in-class analytic problem-solving quizzes, final course grades and a long-term concept retention test
5) *Self-efficacy*: Self-efficacy questions in the end-of-term survey

To prepare for the data analysis, a number of actions were taken. Comparisons were made between the two cohorts in terms of prior academic performance, learning styles and prior course-related knowledge, and no statistically significant differences were found. Combined with the fact that the course was offered in a program that has a fixed curriculum for the first two years, we were confident that the two cohorts were comparable for the purposes of this study. In addition, factor analysis was used to derive a set of composite scores for student engagement and self-efficacy factors. A composite measure for the engagement with the inverted classroom approach was created using cluster analysis on the basis of the lesson video viewing and class attendance data.

Two sets of hierarchical regression analysis were performed on two of the learning outcomes that had statistically significant differences between the two cohorts: final course grades and analytic problem-solving quiz scores. In addition, thematic analysis was applied to the comments for the open-ended survey questions and for the focus group discussions.

Results

The primary findings relating to student perceptions were:

1) **Improved student-faculty interaction:** Improvements in the frequency and quality of in-class interactions between students and faculty were observed with the inverted classroom approach. Only 25% of students in the inverted cohort indicated that they had never had any interaction with the instructor during class, whereas this number was 56% for the traditional cohort. As well, 70% of students in the inverted cohort stated that they were satisfied with their level of interaction during class, compared to 51% for the traditional cohort.

2) **Improved class enjoyment and interest in the course material:** Just over half (56%) of respondents indicated that the inverted classroom approach made the in-class time more enjoyable than a traditional classroom, with 25% indicating that it was not more enjoyable. The inverted cohort's ratings of their enthusiasm at the end of the course was significantly higher than that reported by the traditional cohort (on a scale of 7, M_{inv} = 4.40, M_{trad} = 3.93). Forty-three per cent of students in the inverted cohort ranked the course as either their favorite or second-favorite course of the five they were taking that term, as opposed to 34% for the traditional cohort.

3) **Sufficient support for learning:** Over 70% of students in the inverted cohort indicated that they were given the necessary support to learn the course material effectively and had the opportunity to have their questions answered. As well, more than 80% of the students in the inverted class found the lesson videos to be an effective introduction to the course materials.

4) **Mixed student preference:** Student reaction to the inverted classroom was mixed, with some seeing the possible benefits and engaging actively with the new process and others maintaining a strong preference for the traditional lecture-based approach. Indeed, only 48% of the students indicated that they preferred the inverted classroom approach to the traditional lecture format, with 36% indicating that they preferred the traditional approach.

5) **Use of student time:** Approximately 50% of students indicated that their time, both in class and overall, was used more effectively in the inverted approach than in the traditional approach, with just over one-third of students disagreeing that their time was used more effectively. A sizable minority (34%) also reported that the approach resulted in them having to "cram less" for the major course assessments.

6) **Course workload:** While the overall ratings of the workload for the course were not found to be statistically different between the two cohorts, a vocal minority of students expressed concern over the consistent effort needed to keep up with the video viewing in preparation for class. Indeed, 32% of the inverted cohort versus 22% of the traditional cohort indicated that they disagreed with the statement that "Compared with the other courses that I have taken in my second year, the amount of work required for this course is reasonable."

The major results relating to student behaviours were:

1) **Class attendance:** The inverted classroom approach did not affect class attendance. For both the cohorts, the class attendance averaged about 60% for the term.

2) **Pre-class lesson video viewing:** The percentage of the cohort that completed the pre-class viewing for each class ranged from a low of 34% to a high of 80%, with an average of 57% over the course of the term.

3) **Relationship between class attendance and video viewing:** There existed a reasonably strong correlation between pre-class lesson video viewing and in-class attendance for the inverted cohort ($r = 0.62$, $p < .001$).

4) **Engagement with the inverted classroom approach:** Using the combined measures of in-class attendance and pre-class video viewing, it was found that only one-fifth of the class (21%) actively engaged with the inverted classroom approach as it was intended, meaning that these students attended at least 75% of the classes and were prepared for at least 75% of these class sessions. Over half the inverted cohort (51%) engaged with the process for at least half the classes, while 22% were effectively disengaged from the approach and attended less than 50% of the classes and prepared less than 50% of the time.

Primary findings relating to the effects of the inverted classroom approach on **student self-efficacy** and **learning outcomes** were:

1) **No change in student self-efficacy:** No statistically significant differences were found between the two cohorts in their self-efficacy in explaining the course concepts to others, learning the course material and being successful in an engineering program.

2) **No change in measures of conceptual understanding:** No statistically significant differences were found between the inverted classroom and traditional cohorts in the three measures of students' conceptual understanding of the course material: (a) scores on the post-instruction concept inventory test, (b) the gain scores on the concept inventory test, and (c) the scores on the long-term concept retention test.

3) **Significant improvement in the scores and student confidence in their analytic problem-solving capabilities:** The inverted classroom cohort performed significantly better than the traditional cohort on three of the four in-class "surprise" quizzes that assessed students' ability to solve problems analytically. The comparison of the overall average for all four quizzes for each cohort also found statistically significant differences (out of 10 points, $M_{\text{inv}} = 6.20$, $M_{\text{trad}} = 4.65$ and $r^2 = .16$). The level of confidence in answering the questions in those quizzes was also significantly higher for the inverted cohort than for the traditional cohort.

4) **Course academic performance:** In terms of the overall performance in the course, the inverted cohort had a higher final course mark average than the traditional cohort, but the effect size was very small (M_{inv} = 70.36, M_{trad} = 73.41 and r^2 = .01). It is important to note that while the major assessments in the course were similar in nature, they were not identical for the two cohorts.

Hierarchical regression analyses on the analytic problem-solving quiz scores and the final grades were performed on the data of the two cohorts separately, while entering three blocks of variables: (a) student characteristics, measured by prior academic performance and learning styles; (b) learning experiences, represented by the instructional approach (traditional or inverted), degree of student-faculty interactions during class, and three student engagement factors relating to how students studied in the course; and (c) the three self-efficacy factors.

The regression model associated with the analytic problem-solving quiz scores for both cohorts found that the 14 independent variables accounted for 59% of the variance in these quiz scores. The significant predictors of better performance on these quizzes were prior academic performance (β = .44), using the inverted classroom approach (β = .30), better lecture attendance (β = .18) and a preference for an intuitive learning style (β = .18), when the other variables were controlled.

In terms of the course academic performance, the 14 independent variables in the regression model accounted for 75% of its variance. Again, prior academic performance was the strongest contributor to the course grade (β = .71), while lecture attendance (β = .20) and self-efficacy in explaining course concepts to others (β = .16) were also significant contributors when the other variables were controlled. The use of the inverted classroom approach was not found to contribute significantly to students' overall course performance.

A subsequent set of hierarchical regression analyses was run on the data of the inverted cohort only, while entering two blocks of variables: (a) student characteristics, the same as before, and (b) level of engagement with the inverted classroom approach ("low" and "medium," with "high" as the reference). The result showed that prior academic performance was the most significant predictor of the final course grades (β = .72), and the level of engagement with the inverted classroom approach made a significant difference, with β_{medium} = -0.17 and β_{low} = -0.27, when the other variables were controlled.

Overall, the results of this study support the notion that the inverted classroom approach has the potential of exerting a positive impact on student learning experiences, such as student-faculty interactions and in-class enjoyment, and on certain learning outcomes, particularly the analytic problem-solving capabilities. Further, the importance of a supportive learning environment and student engagement with the inverted classroom approach was strongly supported by the data. It was also found that while the new instructional approach was implemented, students had mixed reactions about the approach itself and the related workload. Students' preferred learning styles appeared to play some role in influencing their perceptions and their learning outcomes.

Recommendations

In order for the inverted classroom approach to improve learning, students must take greater responsibility for their own learning process and ensure that they make good use of the pre-class and in-class learning activities. In order for students to make the necessary transition from the comfort of their traditional mode of learning, it is critical that the instructor provide the support and motivation necessary for students to see value in the new learning approach.

As a result of this study, we make the following recommendations for successful implementation of the inverted classroom approach:

- Motivate and support students to develop new learning techniques.
- Carefully design the lesson videos or pre-class activities using a research-based approach.
- Stress the importance of viewing the lesson videos before attending the class.
- Properly integrate the pre-class lesson videos or activities with the in-class learning experiences.
- Take the time to design well-structured and thoughtful in-class activities.
- Provide a supportive learning environment through the use of appropriate technology and feedback mechanisms.
- Consider using the inverted classroom approach in flexible ways.

Final Reflections

This study contributes to the growing literature on use of the inverted classroom approach for the following reasons.

- It was a comprehensive and systematic assessment of students' behaviours and perceptions associated with the inverted classroom, as well as its effect on student learning outcomes.
- For assessment of learning outcomes, it went beyond the common practice of using the final grades as the primary indicator of outcomes and encompassed a number of additional instruments to measure conceptual understanding and analytical problem-solving capabilities.
- With each cohort having more than 300 students, the findings were based on a relatively large sample size.
- The instructional method was carefully designed on the basis of the key principles embedded in the inverted classroom approach and the assessments were deliberately executed for comparison purposes, albeit with the existence of a few flaws.
- Student engagement with the new approach was examined and assessed.

It is our hope that this study will enhance the understanding about the benefits and challenges of implementing the inverted classroom approach in general, as well as its effects on students' learning experiences and outcomes, which are the focus of this study. We also hope that continued research efforts will be made to examine the effects of the inverted classroom approach across a wide range of disciplines using longitudinal studies. When considering the benefits of the inverted classroom, additional desirable affective and cognitive outcomes should also be assessed, such as the development of critical thinking and life-long learning skills, collaborative and team-based learning skills, degrees of resiliency and self-motivation, and inclusiveness in the learning environment.

As with any educational innovation, the use of the inverted classroom approach is not a solution in and of itself. It is a tool, a vehicle that can enable students to create lasting meaning for themselves through the supportive guidance of their instructor and peers. It must be applied carefully, with consideration given to the holistic experience of the students and the fact that it is still an emerging teaching and learning technique for both students and instructors. More lessons for its effective implementation need to be learned and shared. Yet as the technology and architecture that allow for the implementation of the approach become more widely available, it is expected that both students and educators will come to be more adept at learning and facilitating under the model, and the potential of this approach will be realized more fully.

1 Introduction

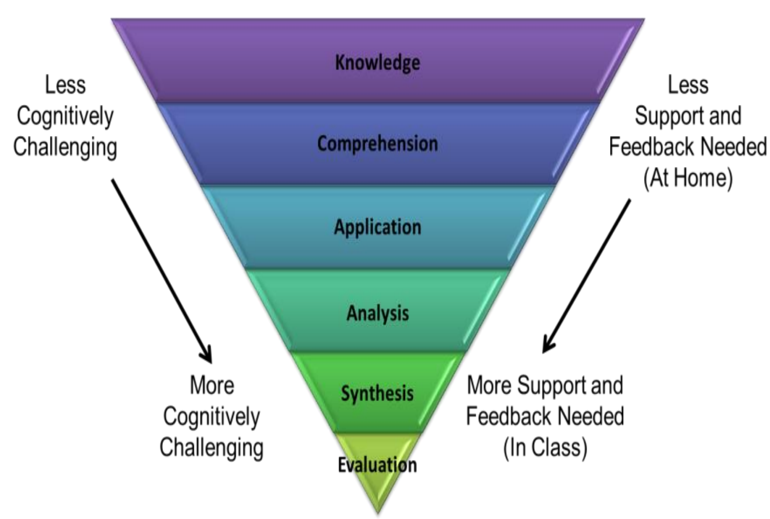
The primary purpose of this study was to assess the effects the inverted classroom approach had on student behaviours and perceptions of their learning experience, and on the course learning outcomes in an intermediate-level engineering physics course.

This report summarizes the key findings from this study and provides a set of recommendations for the appropriate use of the inverted classroom method. This section starts with a short summary of the theoretical foundations for the use of the inverted classroom approach, along with a brief overview of the prior research on this approach. The institutional and course context is then described, along with the specific details of both the inverted classroom approach and the traditional approach used with the treatment group and the control group respectively within the study design. In the following sections, the research methods and data analysis results are then presented, followed by our overall observations, recommendations and final reflections.

The Rationale for Using the Inverted Classroom Approach

The inverted classroom approach is also known as the flipped classroom approach. It involves a reversal of the time and place for traditional lecture and homework, thus transforming teaching and learning methods in many ways. Use of learning technologies, particularly multimedia, has made the inversion of the classroom technically viable. Under the inverted classroom model, students learn the basic facts, background, terminology, physical laws and problem-solving approaches of their course through short videos and embedded quizzes that they watch and complete *prior to* coming to class. This requires students to develop a certain level of understanding of course materials before attending class and allows more time in class for problem-solving and translating conceptual understandings into practical applications. It also creates more opportunities for the instructor to provide students with immediate formative feedback and interact with them in a more meaningful way. Thus it enables students to engage more actively with course material during the face-to-face class time. The approach usually involves a variety of active and collaborative learning exercises and therefore has the potential to promote deeper learning of course material (Prince, 2004; Menekse, Stump, Krause & Chi, 2013). In many ways, this is akin

Figure 1: Inversion of Bloom's Taxonomy of Educational Objectives – Cognitive Domain

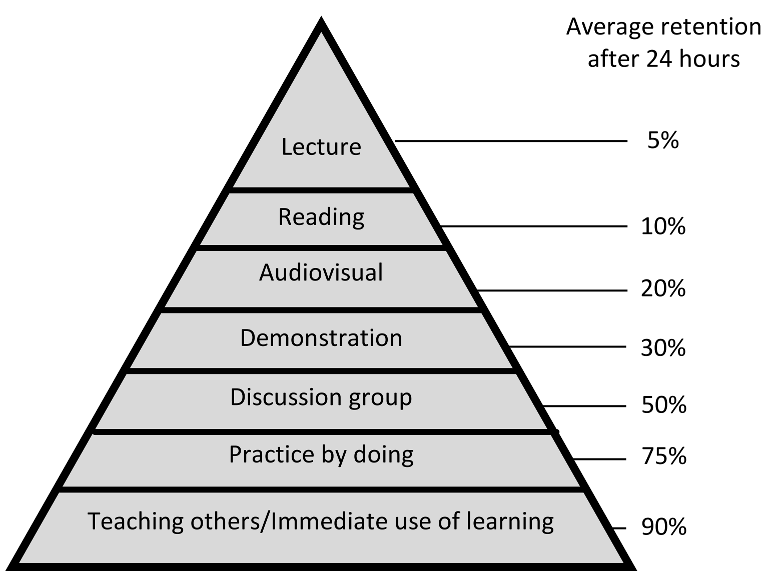


to the practice of requiring readings before class and using class time for debate and discussion, which is common in many humanities and social science courses and seminars. The inverted classroom approach can be viewed as an adaptation of this long-standing instructional method to courses, in such fields as engineering and science, for which readings before class are not typically required.

The potential effectiveness of the inverted classroom approach is supported by several education theories and well-known best practices in teaching. First, the approach offers additional expert support to students at the higher levels of the Cognitive Domain of Bloom's Taxonomy of Educational Objectives, as illustrated in Figure 1 (Bloom, 1956; Talbert, 2011). In many traditionally taught mathematics, science and engineering courses, lectures focus on the lower levels of this taxonomy and provide students with an introduction to the basic knowledge and comprehension of the concept at hand. These lectures also often include worked *examples* of the application of this knowledge but do not allow students to *practice* this application. This means that the application and analysis stages of learning take place outside of the class, usually through homework problem sets or preparations for course assessments. In courses taught in this way, there is usually no direct opportunity for prompt formative expert feedback for the students at the higher, more cognitively challenging levels. Under the inverted classroom model, the pre-class videos and quizzes, which are a main component of the inverted classroom approach, help students begin to develop their learning within the knowledge and comprehension realms. This enables the class sessions to be used to solidify or correct students' conceptual understanding and, more importantly, to help students move into the higher levels of the cognitive domain with the direct support of the instructor.

Another advantage of this new approach is that it provides the opportunity for both the students and the instructor to create more personalized learning experiences, even in large classes. Through the pre-class videos, the core material in the course is available to the students to learn at their own pace and review as needed. This can be particularly helpful for students whose first language is not English or for those that might need some additional time to process new concepts. If designed well, the in-class activities allow the student to engage with the material through a variety of means, including individual thought and reflection as well as paired or group collaborative learning experiences. Given that primary learning opportunities occur during a student's individual engagement with the material,

Figure 1: Average Retention after 24 Hours Depending on Educational Method (adapted from Sousa, 2011)



either through the video viewing and pre-class quiz completion or during the in-class activities, each student must take more ownership of their learning process. In this way, an advantage of the inverted classroom approach is that it can be used to support the intentional and structured development of critical individualized lifelong learning skills. From the instructor's point of view, it is possible to tailor his or her teaching approach to the needs of the class through a careful review of the pre-class exercises (e.g., quizzes) and through the in-class interactions with the students during the periods of activity.

The inverted classroom approach also has the potential to enhance knowledge retention. The retention of new material requires that students "work" with new concepts and integrate these into their own existing knowledge framework. In his book *How Brains Learn*, David Sousa summarizes over 50 years of research using a retention pyramid that illustrates that the rates of material retention 24 hours after instruction vary greatly depending on the mode of instruction used (Sousa, 2011)(see Figure 2). For example, individuals retain on average about 5% to 10% of material learned through verbal processing (lecturing or reading), while this increases to between 75% and 90% when instruction takes a more active form of "practice by doing" or "teach others/immediate use of learning." The pyramid illustrates the effectiveness of an active approach to learning. It should be understood that these numbers are averages and that much depends on the quality of the various activities. The inverted classroom approach is intended to provide more opportunities for those active forms of instruction to help students retain the new knowledge they have learned.

Finally, the inverted classroom addresses each of Chickering and Gamson's (1987) *Seven Principles for Good Practice in Undergraduate Education*:

1) Encourages student-faculty contact
2) Encourages cooperation amongst students
3) Encourages active learning
4) Gives prompt feedback
5) Emphasizes time on task
6) Communicates high expectations
7) Respects diverse talents and ways of learning

Thus the basic premise of the inverted classroom approach is that it has the potential to improve student learning experiences and outcomes by enabling:

1) The instructor to design learning activities and opportunities that ***provide the appropriate scaffolding*** between students' existing understanding and abilities and the desired learning outcomes of the course;
2) Students to solicit support for and receive immediate feedback on their learning during the in-class time through ***more interactions*** with their peers and their instructor;
3) Students to engage in meaningful learning experiences through ***in-class activities and exercises for higher levels of learning***, such as analysis and application;

4) Students to take more ***responsibility for their own learning process*** and create a more personalized learning experience;
5) The instructor to support the students in the intentional ***development of lifelong and self-regulated learning skills*****.**

Literature Review

The effectiveness of the inverted classroom approach has only been considered in the literature over the past 15 years. Two of the earliest publications (Foertsch, Moses, Strikwerda & Litzkow, 2002; Lage, Platt & Treglia, 2000) found that students and faculty reacted quite positively to the inverted classroom. These studies agreed that most students appreciated the ability to view the content, or "lecture," videos in their own time and pace, that the rating of the usefulness of the face-to-face time was higher for the inverted approach relative to the traditional approach, and that the inverted approach increased the interactions between the instructor and students. However, their findings differed in terms of whether the inverted classroom approach required more work of students than a traditional course. Also, in both of these studies, students had problems with the technical delivery and the usability of the videos (e.g., easy fast-forwarding or rewinding) due to the immaturity of the required technology. Lage et al. (2000) also stressed that the inverted classroom approach was able to accommodate various student learning styles.

As the technology required to prepare short videos has become more accessible, an increasing number of instructors at higher education institutions around the world are moving to the inverted classroom model of teaching. As a result, there has been a growing body of literature and media reports on the inverted classroom approach (Hamdan, McKnight, McKnight & Arfstrom, 2014; Talbert, 2014; Watters, 2012) and the approach has been tried out in various disciplines. Some recent research papers (Findlay-Thompson & Mombourquette, 2014; Post, Deal & Hermanns, 2015) have reported mixed reactions towards the use of the inverted classroom approach. Positive comments were related to the flexibility of working on videos at one's own pace, and helping students become independent learners while some students expressed frustration about the approach and concerns over time management in balancing various learning resources.

However, most papers continue to describe the particulars of the approach and the student perceptions of the method, and there is still lack of rigorous empirical studies of the approach. As one recent review paper (Bishop & Verleger, 2013) has concluded, although overall students respond quite positively to the new teaching approach, there is a lack of research that focuses on measuring student learning outcomes. A small body of literature exists that compares the inverted approach to the traditional teaching approach and presents some empirical evidence. A conference paper (Papadopoulos & Roman, 2010) indicates that the inverted model had a greater positive effect on the learning of the basic concepts than did the traditional model in a first-year engineering physics course taught at the University of Puerto Rico. Specifically, a larger increase was found between the pre- and post-test scores on a concept inventory quiz for students who were exposed to the inverted classroom than for those who were taught using a traditional method. However, no statistically significant difference was found in student learning gains. This might be due to the small sample size of the study (inverted: n = 43, traditional: n = 11).

More recent studies have reported mixed results on student learning outcomes. A very positive result was found by a group of instructors at the University of Toronto, who observed an 8% increase in final exam performance when they moved to the inverted classroom approach for a first-year computer programming course (total n = 1,307) (Horton, Craig, Campbell, Gries & Zingaro, 2014). While the final exams for the traditional and inverted cohorts did contain different questions, the researchers found that the difficulty levels of the two exams were rated the same by independent experts in the field. On the other hand, McClelland (2013) found that students taught using the inverted approach (n = 146) in a second-year engineering fluid mechanics course performed slightly worse on the identical final exam than did the traditionally taught cohort in the previous course offering (n = 149) (average = 80.2% versus 83.7%, p < .05); and similar results were observed for common quizzes that were given throughout the term. Both Bates and Galloway (2012), in their introductory physics course, and Choi (2013) in his introductory software engineering course, found that the inverted approach improved conceptual understanding. Yet Choi also found that it did not improve the overall performance in the course. Other papers have reported no significant difference between the traditional and inverted cohorts on common exams or pre-/post-tests of conceptual understanding in first-year engineering and mathematics courses (Lape, Levy, Yong, Haushalter, Eddy & Hankel, 2014; Love, Hodge, Grandgenett & Swift, 2013; Morin, Kecskemety, Harper & Clingan, 2013). In addition, improvements have been observed in terms of how students at the lower end of the grade distribution have performed. For instance, Ossman and Bucks (2014) found that the percentages of students who withdrew, failed or achieved a letter grade of D dropped from 12.1% to 9.1% in a first-year engineering computing course when they moved to an inverted approach.

In all cases, the importance of student engagement with the new learning approach for successful outcomes has been highlighted. As Love et al. (2013) have observed, when students progressed through the term and seemingly adapted to the inverted classroom method, the improvements between term test scores were significantly greater compared to the same gains made by a traditional cohort. As well, Lape et al. (2014) acknowledge the importance of using active learning exercises during the face-to-face time, as opposed to the pure “flip” in which the homework exercises were simply moved into the lectures with instructors providing support for students as they solved the problems. Much of the inconsistency observed in the recent literature on the inverted classroom is likely due to the wide variety of ways in which this approach has been implemented. The types and relative quality of in-class and out-of-class learning materials and experiences within this body of research vary considerably.

In Ontario, the educational materials for the implementation of the inverted classroom approach have appeared occasionally in both K-12 and postsecondary settings. For example, the Ontario Teachers’ Federation hosted a webinar on the topic for K-12 teachers in 2013 (Sherry & Skillen, 2013). Resources about the technique have been posted on the websites of teaching and learning centres of some postsecondary institutions (e.g., Humber College, Western University) and it is reported that Algonquin College has started to use the technique to teach the workings of editing software (Educause, n.d.). As the inverted approach becomes increasingly popular, many questions remain to be answered to understand the extent to which the inverted classroom can enhance teaching and learning.

Research Questions

Given the aforementioned background, this study attempted to answer the following primary research questions:

1) What were **student behaviours** and **perceptions** associated with the inverted classroom approach?
2) As compared to the traditional teaching approach, what effect did the inverted classroom approach have on **student self-efficacy** and **learning outcomes**?

Institutional and Course Background

This study was conducted within the Faculty of Applied Science & Engineering at the University of Toronto, which is a publically funded research-intensive university situated within the Greater Toronto Area. The Faculty of Applied Science & Engineering (FASE) is home to 275 faculty members, 5,000 undergraduate students and almost 2,000 graduate students. The FASE has an international reputation for offering dynamic programs that enable students not only to receive an excellent engineering education but also to develop more fully through work-placement opportunities, such as the Professional Experience Year, or through one of the many Engineering Minor programs. One of the eight departments making up this faculty is the Edward S. Rogers Sr. Department of Electrical and Computer Engineering (ECE), which typically has around 300 undergraduate students in each year of the program, for an overall undergraduate cohort of about 1,500 students. The first two years of the program consist entirely of required courses and each program year is usually split into two or three lecture sections with class sizes varying between 100 to 150 students.

This project was built around the teaching of one of the core second-year, winter-term courses within the ECE program called *ECE221H1S: Electric and Magnetic Fields*. The course focuses on the essential physical understanding of static electric and magnetic fields. Most students in the course have seen about 75% of the course material in one of their first-year courses. In addition, all students would have been exposed to many of these ideas in their high-school curriculum, although there is a significant variation in the extent and quality of that early exposure. However, ECE221H1S approaches the material through the use of vector calculus, which students learn in the previous term. In addition, there is a stronger emphasis on the use of the primary coordinate systems (Cartesian, cylindrical and spherical) in order to solve problems in three dimensions. Due to the abstract nature of the course material along with the addition of these two new mathematical components, this course is typically considered to be one of the most difficult courses of the four-year curriculum. In addition, the winter term of the second year is considered to have the heaviest workload within the ECE program due to the fact that four of the five courses have significant lab components and two of the courses have major design projects, one of which is a term-long web server software project.

The concern for the course was that many students were completing it and moving into the third year of the program with significant deficiencies in their understanding of several basic concepts. This was observed in both the final exam for the course and in the application of these concepts in a subsequent third-year course. This indicated that learning in both the immediate and long-term contexts was not occurring at a desirable level.

Successful learning of the course material depends on a strong conceptual understanding of very abstract material. The course also requires students to properly apply the appropriate mathematics to solve analytic problems. With the need for both problem-solving skills and sound conceptual understanding, the inverted classroom approach was considered to be a promising way for students to learn in this course. This approach enables students and the instructor to make use of the live face-to-face class time to enhance or correct the understanding of the concepts, while at the same time working through the solutions to problems in a collaborative way. Research shows that a more active approach has been quite successful in "conceptually heavy" courses (Chasteen, Pollock, Pepper & Perkins, 2012), and that approaches that allow for in-class responses to conceptual questions and time for follow-up peer instruction have been particularly beneficial in the development of strong conceptual understanding (Crouch & Mazur, 2001).

For many years, the course had been taught by the same instructor in a "traditional" instructor-centred teaching approach. In this approach the lectures were used as the primary means to introduce students to the core concepts within the course, and the instructor spoke for most of the class session. While questions were encouraged and attempts were made to engage with the students, on the whole the student in-class experience was mostly focused on listening to the instructor and taking comprehensive notes. However, this traditional approach did involve a number of technology-based components that were intended to increase student engagement in learning, including the use of a tablet computer as a replacement for the blackboard, the incorporation of animations, applets, videos and live demonstrations, and the use of a classroom audience response system (i.e., iClickers).

Intervention for the Course

When the intervention – the inverted classroom approach – was implemented in 2013, the students were required to take greater ownership of their learning process, as it was expected that they would come to class well-prepared. A series of 35 "lesson videos" were created by the instructor to provide students with an introduction to the fundamentals of the course material. The videos had an average length of around 25 minutes. They were based on previous years' lecture notes for the course and were simple screencasts, created through Camtasia Studio.[1] They were delivered through the learning management system for the course and incorporated "Test Yourself" quizzes throughout the video at approximately 10-minutes intervals. With the pre-class preparation completed, there was significantly more time during the lectures for individual and group active learning exercises requiring students to practice problem-solving on the basis of the key concepts and theories covered in the lesson videos. A detailed comparison of the two instructional approaches is presented in Table 1. A more thorough discussion of how the specific course material was taught using this method can be found in Stickel (2014).

[1] Sample videos can be found at http://youtu.be/S2t1aCwx1wg and http://youtu.be/vVObsHk7klg

Since there was a concern that students might find it difficult to take responsibility for learning the course material presented in the lectures, a number of online resources were made available to enhance the support opportunities for the students. These included:

- Both print and video examples, as well as video summaries of the solution to the first assessment in the course;
- A discussion forum where students could anonymous post questions and answers. This forum was closely monitored by the teaching staff so they could respond quickly to the students;
- A collection of online applet and animation resources;
- The database of lesson and lecture videos.

At the beginning of the course there were also plans to offer online office hours, but it was found that the technology was not capable of closely replicating a live office hour since it did not allow the instructor to accurately draw figures and write solutions to the questions that might be asked. As a result, only live office hours were offered.

Since it was difficult to get a reliable and accurate measure of how much students accessed each of these online resources, it was decided to exclude the use of these materials from the quantitative analysis within this research study. Many of the print and video examples, and the collection of online applet and animation resources, were also available to the traditional cohort. Finally, due to difficulty entering formulas, we found that the discussion forum was not used as much as had been anticipated at the start of the course. Specifically, about 30% of the inverted cohort engaged with the forum through regular reading and occasional posts, while roughly 10% of the cohort was actively engaged through regular question and answer postings.

Table 1: Comparison of the Two Instructional Approaches

Cohort	Summary of the Key Features of the Instructional Approach
Traditional Instructor-Centred Approach (2012)	• Lectures followed a general structure of: (a) concept motivation/ introduction/definitions/derivations, (b) example problem(s), and occasionally (c) discussion of engineering applications, and/or (d) experimental demonstrations. • The instructor used a tablet computer instead of the chalkboard for in-class notes. Lecture outlines had been posted for students prior to class. The instructor accommodated questions during the lectures. • Students responded to in-class questions through the use of a classroom response system (iClickers) (approximately one or two per class). • Fully annotated notes or lecture videos were NOT provided.
Inverted Classroom Approach (2013)	• Students were asked to a watch a video prior to coming to class (ranged between 15 to 40 minutes, with an average length of 25 minutes). • Lesson videos typically covered (a) the concept motivation/ introduction/ definitions/derivations component, and (b) usually one example problem. • Each lesson video contained embedded "pop-up" quizzes (usually two per video and occurred every 10 to 15 minutes). • A 7% course participation grade was provided as an incentive to watch the videos and complete the quizzes prior to the associated class. • The in-class time included a variety of active exercises such as classroom response questions with peer instruction opportunities and individual and group problem-solving experiences. These were based on in-class outlines provided to students before the class. • Some of these active exercises involved the use of the same classroom response system that was used with the traditional cohort. On average, about two to three questions of this type were asked in each class. • During the exercises the instructor circulated through the standard lecture hall, where approximately 100 students were attending the class, given that the cohort was divided into three lecture sections. • After a period of activity, typically between 3 and 10 minutes, the instructor reviewed or summarized the solutions to problems with the entire class, through the use of a tablet computer instead of the chalkboard. • An edited lecture video of these summary discussions by the instructor was provided to students for review purposes after each class. • An online discussion forum[2] was used to support student learning throughout the course. The tool enabled students to post questions, receive answers to these questions, and answer questions from other students outside of class.

[2] *Coursepeer* (http://www.coursepeer.com/) was used to implement the inverted classroom. The system included hosting videos, running embedded quizzes, posting outlines, and an online question-and-answer discussion forum.

2 Research Design

The research study adopted a two-year quasi-experimental design that involved a control group and a treatment group. It was structured such that the course was taught in the traditional way in the winter term of the first year (2012) of the study. In the winter term of the following year (2013), the same instructor taught the course using the inverted classroom approach, with the new cohort of students completing the same set of assessments related to the research study. All the students registered in the course were invited to participate in the study. A number of assessment tools were put in place in both years (see Table 2). A research ethics protocol was approved by the University of Toronto's Research Ethics Office.

Rationale

The authors deliberately chose to apply the intervention to the entire cohort over the full course, rather than to a subset of the cohort or for part of the course, for the following reasons.

First, it was expected that students and the instructor would need some time to become accustomed to the new teaching and learning approach. None of the students had prior experience with the inverted classroom approach, and it was a considerable shift in their method of learning. Thus a study design which focused only on applying the approach for part of the course would not have enabled sufficient time to adapt fully to the new method of instruction.

Second, in a sub-group design, it would be likely that some students in the control group could have accessed the additional materials associated with the inverted classroom approach, thus making it difficult to detect the differences between the two groups as a result of the inverted classroom approach.

Third, since this second-term second-year course was situated within a program that has a fixed curriculum for the first two years, it had been expected that the key characteristics of interest of the two cohorts, such as prior academic performance, learning styles and performance on a pre-instruction concept inventory test, would be very similar. We tested this hypothesis in our data analysis and found it to be supported by the data (see the results in Table 2.)

Nevertheless, as the control and treatment groups were one year apart, their characteristics and learning experiences in other parts of the program could become confounding factors to the results of the study.

Data Collection and Measurements

A total of 12 data sets were collected from the two student cohorts. The data sets can be grouped into the following categories:

1) *Student characteristics*: Prior academic performance and learning style
2) *Student behaviours*: Student lecture attendance, lesson video viewing behaviour, student engagement questions in the end-of-term survey and focus groups
3) *Students' perceptions and evaluation of instruction*: Student responses to the instructional approach through questions in the end-of-term survey and focus groups, and the official faculty course evaluations
4) *Student learning assessments*: Concept inventories – pre- and post-instruction tests, in-class analytic problem-solving quizzes, final course grades and a long-term concept retention test
5) *Self-efficacy*: Self-efficacy questions in the end-of-term survey

The detailed descriptions of these data sets are shown in chronological order by approximate data collection time in Table A-1, found in Appendix A.

Sample Profiles

A total of 310 and 338 students enrolled in the course in 2012 and 2013, respectively. Each year, around 3% of the enrolled students did not complete the course. This resulted in a total of 299 and 329 students in the 2012 and 2013 cohorts who were included in our data files.

Table 2 summarizes the descriptive statistics for the major variables within this study for the two cohorts. To examine the comparability of the two student cohorts, we compared the following indicators: (a) prior academic performance; (b) learning style distribution; and (c) concept inventory pre-test scores. No statistically significant differences were found for these indicators. This suggests that the two student cohorts were comparable in terms of their academic ability before taking the course, their learning styles and prior course-specific knowledge. Thus the data collected from these two cohorts were comparable for the purposes of this study.

The preference profiles for learning styles were quite similar for both student cohorts[3]: slightly more than half of the students were reflective versus active learners; approximately two-thirds of the students were sensing learners in contrast to intuitive learners; approximately 80% were visual learners in contrast to verbal learners; and approximately 60% were sequential learners in contrast to global learners. These distributions are very similar to other reported data for engineering students, except for a significant difference in the reflective/active breakdown, where it has been reported that the average distribution for this reflective/active dimension is around 35%/65% for engineering students (Felder & Brent, 2005).

[3] A brief description of these learning preferences can be found in Appendix B.

Table 2: Summary of Descriptive Statistics of Major Variables

Variables	Definitions and Measurements	Traditional Cohort (2012)		Inverted Cohort (2013)	
		n	Mean (SD) or %	*n*	Mean (SD) or %
Prior academic performance	Average grades in percentage for students' first 15 courses completed in their first three terms of the program. Measuring their academic performance prior to attending the course.	151	73.4 (9.30)	203	73.7 (9.36)
Learning styles	Reflective (vs. Active) Intuitive (vs. Sensing) Verbal (vs. Visual) Global (vs. Sequential)	266	52.6% 39.9% 20.7% 40.2%	280	57.1% 37.5% 18.9% 38.2%
Lecture attendance	Percentage of the lectures attended Measuring student academic engagement	299	59.8 (24.9)	326	59.5 (27.5)
Lesson video viewing	Percentage of the lesson videos for which a student watched at least 70% prior to attending the associated lecture	N.A.		329	56.6 (11.5)
Concept inventory: Pre-test score	Pre-test scores in percentage Measuring student conceptual understanding of the course material at the beginning of the course	287	46.3 (15.5)	316	46.6 (15.3)
Concept inventory: Post-test score	Post-test scores in percentage Measuring student conceptual understanding at the end of the course	286	51.5 (19.0)	314	50.5 (18.3)
Concept inventory: Gain score	Gain scores derived from the 14 questions repeated in both the pre-test and post-test assessments. Measuring the difference in student conceptual understanding from the beginning to the end of the course. The gain calculation was based on Hake's formula (Hake, 1998): $Gain = \frac{Post\ Test\ Score - Pre\ Test\ Score}{100 - Pre\ Test\ Score} \times 100\%$ This provides a measure of student improvement on the common 14 pre/post-test items as a percentage relative to the maximum possible improvement.	276	18.5 (48.7)	297	13.3 (41.9)

Variables	Definitions and Measurements	Traditional Cohort (2012)		Inverted Cohort (2013)	
		n	Mean (SD) or %	*n*	Mean (SD) or %
Analytic problem-solving capabilities	Averaged scores of four in-class quizzes for students who wrote all four quizzes. The full score for each quiz was 10. Measuring student analytic problem-solving capabilities	129	4.65 (1.79)	114	6.20 (1.75)***
Confidence in analytic problem-solving capabilities	Averaged scores of all confidence ratings for those students who wrote all four quizzes. The scale was 1 to 10. Measuring student self-reported confidence in resolving certain problems	129	3.47 (1.44)	114	4.60 (1.71)***
End-of-term student survey[4]	The survey data measured (1) student satisfaction with the course; (2) student perception of the frequency and quality of student-faculty interactions; (3) student engagement; and (4) student sense of self-confidence (i.e., self-efficacy) as related to the course and in studying engineering	167	-	177	-
Course academic performance	Students' final grades in the course in percentage	299	70.4 (13.7)	329	73.4*** (13.1)
Long-term concept retention	Scores in percentage obtained from the long-term concept retention test. Measuring student long-term retention of the conceptual understanding of the course material	69	45.8 (13.8)	51	45.5 (18.3)

*** $p < .001$

[4] This is an instrument used for data collection. Details can be found in Table A-1, Appendix A. Descriptive statistics for the survey questions are reported in Section 3.1. A copy of the instrument is included in Appendix E.

3 Data Analysis and Results

This section consists of two parts, each focusing on one of the two research questions and concluding with a summary.

3.1 Research Question #1: Student Behaviours and Perceptions

*What were the **student behaviours** and **perceptions** associated with the inverted classroom approach?*

To answer this research question, we have organized our findings into three areas:

1) Lesson video viewing, class attendance and engagement with the inverted classroom approach
2) In-class experiences: Student-faculty interactions and opportunities for enhanced engagement with the course material
3) Student perceptions of the inverted classroom approach

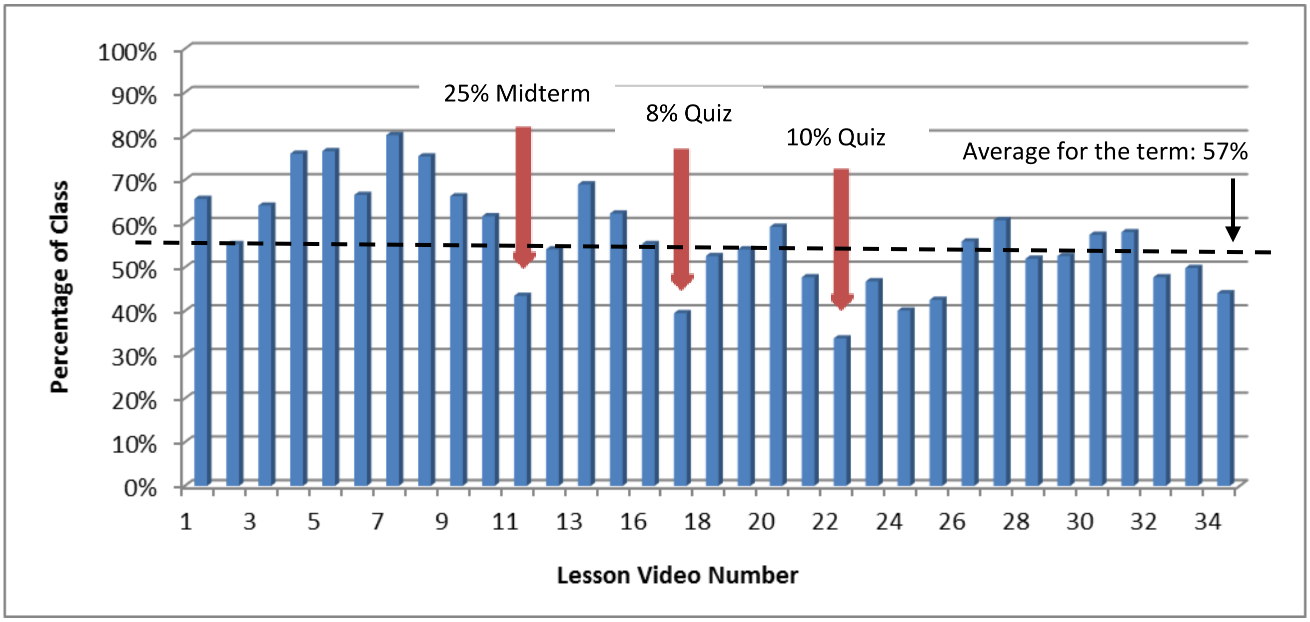
We have concluded this section with a summary and some discussions of our findings related to this research question.

Lesson Video Viewing, Class Attendance and Engagement with the Inverted Classroom Approach

Lesson Video Viewing

A critical element of the inverted classroom approach as it was implemented for this study is that students were expected to watch a short lesson video prior to attending each class. Figure 3 illustrates the percentage of students who watched at least 70% of the associated lesson video prior to the relevant class for each of the 34 class sessions. On average for the term, it was observed that approximately 57% of the students in the inverted cohort prepared for class in this way. As can be seen below, there was a large variation by class session in the percentage of the students who had watched the lesson video before the class, ranging from 34% to 80%, with an average of 57%.

Figure 2: Percentage of Students who Viewed a Minimum of 70% of the Lesson Video Prior to the Relevant Class Session



Whether students made use of the lesson videos before attending the lecture appeared to be associated with their overall workload for a given week. As seen in Figure 3, three of the lowest values coincided with a 25% midterm, an 8% quiz and a 10% quiz, which were times of significantly heavier course work in students' other four courses. This finding was echoed by the voices of the students in focus group sessions:

> *I tried to watch videos as frequently as possible. But as soon as you are into a busy week at the start of mid-terms the amount of videos I watched just fell off, like I was watching every single video and then nothing for a while.* [FG1]

> *As soon as mid-terms start you fall behind for every course and the lectures don't slow down, the material doesn't slow down … But if perhaps during the mid-terms the videos became shorter and more material was covered in class that could be really beneficial because even if you are stuck with I have a mid-term tomorrow I'm going to study for it, I'm not going to watch this video you can go to class and get your important concepts.* [FG1]

Admittedly, another factor that affected video viewing was that some of those videos had only been uploaded the day before the related class, which did not give some students enough time to watch them. This was suggested in the focus group data. This delay in the instructional delivery was due to the fact that it was the first time that the instructor had offered the course in the inverted classroom model and lesson videos were being created on a day-by-day basis during the second half of the course. A small number of students also admitted in the focus groups to not making sufficient efforts to watch the videos:

> *Open the video up, go take a shower come back and then click it on and do the quizzes, and then just record it and then you go back to the other stuff. It happened to a lot of people. I know that.* [FG1]

Nevertheless, when students where asked "When I watched the lesson videos, I usually:" in the end-of-term survey, only 9% of students selected "I did not pay much attention to the video as it played."

Class Attendance

The class attendance patterns for the traditional and inverted cohorts were essentially the same. That is, on average, students in both cohorts attended 60% of the classes, and 66% of the traditional cohort and 63% of the inverted cohort attended more than half of the classes. This suggests that the adoption of the inverted classroom approach contributed little to improvement in class attendance.

Relationship between Lesson Video Viewing and Class Attendance

In order to better understand the relationship between the pre-class video viewing and in-class attendance, we performed two tests. A significant correlation of $r = 0.62$, $p < .001$ was found between these two variables. The chi-square test of independence was also significant, X^2 (9, $N = 326$) = 154.01, $p < .0001$, indicating that these two variables are related. Table 3 summarizes this relationship by showing the number of students in the inverted cohort that fit into 16 possible combinations of pre-class video viewing and class attendance. From this, it can be seen that those who had better class attendance tended to have watched a greater proportion of the lesson videos before class.

The association between video viewing and class attendance was also indicated in student comments:

> *From the very beginning I was like I need to understand what's going on in the videos so when I go to lecture you can understand what he's doing.* [FG2]

> *We don't know what happens in lessons so we don't come to a lecture any more. While you are there, we go to sleep.* [FG1]

> *Some of the students, they didn't watch the video before the class so that's why they are confused. That's why they tend to not to go to the lecture as well.* [FG3]

> *Couldn't watch the lesson video, therefore I thought going into the lecture wouldn't be helpful for me since I would not be able to understand it for an hour.* [open-ended survey response to the question about the primary reason for having missed the lectures]

One of the initial concerns related to the inverted classroom approach was the potential negative effect of the lack of lesson video viewing preparation on in-class attendance. Indeed, the results above do indicate that such an effect existed.

Engagement with the Inverted Classroom Approach

Table 3 shows that only 3% of the inverted cohort attended the majority of the classes but *did not* come to class prepared (that is, having viewed less than 50% of the lesson videos prior to class.) Interestingly, it also gives a good picture of how many students actively engaged with the inverted classroom approach as it was intended to be used. The table shows that only about one-fifth of the cohort (21%) actively engaged with the inverted classroom approach as it was designed, meaning that they attended at least 75% of the classes and came prepared for in-class active learning opportunities at least 75% of the time; 51% attended the classes and had watched the lesson videos at least 50% of the time. On the other hand, 22% of students were more or less disengaged from the process, meaning that they participated less than 50% of the time in both categories.

Table 3: Relationship between Video Viewing and Class Attendance

	Class attendance					
Video Viewing	**Below 25%**	**25%-49%**	**50%-74%**	**75% and above**	**Percent of Cohort**	***n* (Viewing)**
Below 25%	6%	2%	2%	1%	12%	40
25%-49%	5%	9%	8%	3%	25%	82
50%-74%	2%	6%	14%	12%	34%	112
75% and above	0%	3%	4%	21%	28%	92
Percent of Cohort	13%	21%	29%	38%	100%	
n (Attendance)	42	67	94	123		326

Note: The percentages reported in this table were the proportions out of 326 students in the inverted cohort.

In-Class Experiences

Student-Faculty Interaction

In this study, no direct measure of frequency or quality of student-faculty interaction was taken. Instead, we assessed student perceptions of these interactions. This was done by asking three questions relating to when and where the interactions took place, the frequency of these interactions and student satisfaction with their individual degree of student-faculty interaction. The results of these three questions are shown below in Table 4, Table 5 and Table 6.

Table 4 shows that students had significantly higher frequency of interactions with the instructor during and immediately after class under the inverted model, and were more satisfied with their interactions with the instructor during class than were students in the traditional model. However, there was no significant difference between the two cohorts in the overall satisfaction with the student-faculty interactions.

Table 5 shows that the number of students who had *never* had interactions with the instructor *during class* dropped from 54% under the traditional model to 25% under the inverted model. Thirty-one per cent of students in the inverted cohort reported that they had interactions with the instructor during class “about once a week,” “two to three times a month” or “about once a month,” compared to 14% of students in the traditional cohort.

Table 4: Comparisons of Student-Faculty Interactions

	Traditional Cohort		Inverted Cohort	
	n	Mean (SD)	*n*	Mean (SD)
Frequency of Student-Faculty Interactions (out of 6)				
During class	165	1.88 (1.33)	172	2.59*** (1.48)
Immediately after class	165	1.79 (1.07)	174	2.06* (1.22)
During the instructor's office hours	165	1.62 (1.00)	172	1.23*** (.53)
Outside the class (e.g., hallway conversation)	165	1.54 (.97)	174	1.59 (.93)
Satisfaction with Student-Faculty Interactions (out of 5)				
During class	154	3.55 (.81)	170	3.91** (.92)
Immediately after class	155	3.57 (.86)	170	3.68 (.91)
During the instructor's office hours	156	3.55 (.86)	162	3.41 (.85)
Outside the class (e.g., hallway conversation)	154	3.47 (.81)	165	3.5 (.82)
Perceived Adequacy of Student-Faculty Interactions (out of 4)				
Overall, the level of my personal interaction with the instructor for ECE221 this term was	152	2.40 (1.02)	168	2.55 (.96)

* $p < .05$; ** $p < .01$; *** $p < .001$

Table 5: Frequency of Students' Interactions with the Instructor

Question: **Think of your personal interaction with the instructor for ECE221 this term. Indicate how often you interacted with the instructor in the following situations.**	**Never**	**A few times during the term**	**About once a month**	**Two to three times a month**	**About once a week**	**More than once a week**
Traditional Cohort						
During class	**53.9%**	27.9%	6.1%	4.2%	3.6%	4.2%
Immediately after class	50.3%	34.5%	4.8%	6.1%	4.2%	0.0%
During the instructor's office hours	60.6%	27.3%	4.2%	5.5%	1.8%	.6%
Outside the class (e.g., hallway conversation)	66.7%	22.4%	4.8%	3.0%	2.4%	.6%
Inverted Cohort						
During class	**25.0%**	39.0%	8.1%	12.8%	10.5%	4.7%
Immediately after class	42.0%	31.6%	10.9%	10.3%	4.0%	1.1%
During the instructor's office hours	82.0%	12.8%	5.2%	0.0%	0.0%	0.0%
Outside the class (e.g., hallway conversation)	60.9%	27.6%	6.3%	2.9%	1.7%	.6%

Table 6 shows that 69% of students expressed satisfaction with their interactions with the instructor during class under the inverted model, compared to 49% under the traditional approach, X^2 (2, N = 324) = 21.21, $p < .0001$. Students were also asked to rate the level of adequacy of their student-faculty interaction. Fifty-five percent of the students who learned under the inverted classroom model reported "very adequate" or "adequate," in contrast to 42% of those in the traditional cohort, X^2 (3, N = 320) = 9.29, p = .03.

Table 6: Students' Satisfaction with their Interactions with the Instructor

***Question*: Thinking of your personal interaction with the instructor for this course, indicate how satisfied you were with the level of interaction in the following situations:**	**Dissatisfied or Very Dissatisfied**	**Neither satisfied nor dissatisfied**	**Satisfied or Very Satisfied**
Traditional Cohort			
During class	6.5%	44.2%	**49.4%**
Immediately after class	5.8%	45.8%	48.4%
During the instructor's office hours	6.4%	48.1%	45.5%
Outside the class	4.5%	57.1%	38.3%
Inverted Cohort			
During class	4.7%	25.9%	**69.4%**
Immediately after class	5.9%	38.2%	55.9%
During the instructor's office hours	6.2%	56.2%	37.7%
Outside the class	5.5%	49.7%	44.8%

The findings about student-faculty interactions are also supported by some of the qualitative data. In response to the question "In terms of supporting your learning of the course material, what was the most useful aspect of the classroom experience (i.e., the lectures)?" on the end-of-term student survey, some students provided positive comments on the quality of the interactive environment during class, which allowed them to obtain prompt feedback to their questions. Comments from the inverted cohort included:

> *Being able to ask questions and get my answers on the spot. This helps tie the answer more closely to all the details surrounding the question.*
>
> *It was more interactive, and focused more on reviewing material that was already taught from the videos.*
>
> *The interaction the instructor had with students, i.e., not always writing on a chalkboard and showing experiments.*

In addition, the relevant student comments from the inverted cohort focus group sessions were:

> *He's not tight to the board like most professors are: they are teaching they are writing on the blackboard. He walks around and when he's asking these little questions he walks around the room, looking for people who have questions. If you have a question he'll come over and discuss it with you one on one or with your little group and it connects us with the professor so we feel more comfortable asking questions and that's good.* [FG1]

> *Last term, I didn't do any interaction. This time I did, actually. Once per week. Actually I tried to raise my hand to try to answer some question.* [FG3] (a student who had taken the course in 2012 and retook the course in 2013)

Opportunities for Enhanced Engagement with the Course Material

One of the great benefits of the inverted classroom approach is that it gives the instructor more flexibility in how to use their face-to-face time with the students. For both the traditional and inverted cohorts, a significant amount of in-class time was used for demonstrations and discussions of how the course material was related to recent technological innovations and cutting-edge research. However, for the inverted cohort, the range of demonstrations and application examples was expanded as more time was devoted to practical exercises.

Indeed, students in the inverted cohort appeared to enjoy the course more than did students in the traditional cohort. When asked to rank all five courses they were taking that semester in order of preference in the end-of-term survey, 78% of students in the inverted classroom cohort ranked the course under study, ECE221, in their top three, as opposed to 66% in the traditional cohort, with X^2 (4, N =340) = 11.95, p =.02. Also, the rating for the statement “Overall, I enjoyed taking this course” was higher for the inverted cohort (M_{inv} = 5.05. SD = 1.53) than the traditional cohort (M_{trad} = 4.81, SD = 1.61), although the difference was not statistically significant, $t(341) = 1.40$, $p = .16$. This result was noteworthy given that over the two years of this study, there were no major changes to any of the five courses that students were taking in that term.

Furthermore, the results for the relevant questions on the official faculty course evaluation survey, listed in Table 7, show that the inverted cohort’s ratings of their enthusiasm at the end of the course was significantly higher than that reported by the traditional cohort (M_{inv} = 4.40, SD = 1.52, M_{trad} = 3.93, SD = 1.76, $t(235)$= 2.19, p = .03). This suggests that students in the inverted classroom cohort gained a greater appreciation for the course material, which may have impacted their overall enthusiasm for the course. When asked “Considering your experience with the course, and disregarding your need for it to meet program or degree requirements, would you still have taken this course?”, 65% of the inverted cohort responded “*Yes,*” compared to only 54% of the traditional cohort, although the difference was not statistically significant.

Table 7: Official Faculty Course Evaluation Questions Relating to Interest in Subject Matter and Value of Learning Experience

Evaluation Questions	Traditional Cohort			Inverted Cohort		
(on a 7 point scale)	*n*	Mean	SD	*n*	Mean	SD
Your level of enthusiasm for taking this course, at the time of initial registration	109	4.28	1.52	132	4.20	1.39
Your level of enthusiasm now that you have completed the course	107	3.93	1.76	130	4.40*	1.52
The value of the overall learning experience was	108	4.56	1.16	131	4.71	1.16
The intrinsic interest of the subject matter is	105	4.36	1.47	128	4.73	1.52

* $p < .05$

The students also found the teaching tools, such as demonstrations and video clips interesting, so these tools may have played a role in contributing to greater student motivation for learning although not directly contributing to their learning outcomes. As the students in the focus group sessions commented:

> *I think it's definitely helpful because first time I was not really interested in this course and definitely raised my interest for this. Even though we don't know what's going on but we think it's cool and then we put more effort to understand what's going on.* [FG1]

> *It gives me the overall picture. I helps me to understand how real world works. I would just say like just an extra to the lesson video. It relates to the real world.* [FG3]

> *It's like that was cool, but then it's not going to help us solve the problem.* [FG1]

Perceptions of the Inverted Classroom Approach

Table 8 presents how students perceived the inverted classroom approach compared to the traditional instructional approach. It suggests that when the inverted classroom approach was used, more than 70% of students thought positively about the supportive learning environment (Q27 and Q28), while approximately half of the students considered their classroom experiences as positive (Questions 23, 24, 25, 29 and 30). In particular, 48% of the students agreed or strongly agreed that "Overall, the inverted classroom approach allowed me to make effective use of my time to develop my understanding of the course material." However, only 35% found that it reduced their usual "cramming" cycle of preparing for major assessments. The considerable percentage (25% to 38%) of students who disagreed with these statements shows that the technique was not effective for, or appreciated by, all students.

In addition, the traditional cohort rated the statement "The lecturing approach that the instructor took was effective in helping me learn the material in the course" more positively than the inverted cohort, with 85% versus 70% in agreement and 8% versus 18% disagreeing, $M_{\text{inv}} = 5.09$, $SD = 1.55$, and $M_{\text{trad}} = 5.43$, $SD = 1.20$, $t(330) = 2.29$, $p = .02$.

With respect to the student reaction to the statement "Compared with the other courses that I have taken in my second year, the amount of work required for this course is reasonable," the traditional cohort's rating ($M_{\text{trad}} = 4.79$, $SD = 1.52$) was slightly higher than the inverted cohort's ($M_{\text{inv}} = 4.51$, $SD = 1.59$, $t(340) = 1.65$, $p = .10$). Twenty-two per cent of the traditional cohort versus 32% of the inverted cohort indicated that they disagreed with the statement. This suggests that the inverted classroom approach was perceived as carrying a heavier workload for a portion of the inverted cohort, given that the other workload components of the course remained the same between the two years.

Table 8: Perceptions about the Inverted Classroom Approach

In comparing the "inverted classroom approach" that was used in ECE221 with courses that you have had which were taught using the "traditional" lecturing approach, …	*n*	Mean* (SD)	Disagree or Strongly Disagree	Neither agree nor disagree	Agree or Strongly Agree
Q28: I feel that I had the opportunity to get all of my questions about the material answered (i.e., in class, with the instructor, on CoursePeer, etc.)	176	5.22 (1.35)	10.2%	16.5%	73.3%
Q27: I feel that I was given all the support I needed in this course to learn the material well	177	5.21 (1.54)	12.4%	17.5%	70.1%
Q30: Overall, the inverted classroom approach in this course has provided me with an effective learning experience	177	4.53 (1.73)	25.4%	19.2%	55.4%
Q25: The inverted classroom approach made the in-class time more enjoyable	177	4.53 (1.71)	25.4%	18.6%	55.9%
Q23: Overall, the inverted classroom approach allowed me to make effective use of my time to develop my understanding of the course material	177	4.27 (1.74)	35.0%	16.9%	48.0%
Q24: The inverted classroom approach made the in-class time more useful in developing my understanding of the course material.	177	4.24 (1.80)	37.9%	10.7%	51.4%
Q29: In comparison with the traditional lecturing approach, I prefer the inverted classroom approach	176	4.15 (1.95)	34.7%	17.0%	48.3%
Q26: With the inverted classroom approach I did not have to "cram", or catch up as much as I normally would have had to before the term test and the midterm	177	3.59 (2.03)	52.5%	12.4%	35.0%

* 7-point Likert-scale ranging from "strongly disagree" (1) to "strongly agree" (7)

Six questions in the end-of-term survey addressed student perceptions of the lesson videos, a key component in the inverted model. As shown in Table 9, more than 80% of the students agreed or strongly agreed that the lesson videos were an effective introduction to the main concepts covered in the course and effectively prepared them for the lectures that followed. This means that the lesson videos successfully fulfilled their intended role in the inverted classroom approach.

With respect to the characteristics of the lesson videos, 62% of students in the inverted cohort considered them to be interesting, while 39% thought the length of the videos appropriate. The follow-up student survey and focus group data suggest that many students who disagreed with this statement thought that the videos should have been shorter than the 25-minute average length.

Table 9: Perceptions of Lesson Videos

Please indicate to what extent you agree or disagree about the following statements about the lesson videos.	*n*	Mean* (SD)	Disagree or Strongly Disagree	Neither Agree nor Disagree	Agree or Strongly Agree
Q17: The lesson videos were an effective introduction to the main concepts covered in the course	177	5.62 (1.40)	8.5%	9.0%	82.5%
Q18: The lesson videos effectively prepared me for the lectures which followed	176	5.44 (1.37)	11.4%	7.4%	81.3%
Q22: The process of accessing and viewing the videos worked well for me	176	4.95 (1.68)	21.0%	13.1%	65.9%
Q20: The quizzes that were embedded in the videos were very helpful to me in developing my understanding of the course material	177	4.88 (1.49)	18.1%	16.4%	65.5%
Q19: The lesson videos were interesting	177	4.81 (1.58)	20.9%	17.5%	61.6%
Q21: The length of the lesson videos was appropriate	177	3.85 (1.75)	47.5%	13.6%	39.0%

* 7-point Likert-scale ranging from “strongly disagree” (1) to “strongly agree” (7)

From the qualitative data, many students commented on how beneficial it was to have a well-organized set of lesson videos available to them to “learn at one’s own pace” and to have for “later review.” One focus group participant stated:

> *I guess to me compared to traditional lectures, it’s making lectures that are completely not understandable to something that I connect with, get something out of… To me one benefit is really I get a chance to replay it, to learn at my own pace, so it really benefits more that way because I’m learning not like some other courses*. [FG1]

Overall, some students did see the value of using the inverted classroom approach. As two students in a focus group commented:

> *I think the more you focus on covering concepts and theories at home, the longer students are going to have to spend on their own familiarizing themselves with the concepts and theory so you can then go into class and do these examples.* [FG1]

> *It’s a good idea because it gives you a chance to be familiar with the material first. Then if you have any questions you are in the lecture you have [the professor] in front of you, you can ask all these*

> *questions you need to ask. Rather than let's say a course where they teach you the material and instantly give an example you don't have time to get familiar with and really absorb it.* [FG1]

On the other hand, the new teaching approach did require students to adjust their learning strategies and acquire better time management skills. The same student who made the comment above described the situation in this way:

> *But the one drawback, I would say, is that the work does pile up, You end up having to spend more time to stay up to date with the lectures and the lessons and it is pretty much adds up to having like five lectures a week instead of three. It's a heavier workload.*

Another student in a focus group commented:

> *Probably half of students, they don't watch all the videos. One thing, we don't have the time. Before every lecture, that's 30 minutes. Sometimes your students, not all of them can manage time very well. There's a lab, or there's a project, a code document due tomorrow; but there's still a lecture tomorrow. We don't have time to view the videos. …. Professor, he wants us to interact with him. Give us the question or give us some questions, and we do it; afterwards, we discuss the problem together, everyone in the class. I think most students, they just get used to the old ways. They're not getting used to the new ways.* [FG4]

Some respondents to the student survey stated clearly that they disliked the inverted classroom approach. One student almost shouted to say, "*BACK TO NORMAL!!!!!!!!!!!! I tend to remember everything that happens in class and every concept taught in class, but now going to lectures is the least useful thing for the study*."

Our data also suggested to us that student perceptions were affected by their learning style. Some students, like the student who made the comment above, learn better in a traditional lecture-based environment. Others appreciated the inverted classroom approach better, as another student in a focus group shared:

> *I am not the lecture type of person so the inverted approach works well for me… I don't remember stuff right away I need to understand it, look at it, see how it applies to me.* [FG1]

Summary and Interpretation

The data in this section can be summarized as follows in terms of student behaviours and perceptions.

Student Behaviours

The primary findings for the student behaviours associated with the inverted classroom approach were:

- *Engagement with the inverted classroom approach*: About one-fifth of the inverted cohort (21%) actively engaged with the inverted classroom approach by attending and coming prepared through the pre-class video viewing to at least 75% of the classes. About 50% of the class attended and came prepared at least 50% of the time, while 22% were essentially disengaged and did not prepare or come to class for more than half of the class sessions. These results indicate that a good portion of the students were not fully engaged with the new learning approach. It was found through the focus group discussions that some students did not buy into the inverted classroom approach and others saw the potential value in the approach but were unable to be fully engaged in the new approach due to their inadequate time management given the heavy course work during the term.

- *Class attendance and lesson video viewing*: The lecture attendance for the inverted cohort averaged about 60% for the term, and this was the same for the traditional cohort. However, it was found that most of the students in the inverted cohort who had *not* prepared by watching the lesson video decided not to come to class. This was also supported by the reasonably strong correlation between pre-class lesson video viewing and class attendance, $r = 0.62$, $p < .001$, and the focus group sessions, in which students made it clear that one of the main reasons for missing lectures was that they did not feel prepared enough to go.

- *Lesson video viewing and course workload*: In terms of the pre-class video viewing, there was a wide variation by class session in the amount of the lesson videos that the students had watched. The low rate of lesson video viewing appeared to be associated with the immediate demands of the other courses, such as major assessments. This observation was also supported by focus group data. There was no clear evidence from the survey data that the inverted classroom approach resulted in a higher than normal course workload over the entire term. Nevertheless, there was a small minority of students who raised this as a point of concern in the focus group sessions and the open-ended comments on the survey.

Student Perceptions

Overall, the students had mixed feelings about the inverted classroom approach. Specifically, the primary findings were:

- *Overall perception*: Forty-eight per cent of the inverted cohort indicated that they preferred the inverted classroom approach to the traditional lecture format, while 35% of the class indicated their preference for the traditional approach. On the other hand, over 80% of the students in the inverted cohort found the lesson videos to be an effective introduction to the course material, though they would have liked the videos to be shorter than the average length of 25 minutes.

- *Effective use of time for learning*: For the majority of the class, the implementation of the inverted classroom did not considerably reduce the need for students to "cram" prior to a major assessment, with 53% of the students indicating that they continued to rely on this mode of studying. Around 50% of the students indicated that both within class and overall, their time was used more effectively as compared to the traditional approach, while approximately 35% did not.

- *In-class experience*: More than half of the students in the class (56%) indicated that the inverted classroom approach made the in-class time more enjoyable than a traditional classroom, while 25% indicated otherwise. However, the inverted cohort rated the effectiveness in the lecturing approach the instructor took in helping them learn the material in the course *less* favorably than the traditional cohort, with 18% versus 8% disagreement, although this difference was not statistically significant. From the comments from focus group discussions, it appears that a student's dominant learning style had an effect on how useful and enjoyable they found the in-class experience to be.

- *Supportive learning environment*: The students were generally positive about their learning environment. Over 70% of students in the inverted cohort indicated that they were given the necessary support to effectively learn the course material and had the opportunity to have their questions answered.

- *Student-faculty interactions*: With the inverted classroom approach, the students had significantly higher frequency of interactions with the instructor during and immediately after class than with the traditional approach, with only 25% of the inverted cohort indicating that they never had any interactions with the instructor during class, as compared to 54% of the traditional cohort. The inverted cohort was also more satisfied with their in-class interactions with the instructor. The perceived adequacy of student-faculty interaction in the course also increased by 13% between the two cohorts.

- *Greater interest in subject matter*: There is evidence that the inverted classroom approach resulted in greater student interest in the course, with the rating of their enthusiasm at the end of the course being higher for the inverted cohort (M_{inv} = 4.40, SD = 1.52, M_{trad} = 3.93, SD = 1.76, $t(235)$= 2.19, p = .03). A significantly higher percentage of the inverted cohort than the traditional cohort (78% versus 66%) also ranked the course within the top three of the five courses they were taking during the term. Also, there was a higher rating for the inverted cohort on the intrinsic interest in the subject material although this result was not significant (M_{inv} = 4.73, SD=1.52, M_{trad} = 4.36, SD=1.47, $t(225)$ = 1.84, p = 0.065). The rating for the statement "Overall, I enjoyed taking this course" was slightly higher for the inverted cohort than the traditional cohort, but with an insignificant difference.

In moving to the inverted classroom approach, there were a number of anticipated potential benefits, as well as some significant concerns. Aside from the primary goal of improving student learning within the course, it was also hoped that students would benefit by:

- Being able to use their time more effectively to learn the course material
- Having a more enjoyable learning experience
- Becoming more engaged with and interested in the course material

On the other hand, there was a significant concern that students would:

- Not accept the new learning process and not complete the required pre-class lesson video viewing
- Not attend class if they fell behind in the lesson video viewing
- Find the course workload higher than normal due to the need to view the videos consistently
- Feel they were not getting the support they needed to learn the material through this approach

The results of this study show that many of these benefits and concerns were valid, albeit to varying degrees.

3.2 Research Question #2: Effects on Student Self-Efficacy and Learning Outcomes

> *As compared to the traditional teaching approach, what effect did the inverted classroom approach have on **student self-efficacy** and **learning outcomes**?*

Self-Efficacy

Students were presented with 30 self-efficacy questions on a 7-point Likert scale to investigate their level of confidence in various aspects of the course materials and on their capacity to study engineering in general, including 10 questions taken directly from the validated Longitudinal Assessment of Engineering Self-Efficacy instrument (Marra, Rodgers, Shen & Bogue, 2009). Through factor analysis using polychoric correlation conducted for this study, three factors were derived for each cohort: self-efficacy in explaining course concepts to others, in studying engineering, and in learning the course material (Table 10). The factor loadings and those question items associated with the three factors are reported in detail in Tables C-1 and C-2 of Appendix C.

Table 10 shows that no significant difference was found between the two cohorts on any of the three self-efficacy factors. It also shows that students were the least confident in their ability to explain the course material to others, such as a fellow second-year student, but they appeared to have greater degree of confidence in their ability to learn the course material and succeed in engineering.

Table 10: Comparisons of Self-Efficacy Variables

Three Self-Efficacy Factors	Traditional Cohort		Inverted Cohort	
	n	Mean (SD)	*n*	Mean (SD)
Self-efficacy in explaining course concepts to others	163	4.56 (1.26)	170	4.43 (1.28)
Self-efficacy in studying engineering	160	5.10 (1.12)	166	5.14 (1.04)
Self-efficacy in learning the course material	165	5.22 (1.09)	173	5.22 (.95)

However, students in the two cohorts were found to differ considerably on their responses to two of the 30 self-efficacy questions.[5] It is interesting to note that the two questions both dealt with the material covered by lesson videos #22 and #24 which, as discussed previously (see Figure 3), had particularly poor viewership due to students' heavy workload in their other courses at that time.

Further results relating to the correlations between the learning outcomes, student-faculty interaction variables and self-efficacy factors can be found in Stickel, Liu and Hari (2014).

Learning Outcomes

Student understanding of the course material was measured in different ways that focused on short-term and long-term conceptual learning, analytic problem-solving capabilities and final course grades. The data collection methods are described in Table A-1 of Appendix A (see items 5, 6, 7, 11 and 12). The conceptual tests targeted students' understanding of the course's foundational concepts, while the in-class analytic problem-solving quizzes tested their ability to apply the requisite mathematical techniques to solve problems that were based on these concepts. The course was delivered such that the development of *both* conceptual and analytic understanding was emphasized, and the homework problems, quizzes and exams also reflected this shared emphasis.

Five indicators of learning outcomes were investigated: concept inventory post-test scores, concept inventory gain scores, analytical problem-solving quiz scores (APSQs), long-term concept retention test scores and course academic performance (CAP). The descriptive statistics for these five outcomes have been shown in Table 2. To facilitate reading, we are presenting the data again below in Table 11.

[5] Those two questions were Q59, "I can clearly explain the basic relationship between **magnetic** fields and their sources (currents) to another second-year ECE student," with M_{inv} = 4.40, SD = 1.66, M_{trad} = 4.77, SD = 1.47, $t(335)$= 2.15, p = .03, and Q60, "I can clearly explain how **magnetic** fields interact with materials, such as iron, to another second-year ECE student," with M_{inv} = 4.22, SD = 1.61, M_{trad} = 4.60, SD = 1.45, $t(333)$= 2.29, p = .02.

Table 11: Descriptive Statistics of Learning Outcome Variables under Investigation

Learning Outcome Variables	Traditional cohort		Inverted cohort	
	n	Mean (SD)	*n*	Mean (SD)
Concept inventory: Post-test scores (percentage)	286	51.5 (19.0)	314	50.5 (18.3)
Concept inventory: Gain scores (percentage)	276	18.5 (48.7)	297	13.3 (41.9)
Analytic problem-solving quiz scores (for those that wrote all four in-class quizzes) (APSQs) (total score of 10)	129	4.65 (1.79)	114	6.20** (1.75)
Course academic performance (CAP) (percentage)	299	70.4 (13.7)	329	73.4*** (13.1)
Long-term concept retention test scores (percentage)	69	45.8 (13.8)	51	45.5 (18.3)

** $p < .01$; *** $p < .001$

Statistically significant differences between the two cohorts were found in two of the five measures: the analytic problem-solving quiz scores, with $M_{inv} = 6.20$, $SD = 1.75$ and $M_{trad} = 4.65$, $SD = 1.79$, $t(241) = 6.78$, $p < .001$, $r^2 = .16$; and course academic performance, with $M_{inv} = 73.4$, $SD = 13.1$ and $M_{trad} = 70.4$, $SD = 13.7$, $t(626) = 2.84$, $p < .01$, $r^2 = .01$. In other words, the inverted cohort did better than the traditional cohort in these two outcome measures, although the effect size of the difference for analytical problem-solving quiz scores was medium while the effect size for the difference for course academic performance was very slight.[6]

No significant difference was found between the two cohorts in the post-test scores or the gain scores of the concept inventory, nor in the long-term concept retention test scores. To verify our findings about the concept inventory (CI) post-test scores, we performed analysis of covariance (ANCOVA) with the instructional method as the independent variable, CI pre-test scores as the covariate and the post-test scores as the dependent variable. The relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1,575) = .002$, $MSE = .31$, $p = .97$, partial $\eta^2 < .001$; this means that the homogeneity of slopes assumption for ANCOVA was met. The result from ANCOVA was insignificant for the instructional method, $F(1,576) = .50$, $MSE = 83.09$, $p = .48$, partial $\eta^2 = .001$. This means that the difference between the two cohorts in CI post-test scores was not statistically significant when controlling for the CI pre-test scores.

On an additional note, while writing the four in-class analytic problem-solving quizzes, students were also asked to rate their confidence for each of their answers on a scale of 1 (Basically Guessed) to 10 (Very Sure). These in-class quizzes were administered to students in the same class sessions in both years and each cohort was given exactly the same amount of time to complete the quiz. The inverted cohort had no prior exposure to these quizzes, which were kept secure and confidential during the previous year with no copies

[6] The effect size for mean difference is interpreted as small if $0.01 < r^2 < 0.09$; medium if $0.09 < r^2 < 0.25$; and large if $r^2 > .25$ (Cohen, 1992).

or solutions being posted. To ensure consistency in the marking of each quiz the same teaching assistant marked all of the quizzes for both cohorts in the summer of 2013 and was not told anything about the project or which group was the inverted cohort.

The results for these quizzes are summarized in Table 12 below. For the scores of the first three quizzes, students in the inverted cohort outperformed those in the traditional cohort by significant margins. For the inverted cohort, the final quiz took place in the third to last week of the term and covered topics associated with lessons 22 and 24, which had very low pre-class viewership due to the heavy course workloads during those weeks (see Figure 2). Despite the disadvantaged situation, students in the inverted cohort performed roughly the same as those in the traditional cohort.

Students in the inverted cohort also demonstrated a significantly greater degree of confidence in their ability to solve those quiz problems in the first three quizzes. The positive association between the confidence level and academic performance agrees with the findings of other studies (Lane, Lane & Kyprianou, 2004; MacPhee, Farro & Canetto, 2013). However, the higher confidence level in solving those quiz questions on the part of the inverted cohort did not seem to have been translated into higher overall self-efficacy ratings, as shown in Table 10. This can be explained by the different foci of the two instruments: the APSQ confidence scores likely focused more around the ability to apply the appropriate mathematical techniques, while the self-efficacy factors related more to the development and sharing of a conceptual understanding of the course material.

Table 12: Comparisons of In-Class Analytic Problem-Solving Quiz Scores

In-Class Quiz Number, Total Score and Confidence Rating		Traditional Cohort		Inverted Cohort	
		n	Mean (SD)	*n*	Mean (SD)
Quiz 1	Score (total: 10)	215	4.49 (2.53)	242	5.52*** (2.49)
	Conf. part (a)	207	5.57 (2.73)	237	6.22* (2.77)
	Conf. part (b)	167	3.38 (2.34)	215	4.18** (2.65)
Quiz 2	Score (total: 10)	204	4.57 (2.12)	207	5.82*** (2.38)
	Conf. part (a)	184	4.34 (2.27)	200	4.71 (2.53)
	Conf. part (b)	136	3.00 (2.15)	190	3.81** (2.51)
Quiz 3	Score (total: 10)	203	3.92 (2.51)	227	6.95*** (2.28)
	Conf. part (a)	204	2.29 (2.29)	227	4.60*** (2.74)
	Conf. part (b)	204	1.85 (2.19)	227	3.75*** (2.89)
	Conf. part (c)	204	0.77 (1.32)	227	2.57*** (2.73)
Quiz 4	Score (total: 10)	222	4.68 (2.50)	168	4.54 (2.79)
	Conf. part (a)	222	7.56 (2.93)	168	7.45 (2.91)
	Conf. part (b)	222	4.06 (3.31)	168	3.85 (3.15)
	Conf. part (c)	222	1.30 (2.08)	168	1.58 (2.37)
All four quizzes	Score (10)	129	4.65 (1.79)	114	6.20*** (1.75)

Note: The scale for the confidence rating was 1 to 10; * $p < .05$; ** $p < .01$; *** $p < .001$

When an average confidence rating was determined for each student and then compared to their ratings of the three self-efficacy factors, there was a reasonable correlation between these variables for both the inverted cohort (*r* ranged from 0.41 to 0.47) and the traditional cohort (*r* ranged from 0.29 to 0.39). The fact that the correlations for the traditional cohort were lower for each factor indicates that these students were less confident about their learning throughout the term yet became more confident towards the end of the term.

For a deeper understanding of what may have contributed to the achievement of those learning outcomes, we performed the following two analyses:

- Correlation analysis of the associations between the five outcome variables and three self-efficacy factor scores as a type of intermediate outcomes. The results of this analysis are presented in Appendix D.
- Hierarchical regression analysis on the two outcome variables that were found to be statistically significantly different between the two student cohorts: analytical problem-solving quiz scores and course academic performance. This was done to examine the strength of the relationship between the instructional method and the two learning outcomes and to find out what other factors contributed to the significant difference in addition to the instructional method if they had any effect.

Results from Regression Analysis

The following three groups of independent variables were included in the hierarchical regression analysis. The descriptive statistics for these variables are summarized in Table 13.

1) Student characteristics:
   - Prior academic performance
   - Learning styles: reflective vs. active; intuitive vs. sensing; verbal vs. visual; and global vs. sequential

2) Student learning experiences:
   - Instructional approach: traditional or inverted
   - Frequency of student-faculty interactions during class
   - Student academic engagement factors[7]: (1) extra efforts in studying; (2) review of posted materials; and (3) problem-solving practice
   - Lecture attendance

[7] Factor analysis was conducted on these questions. Details of the factor analysis can be found in Appendix C and the full set of results for these survey questions is presented in Appendix D.

3) Intermediate outcomes:
   - Student self-efficacy: (1) self-efficacy in explaining course concepts to others; (2) self-efficacy in studying engineering; (3) self-efficacy in learning the course material

One-way analysis of variance (ANOVA) was conducted to evaluate whether there was any interaction effect of the two instructional methods and the four learning style variables on the analytical problem-solving quiz scores. The ANOVA results indicated no significant interaction. The problem-solving quiz scores of the reflective students were higher than those of the active students, F (1,209) = 8.70, MSE = 26.27, p = .004, partial η^2 = .04; and the problem-solving quiz scores of the intuitive students were higher than those of the sensing students, F (1,209) = 16.23, MSE = 47.45, p < .001, partial η^2 = .07. This means that student learning styles played an important role in the difference in their analytical problem-solving quiz scores; however, learning styles did not affect the way in which the instructional method affected the differences between the two cohorts for this outcome, i.e., analytical problem-solving quiz scores.

Table 13: Descriptive Statistics of all Variables for Regression Analysis on two Outcome Variables

	Sample for APSQs (n=127)		**Sample for CAP** (n=217)	
Variables	**Mean (or %)**	**SD**	**Mean (or %)**	**SD**
Learning Outcomes				
Analytical problem-solving quiz scores (APSQs) (total score: 10)	5.55	1.80		
Course academic performance (CAP) (total score: 100)			76.1	12.36
Student Characteristics				
Prior academic performance (total score: 100)	75.4	9.51	74.2	9.38
Learning style – Reflective	53.5%		53.9%	
Learning style – Intuitive	36.2%		39.2%	
Learning style – Verbal	23.6%		18.9%	
Learning style – Global	33.9%		41.0%	
Learning Experiences				
Instructional approach – Inverted	52.8%		51.2%	
Student-faculty interactions during class (5-point scale)	2.42	1.58	2.23	1.47
Student engagement factor 1: *Extra efforts in studying* (3-point scale)	1.44	0.40	1.46	0.39
Student engagement factor 2: *Review of posted materials* (3-point scale)	2.41	0.53	2.38	0.54
Student engagement factor 3: *Problem-solving practice* (3-point scale)	1.88	0.57	1.90	0.55
Lecture attendance (percentage)	83.8	12.13	74.2	20.30
Intermediate outcomes				
Self-efficacy factor 1: *Explaining course concepts to others* (7-point scale)	4.54	1.30	4.47	1.22
Self-efficacy factor 2: *Studying engineering*	5.21	1.12	5.13	1.08
Self-efficacy factor 3: *Learning the course material*	5.33	0.97	5.23	1.00

In light of Astin's (1991) Input-Environment-Outcome analytical framework, the three groups of independent variables were entered sequentially as Block 1, 2 and 3 into the regression models to determine the amount of unique variance each block of independent variables contributed to the prediction of the learning outcomes under investigation.

The assumptions of linearity, normality, homoscedasticity and independence of error terms for regression analysis were tested. Scatter plots between the analytical problem-solving quiz scores and all the continuous independent variables appeared to be relatively linear. The generated histogram of residuals and normal probability plot supported the assumption of normality. The pattern in the residual scatter plot supported the assumption of homoscedasticity. Durbin-Watson statistic was 2.17 for the APSQs model and 2.06 for the CAP model, showing that the assumption of independence of error terms had been met. Outlier analysis was also conducted by checking three residual statistics: standardized predicted values, Cook's distance and Leverage values, which revealed no outliers. In addition, multicolinearity was checked by examining the Variance Inflation Factor (VIF), which ranged from 1.10 to 2.72 for all independent variables in the APSQs model and ranged from 1.08 to 2.43 in the CAP model. Based on these indicators, we were confident in our results from the hierarchical linear regression analysis.

As shown in Table 14 for the APSQs, the 14 variables accounted for 59% of the variance (R^2 = .59). Of all three groups of the independent variables, student characteristics, as represented by students' prior academic performance and their learning styles, accounted for 36% of the variance in APSQs; learning experiences, as represented by the instructional method, student-faculty interaction, lecture attendance and academic engagement, constituted 20% of the variance; and the three self-efficacy measures as an intermediate outcome made up 4% of the variance.

Also included in Table 14 are the regression coefficients for the three regression models. Model 1 coefficients reflect the effects associated with each independent variable while controlling for student characteristics only. In model 2, variables that reflected student learning experiences were added. Model 3 coefficients additionally took into account three measures of self-efficacy. Among all the independent variables, prior academic performance was the strongest contributor to the APSQs (β = .44, t = 5.47, p < .001), and using the inverted classroom approach was the second strongest contributor (β = .30, t = 4.59, p < .001) when other variables were controlled. In addition, intuitive students had higher APSQs than sensing students (β = .18, t = 2.64, p =.01) and a better lecture attendance contributed to better APSQs (β = .18, t = 2.62, p = .01).

When dividing the standardized regression coefficients (i.e., β values) from Table 14 into the pooled standard deviations of the outcome measure, we obtained a measure of effect size (Hays, 1994). From this, it was found that the advantage of using the inverted classroom approach was .17 of a standard deviation in the increase of analytical problem-solving quiz scores when controlling for other variables.

Table 14: Standardized and Unstandardized Coefficients of Predictors for Analytical Problem-Solving Quiz Scores

		Analytical Problem-Solving Quiz Scores		
Variables	***r***	**Model 1**	**Model 2**	**Model 3**
Student Characteristics				
Prior academic performance	.54***	.56*** (.11)	.55*** (.10)	.44*** (.08)
Learning style – Reflective	.20*	.02 (.08)	.06(.23)	.09 (.31)
Learning style – Intuitive	.17*	.23**(.85)	.21** (.79)	.18* (.68)
Learning style – Verbal	.21**	.09 (.36)	.02 (.06)	.00 (.00)
Learning style – Global	.08	-.01 (-.03)	-.06 (-.21)	-.05 (-.20)
Learning Experiences				
Instructional approach	.38***		.30*** (1.07)	.30*** (1.08)
Student-faculty interactions during class	.29***		.08 (.09)	.03 (.04)
Student engagement factor 1: *Extra efforts in studying*	.31***		.18* (.80)	.10 (.44)
Student engagement factor 2: *Review of posted materials*	.15*		.01 (.03)	-.01 (-.03)
Student engagement factor 3: *Problem-solving practice*	.02		-.02 (-.07)	-.04 (-.14)
Lecture attendance	.16*		.16* (.02)	.18* (.03)
Intermediate outcomes				
Self-efficacy factor 1: *Explaining course concepts to others*	0.43***			.15 (.20)
Self-efficacy factor 2: *Studying engineering*	0.49***			.08 (.13)
Self-efficacy factor 3: *Learning the course material*	0.43***			.05 (.09)
R^2 change		.36	.20	.04
F change		13.78***	8.44***	3.28*
R^2		.36	.56	.59
F		13.78***	13.17***	11.67***

* $p < .05$; ** $p < .01$; *** $p < .001$

The results for course academic performance (CAP) are shown in Table 15 and the 14 variables accounted for 75% of the variance. Of the three groups of independent variables, student characteristics accounted for 66% of the variance; learning experiences constituted 7% of the variance; and three self-efficacy measures made up 2% of the variance.

As also summarized in Table 15, among all the independent variables, prior academic performance was the strongest contributor to the CAP ($\beta = .71$, $t = 15.87$, $p < .001$). Lecture attendance ($\beta = .20$, $t = 5.39$, $p < .001$) and self-efficacy in explaining course concepts to others ($\beta = .16$, $t = 3.31$, $p = .02$) also contributed to increased course academic performance when other variables were controlled for. Interestingly, this model suggests that the instructional approach was not a significant contributing factor to students' overall course performance.

Table 15: Standardized and Unstandardized Coefficients of Predictors for Course Academic Performance

		Course Academic Performance		
	r	**Model 1**	**Model 2**	**Model 3**
Student Characteristics				
Prior academic performance	.80***	.82*** (1.08)	0.77*** (1.01)	0.71*** (.94)
Learning style – Reflective	.13*	-.07 (-1.69)	-.03 (-.69)	-.02 (-.50)
Learning style – Intuitive	-.026	.07 (1.66)	.04 (1.11)	.02 (.59)
Learning style – Verbal	.14*	.08 (2.42)	.04 (1.24)	.03 (.93)
Learning style – Global	.02	-.01 (-.35)	.00 (.06)	.01 (.26)
Learning Experiences				
Instructional approach - Inverted	.14*		.05 (1.20)	.06 (1.48)
Student-faculty interactions during class	.22***		.08 (.66)	.04 (.33)
Student engagement factor 1: *Extra efforts in studying*	-.01		.07 (2.29)	.03 (.88)
Student engagement factor 2: *Review of posted materials*	.13*		.09* (2.04)	.08 (1.72)
Student engagement factor 3: *Problem-solving practice*	.17**		.06 (1.27)	.04 (.92)
Lecture attendance	.36***		.19*** (.12)	.20*** (.12)
Intermediate outcomes				
Self-efficacy factor 1: *Explaining course concepts to others*	.38***			.16** (1.65)
Self-efficacy factor 2: *Studying engineering*	.53***			.02 (.28)
Self-efficacy factor 3: *Learning the course material*	.38***			.00 (.00)
R^2 change		.66	.07	.02
F change		81.21***	9.09***	6.42***
R^2		.66	.73	.75
F		81.21***	50.37***	44.09***

* $p < .05$; ** $p < .01$; *** $p < .001$

To further look into how the inverted classroom approach had impacted student learning in those two outcome variables, we performed another set of regression analyses for the inverted student cohort only. As the student-faculty interactions and the three student engagement factor variables were not found to be significant in our exploratory attempts, we decided to remove them from the models. Instead, this analysis focused on assessing how the degree of engagement with the inverted classroom approach affected the two learning outcomes. It should be noted that while this study did not include any direct measure of the level of engagement with the inverted classroom approach, lesson video viewing and class attendance data were considered to be a reasonable proxy for engagement as they were indicative of two major areas of students' exposure to the inverted classroom approach, as explained in Section 3.1.

Under *k*-means cluster analysis on the class attendance and lesson video viewing data, the cohort was separated into three groups with high, medium and low levels of engagement with the inverted classroom approach. Table 16 summarizes the average *z*-scores for these three clusters for each of the engagement levels. The clustering resulted in three similar sized groups with the high and low engagement groups having an average class attendance and video viewing about one standard deviation above or below the average for the cohort.

Table 16: Characteristics of the Inverted Classroom Engagement Clusters for the Inverted Cohort

	Group 1: High engagement	Group 2: Medium engagement	Group 3: Low engagement
Class attendance	1.01	.08	-1.24
Video viewing	1.07	-.09	-1.04
n	101	136	92

Table 17 shows the descriptive statistics of the variables involved in the analysis. When compared with the profile of the whole inverted cohort, as shown in Table 2, the samples for this analysis were fairly representative of the full cohort in terms of the variables of interest.

Table 17: Descriptive Statistics of All Variables for Regression Analysis of Two Outcome Variables: The Inverted Cohort Only

	Sample for APSQs (*n* = 75)		Sample for CAP (*n* = 172)	
Variables	**Mean (or %)**	**SD**	**Mean (or %)**	**SD**
Learning Outcomes				
Analytical problem-solving quiz scores (APSQs)	6.12	1.71		
Course academic performance (CAP)			75.7	12.3
Student Characteristics				
Prior academic performance	75.6	9.54	73.4	9.33
Learning style – Reflective	54.7%		52.9%	
Learning style – Intuitive	32.0%		38.4%	
Learning style – Verbal	25.3%		20.3%	
Learning style – Global	36.0%		42.4%	

Tables 18 and 19 represent the final models for analytic problem-solving quiz scores and course academic performance. The analysis kept the high engagement group as the reference, thereby producing results for the other two groups.

Table 18 shows that these variables accounted for 45% of the variance in the academic problem-solving quiz scores. Student characteristics, as represented by students’ prior academic performance and their learning styles, accounted for 42% of the variance; and the level of inverted classroom engagement constituted 3.5%

of the variance. Among the independent variables, only two were significant contributors to academic problem-solving quiz scores when controlling for other variables: prior academic performance (β = .47, *t* = 4.82, *p* < .001) and intuitive learners (β = .34, *t* = 3.46, *p* < .01).

Table 18: Standardized and Unstandardized Coefficients of Predictors for Analytical Problem-Solving Capabilities: Inverted Cohort Only (*n* = 75)

		Analytical Problem-Solving Quiz Scores	
	r	**Model 1**	**Model 2**
Student Characteristics			
Prior academic performance	0.52***	0.54*** (.10)	.47*** (.09)
Learning style – Reflective	0.21	0.11 (.37)	.13 (.43)
Learning style – Intuitive	0.31**	0.37*** (1.33)	.34** (1.23)
Learning style – Verbal	0.13	-0.02 (-.07)	-.04 (-.17)
Learning style – Global	0.03	-0.10 (-.34)	-.10 (-.36)
Degree of Engagement with the Inverted Classroom Approach			
Medium engagement	-0.11		-.09 (-1.29)
Low engagement	-0.37**		-.19 (-.73)
R^2 change		.42	0.035
F change		9.83***	2.16***
R^2		.42	.45
F		9.83***	7.87***

** *p* < .01; *** *p* < .001

Table 19: Standardized and Unstandardized Coefficients of Predictors for Course Academic Performance: Inverted Cohort Only (*n* = 172)

		Course Academic Performance	
Indicators of Teaching Effectiveness	*r*	**Model 1**	**Model 2**
Student Characteristics			
Prior academic performance	.795***	0.80*** (1.05)	0.72*** (.95)
Learning style – Reflective	.155*	-0.03*(-0.62)	-0.05 (-1.18)
Learning style – Intuitive	.071	0.04 (1.05)	0.09 (2.16)
Learning style – Verbal	.046	0.02 (.59)	0.00 (.03)
Learning style – Global	.054	0.03 (.74)	0.06 (1.43)
Degree of Engagement with the Inverted Classroom Approach			
Medium engagement	-.284***		-0.17** (-4.29)
Low engagement	-.233**		-0.27*** (-8.57)
R^2 change		.64	0.05
F change		58.04***	14.27***
R^2		.64	.69
F		58.04***	52.17***

** *p* < .01; *** *p* < .001

Table 19 shows that the independent variables accounted for 69% of the variance in the course academic performance. Student characteristics, as represented by students' prior academic performance and their learning styles, accounted for 64% of the variance; and the level of inverted classroom engagement constituted 5% of the variance. Among the independent variables, three were significant contributors to course academic performance when controlling for other variables: prior academic performance ($\beta = .72$, $t = 15.20$, $p < .001$), medium level of engagement ($\beta = -.17$, $t = -3.41$, $p < .01$) and low level of engagement ($\beta = -.27$, $t = -5.22$, $p < .001$).

Summary and Interpretation

In the above section, we have presented our findings on the effects of instructional method on student self-efficacy and the five learning outcomes that were assessed at different points throughout the course. The results are summarized below.

Self-Efficacy

No significant difference was observed between the two cohorts' ratings of their self-efficacy as it related to explaining course concepts to others, learning the material in the course or studying engineering. For all three factors, both cohorts demonstrated reasonably high self-efficacy ratings, with means between 4.43 and 5.22 on a 7-point scale and the lowest ratings being associated with explaining course concepts to others.

However, the inverted cohort reported a higher level of confidence in answering the analytic problem-solving questions than the traditional cohort in three of the four quizzes, except the one that involved course material with a low pre-class video viewership.

Learning Outcomes

In addition to measuring overall course academic performance, three measures of conceptual understanding of the course materials – Concept Inventory gain scores and post-test scores, and long-term concept retention scores – and a set of analytic problem-solving quiz scores were used to assess students' learning outcomes.

Two of these outcome measures – analytical problem-solving quiz scores and course academic performance – showed statistically significant differences between the two cohorts, with the former having moderate practical significance ($r^2 = .16$) and the latter being negligible in terms of practical significance ($r^2 = .01$).

In our further correlation analyses we examined the associations among the five learning outcomes and three self-efficacy measures, and performed regression analyses on the two outcomes that had significant differences between the two cohorts. The correlation results (see Appendix D) show that:

- The associations among the five outcome measures varied considerably. This confirms that the five outcome measures were very different in terms of assessing student learning, with some assessing students' conceptual understanding and others measuring their analytic problem-solving capabilities.
- The relationships between the outcome variables and the self-efficacy measures were also different between the two cohorts. It appears that for the inverted cohort, the self-efficacy measures were better indicators for the students' learning outcomes in areas of short-term conceptual understanding (measured by Concept Inventory post scores), long-term conceptual understanding (measured by long-term concept retention test) and overall academic performance in the course (measured by course grades).

Two sets of hierarchical regression analysis were performed. In the first one, the hierarchical regression models included 14 independent variables in three groups when using the data from the two cohorts. The results show that:

- For analytic problem-solving quiz scores, the variables being examined accounted for 59% of the variance, of which student characteristics accounted for 36%, learning experiences constituted 20% and self-efficacy measures made up 4%. Among all the independent variables, significant contributors were prior academic performance (β = .44), using the inverted classroom approach (β = .30), an intuitive learning style (β = .18) and better lecture attendance (β = .18). Specifically, the advantage of using the inverted classroom approach was found to be an increase of .17 of a standard deviation in the analytical problem-solving quiz scores.

- For course academic performance, the 14 variables accounted for 75% of the variance, of which student characteristics accounted for 66%, learning experiences for 7% and self-efficacy measures for 2%. Significant contributors were prior academic performance (β = .71), lecture attendance (β = .20) and self-efficacy in explaining course concepts to others (β = .16). Interestingly, the instructional approach was not found to be significant in contributing to students' overall course performance. It should be noted that the major assessments that contributed to the course academic performance were not exactly the same for the two cohorts.

The second set of hierarchical regression models for the inverted cohort alone, which included independent variables relating to student characteristics and the level of engagement with the inverted classroom approach, show that:

- For analytic problem-solving quiz scores, the variables under investigation accounted for 45% of the variance, of which student characteristics constituted 42% and the level of engagement constituted 3.5%. While controlling for the other variables, the significant contributors were prior academic performance (β = .47) and being an intuitive learner (β = .34).

- For course academic performance, the variables accounted for 69% of the variance, of which student characteristics contributed to 64% and level of engagement 5%. While controlling for other variables, the significant contributors were prior academic performance (β = .72), medium engagement (β = -0.17) and low engagement (β = -0.27).

The results above consistently suggest that prior academic performance was the greatest predictor for both learning outcomes under investigation – analytic problem-solving capabilities and course academic performance. As would be expected, this supports the notion that students' academic abilities are a key factor to their learning.

Another consistent finding in all these models was the contribution of class attendance to both of the learning outcomes. Comparing the two cohorts, the students who had learned under the model of inverted classroom performed better in their analytic problem-solving than those who had learned under the "traditional" approach. For the inverted cohort, when other factors such as prior academic performance and learning style were controlled, a higher degree of engagement with the inverted classroom process was associated with better overall course academic performance. All these results demonstrate the effectiveness of teaching when the inverted classroom approach was employed.

Learning styles were found to have significantly affected students' analytic problem-solving capabilities but not their overall performance in the course. This suggests that while students' ways of learning to solve problems were different and certain learning preferences positively contributed to the improvement in their problem-solving abilities, they managed to do well in the areas in which they were assessed for their final grades, regardless of preferred learning style. Specifically, it was found that those students who were oriented to theories and discovering underlying relationships (i.e., intuitive learners) achieved better outcomes in problem-solving capabilities than those who were concrete thinkers and tended to learn facts and procedures (i.e., sensing learners). This may suggest that a good fit of learning styles with the nature of the course was helpful to the enhancement of learning outcomes.

Limitations

The findings above must be interpreted with a few caveats in mind. One is that the student cohorts that attended the course probably had higher pre-test scores than their peers taking a similar course at other universities. This is partly because the university they were attending (i.e., the University of Toronto) was a highly selective one and the student cohorts participating in this study were generally strong academically. In addition, students in this program had already been introduced to many of the primary course concepts during an introductory first-year course. Their familiarity with the subject matter was supported by their relatively high concept inventory pre-test scores, which averaged approximately 46% for both cohorts (Table 2). This result is not typical of assessments of learning gains. For example, in one study (Ding, Chabay, Sherwood & Beichner, 2006), the pre-test result for assessing conceptual learning gains through pre/post-test comparisons was around 23%. As well, gain scores are typically around 25% for traditional lecture-based classes, and improve to 50% to 60% for classes that incorporate active learning exercises, such as peer instruction (Crouch & Mazur, 2001). The relatively high pre-test scores may have affected the variance of the gain scores due to the ceiling effect. This may also explain why the mean in gain scores in the concept inventory tests for the inverted cohort (*M* = 13.33, *SD* = 41.86) was lower than that for the traditional cohort (*M* = 18.47, *SD* = 48.67) and why a very wide variation occurred for the data of both cohorts.

Second, as alluded to earlier, although the difference in course academic performance was statistically significant between the two cohorts, we are not confident enough to conclude that students in the inverted cohort did better in their overall academic performance in the course. This is because we were short of statistical evidence that the internal properties of the major assessments were rigorously comparable given that the questions on the midterms and final exams were different. However, the overall marking scheme and assessment components[8] were kept quite similar for the two cohorts and the students had the same tutorial and computer lab arrangements in the two years. As such, the results regarding course academic performance should be interpreted with caution.

Third, it should be also noted that there were some flaws in the administration of the concept inventory assessment in this study. For both cohorts, students were only given a 1.5% credit for writing the test, with no marks given to the performance on the test, and students were told they did not need to study for the test. However, a confounding factor was that the concept inventory post-test was administered in slightly different ways for the two cohorts: the traditional cohort had the course final exam four days after the test, whereas the inverted cohort wrote the test eleven days before the course final exam. The proximity of the test to the final exam for the traditional cohort may mean that students in this group were more likely to have begun studying for the final exam, thereby also improving their performance on the concept inventory test. So it was expected that the traditional cohort had been generally better prepared for the test than the inverted cohort. It would have been a better measurement if the two concept inventory post-tests had been incorporated into the final exam, as is typically done in physics education research. This was, however, impossible in this study for logistical reasons.

[8] The course had three major assessments including a term test (10%), a midterm (20%) and a final exam (40%).

4 Concluding Remarks

In this section, we will provide a summary of our findings from this two-year study. Based on those findings and our own experiences conducting this research, we will also make some recommendations for using the inverted classroom approach in higher education settings. We will conclude this report by some final reflections on this study.

Overall Observations

Based on the results presented in this report, we have made the following observations about students' behaviours, perceptions and learning outcomes when the inverted classroom approach was used in the second-year engineering course.

- *Importance of a supportive learning environment.* The concern about students feeling that they were "on their own" under the inverted classroom approach turned out to be untrue in this study, with over 70% of students in the inverted cohort indicating that they were given the necessary support to learn the course material effectively and that they had the opportunity to have their questions answered. These positive results may be related to the supplementary resources that had been made available to the inverted cohort. Although these resources were not part of the inverted classroom approach, they proved to be important to student learning while the new teaching approach was executed. As well, the majority of students appreciated having the pre-class lesson videos as a learning resource that they could use to learn at their own pace and in their own way. More than 80% of the students in the inverted class found the lesson videos to be an effective introduction to the course material. All this points to the importance of a supportive learning environment when pedagogical innovation is implemented.

- *Increased opportunity for student-faculty interaction*. Agreeing with other studies (Foertsch et al., 2002), our quantitative and qualitative data show that the new instructional mode significantly enhanced student-faculty interactions. Only 25% of students in the inverted cohort indicated that they had never had any interaction with the instructor during class, in contrast to 56% for the traditional cohort. As well, 70% of students in the inverted cohort stated that they were satisfied with their level of interaction during class, compared to 51% for the traditional cohort. The perceived adequacy of student-faculty interaction also improved, albeit by a relatively small margin (13%). These findings lend credence to the notion that the inverted classroom provides greater opportunity for student-faculty interaction (Lage et al., 2000).

- *Importance of engagement with the inverted classroom approach*. The inverted cohort was required to watch a short lesson video before attending the class. Although the requirement was critical to student learning during class, on average 57% of the students had prepared themselves this way by having watched at least 70% of the related videos. In the absence of a rigorous assessment of engagement with the process, this study examined the relationship between students' degree of pre-class video viewing and class attendance to measure their engagement level with the new instructional approach. Using this measure, we found that only 21% of the class was highly engaged with the process, while 22% was more or less disengaged. This insufficient exposure to the inverted classroom process likely affected student perceptions of the inverted classroom approach as well as achievement of some of its desired benefits.

Further, there was a strong correlation between lesson video viewing and class attendance (r = 0.62). This indicates that the students who chose to come to class were typically the ones who had prepared beforehand, and those who had not watched the lesson video before the start of the class were less likely to attend the class. It was learned from focus groups that some students understood the value of the inverted approach but found it challenging at times to fit the video viewing into their schedules. Once they fell behind, it was difficult for some of them to catch up, which became the most significant reason given by the inverted cohort for missing class. This points to the importance of raising students' awareness to the benefits of following the appropriate learning cycle with the inverted classroom mode so that they can make timely, appropriate adjustment in their time management and learning approaches to better engage with the new instructional approach.

- *Mixed reactions*. Student reaction to the inverted classroom was mixed, with some seeing the possible benefits and engaging actively with the new process and others maintaining a strong preference for the traditional lecture-based approach. Indeed, only 48% of students who had learned under the inverted classroom model indicated at the end of the term that they preferred the inverted classroom approach to the traditional lecture format, with 36% of the class appearing to prefer the traditional approach and 16% being neutral. More than half the class (56%) agreed that the inverted classroom approach made the in-class time more enjoyable than a traditional classroom, and 50% of the students agreed that both during class and overall, their time was used more effectively compared to the traditional approach. Despite the fact that only 34% of the students agreed that the consistent effort required to keep up with the lesson video viewing reduced their need to "cram" before the course's major assessments, this is a sizeable enough minority to suggest that at least some students developed more effective study habits under the inverted classroom approach. In addition, students in the inverted cohort appeared to enjoy new instructional environment better as they had a considerably higher rating of their enthusiasm at the end of the course than did those in the traditional cohort, and 43% of the inverted cohort ranked the course as among the top two of their favorite courses out of the five they were taking that term, as opposed to 34% for the traditional cohort. The mixed reactions to the inverted classroom echo the findings in other studies (Findlay-Thompson & Mombourquette, 2014; Post, Deal & Hermanns, 2015) but are no surprise for any instructional innovation initiatives.

- *Mixed perceptions about workload.* While there was no statistically significant difference between the traditional and inverted cohorts in their perceived course workload on the survey, it was clear from the comments in the focus groups and open-ended survey questions that a heavier workload under the inverted classroom model was a point of concern for a minority of the students.

- *Self-efficacy*. Our data did not support our hypothesis that the inverted classroom model would improve student self-efficacy as it related to explaining course concepts to others, learning the course material, or studying engineering. However, it was observed that the inverted cohort demonstrated significantly higher confidence ratings on their in-class quizzes when their learning was not heavily interrupted by other academic commitments. This indicates that the inverted approach did positively influence students' self-efficacy in their analytic problem-solving capabilities, even though that did not translate into an enhanced overall self-efficacy as it related to the course material.

- *Limited enhancement of learning outcomes.* In this study, we examined five indicators of student learning outcomes: (a) the post-instruction concept test; (b) the pre/post gain score for conceptual understanding; (c) the performance on the four in-class analytic problem-solving quizzes; (d) the academic performance in the course (i.e., the final mark for the course); and (e) the long-term concept retention test (implemented four months after the end of the course). Of the five measures, two were found to be statistically significantly higher among the inverted cohort than among the traditional cohort – analytic problem-solving scores and course academic performance. The inverted classroom approach was also found to foster improvement in analytic problem-solving capabilities. The inverted cohort performed significantly better than the traditional cohort on three of the four common in-class quizzes that assessed student ability to solve problems analytically. While controlling for other variables, including prior academic performance, learning style and lecture attendance, it was also found that the advantage of using the inverted approach was an increase of .17 of a standard deviation for the analytical problem-solving quiz scores. In addition, the inverted cohort had a higher average in their final course grades than the traditional cohort, though with a small effect size (r^2 = .01). However, higher degrees of engagement by regularly watching the lesson videos and attending classes contributed to better course academic performance while controlling for students' prior academic performance and learning styles. As for the three learning outcomes that assessed conceptual understanding, no significant difference was found between the scores of the traditional and inverted cohorts.

  Mixed results are revealed in the literature regarding the learning outcomes from the use of the inverted classroom approach: some report that the final grades of the students studying under the inverted classroom model did not differ significantly from those who had learned in a traditional format (Choi, 2013; Harrington, Bosch, Schoofs, Beel-Bates & Anderson, 2015; Winter, 2013), and others find improvement (Horton, Craig, Campbell, Gries & Zingaro, 2014; Talley & Scherer, 2013). Our findings agree with those studies that did not obtain significantly different outcomes from the inverted cohort in conceptual understandings (Lape et al., 2014; Love, Hodge, Grandgenett & Swift, 2013; Morin, Kecskemety, Harper & Clingan, June 2013). The small improvement in the inverted cohort's final grades coincide with the negligible effects the inverted classroom approach had on students' overall understanding of the course material. However, it is meaningful to learn that the inverted classroom approach was found to be contributive to students' higher-order thinking skills - problem-solving capabilities. This makes sense as more problem-solving learning activities were added to the face-to-face classes as a result of the use of the inverted classroom approach.

- *Influence of learning styles*. Although it is argued that the inverted classroom approach is able to accommodate students with various learning styles (Lage, Platt & Treglia, 2000), the findings in this study suggest that learning styles did make a difference in student perceptions about the approach and certain learning outcomes. Specifically, those students who found themselves to perform better in a traditional lecture-based environment tended to dislike the inverted classroom approach. Our data also consistently show that in this particular engineering physics course, those intuitive learners who were oriented to theories and discovering underlying relationships achieved better outcomes in analytical problem-solving quizzes than those sensing learners who were concrete thinkers and tended to learn facts and procedures.

Based on the results above, it can be argued that the inverted classroom teaching approach has a positive impact on the student learning experience and learning outcomes, albeit to a limited extent in this study. It is important to note that this was the first experience for both the instructor and the students with the inverted classroom approach. Situated in an instructor-focused, lecture-based learning environment, students are likely to need a good amount of time to adjust their learning methods to adapt to a single different course where active learning is nurtured and a greater degree of motivation for self-directed learning is required.

Recommendations

The inverted classroom approach entails significant changes in both how an instructor teaches and how students learn. It requires that students truly take ownership of their learning process. It is critical that the instructor provide the support and motivation necessary for the students to see the value and become fully engaged in the new learning method. We hereby make the following recommendations for successful implementation of the inverted classroom approach:

- *Motivate the students to develop new learning techniques*. A major challenge in implementing the inverted classroom approach is student buy-in. When students are not sure of the benefits of the new instructional method to their learning, they are less motivated to engage in the process. The instructor should explicitly communicate the course expectations to students and make them fully aware of the requirements related to the instructional change so that they could adjust their learning approaches to the new requirements in a timely manner. It is beneficial if the instructor introduces some fundamental concepts of how people learn effectively, and provides opportunities for students to assess and critique their own learning style, and consider what studying techniques best help them learn.

- *Stress the importance of viewing the lesson videos before attending the class*. Preparation for the class by video viewing is the facilitator as well as the barrier to students' class attendance. It is critical to make sure that students are intellectually ready for the problem-solving activities during their in-class time. A helpful technique, which was employed in the implementation used in this study, is to allocate a portion of the course mark to the completion of in-video or in-class quizzes.

- *Carefully design the lesson videos*. As the lesson videos contain the key information that students have to know before reaching a higher cognitive level while they are in class, those videos should be carefully created, with proper scaffolding and clearly presented information. Robert Gagne's *Nine Events of Instructional Design* (Gagne, Wager, Golas & Keller, 2004) and Richard Mayer's information processing-based theory on how to best present information in a multimedia context (Mayer, 2005; Shah, French, Rankin & Breslow, 2013) are helpful resources for video design.

- *Provide proper transitioning from the pre-class lesson videos to the in-class learning experiences*. It was observed early on with the inverted cohort how important it was to ensure that the in-class experiences be seamlessly built upon the pre-class videos. Many students in this cohort requested that each class begin with a short summary of the main lesson video concepts. To facilitate this, each lesson video ended with *Three Key Points*, and these were then summarized and expanded upon at the start of each class. Often *Lesson Video Review Questions* were incorporated into this short review through the use of an in-class response system.

- *Design effective in-class activities to foster active learning*. While high-quality pre-class resources and activities are important, of even greater importance is how the in-class time is managed by the instructor. Creating and facilitating effective active learning activities can be a challenging task, especially in a large traditional lecture hall where the architecture does not easily support collaborative learning. *Differentiated Overt Learning Activities* (DOLA) (Menekse, Stump, Krause & Chi, 2013) is a helpful general framework for the design of such active learning experiences.

- *Provide a supportive learning environment.* Implementing instructional change is a challenging task for both the students and the instructor. A learning environment where the students feel that they are being supported is crucial to the success of their learning. A supportive learning environment can be fostered by providing supplementary learning resources, clearly articulating the learning objectives or outcomes of the course, and, perhaps most importantly, the presence of an instructor with a truly caring heart for student learning. The instructor can create open channels to gather prompt anonymous feedback from students on the instructional method to ensure that small improvements can be made as needed and the students can take more ownership of the course design. For large classes, good teaching assistants are also critical components of a learner-friendly environment.

- *Adopt a flexible mode of using the inverted classroom approach*. Instead of inverting an entire class, perhaps the instructor could consider using the inverted approach for part of a course or for a collection of topics. It is a considerable amount of work to produce, create, edit, post and manage 30 to 35 lesson videos and associated quizzes that are needed to run a single term course. In addition, the creation of effective in-class activities takes significant consideration and effort. In some cases, it may be more appropriate to invert a few lectures during the term or focus the inversion around a particular topic. Another option is to "outsource" the lesson video content by making use of the large set of existing materials openly available online and then use the in-class time in a more active way.

Final Reflections

There is a growing interest in the use of technology to improve the student learning experience in higher education. With the developing awareness of the science behind learning, an increasing number of higher education instructors are looking for alternative means to use their time with students more effectively, and some see technology as a potential part of the solution. While the motivation of instructors may vary, there are a few common ideals that we are looking to achieve in our teaching experiences with students. We hope to inspire students to engage with the material through their own efforts outside of class. We expect that students leave our classes a little wiser – with a greater understanding of the material, even just a single insight, but something that will impact them as they continue to integrate the concepts into their own growing knowledge base. And, we strive to be a good model for them in how we think, how we learn, how we analyse problems and how we conduct ourselves, perhaps in a way that is discipline-specific. Thus, in whatever way technology is applied to teaching, it must be used purposefully and so that it allows us to focus better on the above ideals or address these ideals more effectively.

This was the motivation behind the move to the inverted classroom approach for the engineering physics course in this study. This move also represents two forces that drive instructional change in higher education: one prompted by new technology and the other shaped by the new vision of what constitutes "good learning" (Fink, 2003).

The instructional design based on the inverted classroom approach in this study enabled the instructor to:

- Incorporate more student-centred active learning activities;
- Encourage student-led cooperative learning in the classroom;
- Empower students to take greater responsibility for their learning and develop personalized skills for life-long learning;
- Focus more on problem-solving during the face-to-face class time;
- Design the progression of learning through appropriate scaffolding and integration with the students' existing knowledge framework;
- Provide effective, prompt formative feedback throughout the learning process; and
- Contextualize the material to improve student motivation and further study.

All these efforts reflect a shift to the student-centred paradigm for higher education teaching, which sees students as active constructors of knowledge and focuses on developing their competencies and talents (Campbell & Smith, 1997).

This study aimed to evaluate the effects of the inverted classroom approach on student behaviours, perceptions and learning outcomes. To do so, we employed a variety of assessments (see Table 2 and Table A-1, Appendix A). To achieve reasonable rigor in the analysis, we used a variety of statistical methods. All this demonstrates the complexity in research design for assessing the effects of a new instructional approach.

We believe that our study contributes to the growing literature on use of the inverted classroom approach for the following reasons.

- It was a comprehensive and systematic assessment of students' changed behaviours and perceptions associated with the inverted classroom as well as their learning outcomes.
- For assessment of learning outcomes, it went beyond the common practice of using the final grades as the primary indicator of outcomes and encompassed a number of additional instruments to measure conceptual understanding and analytical problem solving capabilities.
- With each cohort having more than 300 students, the findings were based on a relatively large sample size, larger than the vast majority of studies under the scoping review by O'Flaherty and Philips (2015). Admittedly, the sample sizes varied in regression analyses depending on the different variables included.
- The instructional method was carefully designed on the basis of the key principles embedded in the inverted classroom approach and the assessments were deliberately executed for comparison purposes albeit the existence of a few flaws.
- Student engagement with the new approach was examined and assessed. This seems to be a missing component in the existing literature.

It is our hope that this study, though conducted within a single engineering physics course with a single instructor, helps enhance the understanding among educators and researchers about the benefits and challenges in implementing the inverted classroom approach and its effects on students' learning experiences and outcomes. Lessons we have learned from conducting this study include the utilization of multiple assessment tools and methods to measure different learning outcomes, and careful documentation of implementation details of both the traditional and new instructional approaches as they were used.

There are many good reasons to believe that the inverted classroom approach fosters better student learning experiences and contributes to the enhancement of student learning outcomes, as discussed at the beginning of this report. However, the findings from this study, along with the ones obtained from other studies, have not yet reached a consensus about its effects, particularly on learning outcomes. Continued research studies are needed.

For future studies, we have the following suggestions. First, although control/treatment design that is run in parallel or in successive years (the case of this study) is a common approach to evaluating the effects of a new instructional method, a longitudinal design that involves a longer period of observation of perceptions and outcomes is helpful to drawing stronger conclusions about its impact. Second, problem-solving capabilities seem to be a promising gain from the inverted classroom approach, as found in this study. Further research is needed to confirm this finding and explore how the inverted classroom approach contributes to this particular area. Third, assessment of the effects should be conducted when the instructor has become more experienced in using the inverted classroom approach and the student cohort has become more familiar with what is required of them by the approach. The findings will be more convincing than the ones in this study that was applied to the first-time practice of the approach. Fourth, as the inverted classroom approach is conducive to multiple affective and cognitive outcomes such as the development of critical thinking, collaborative and team-based skills, resilience and self-motivation, inclusiveness, and life-long learning skills, these could become the object of outcomes assessment under the inverted classroom model. Finally, similar research endeavours should be made in other disciplines or fields of study at Ontario postsecondary institutions.

Finally, although the focus of this study was not to evaluate the effects of technology itself on student learning, our reflections on the implementation process of the inverted classroom approach tell us that technology did play a facilitating role for the success in applying the approach. For two years, a set of computer-based tools, such as tablets, applets, iClickers, videos, online discussion forums and feedback mechanism, and other online materials and content were used throughout the course. They were not used for their own sake; rather, they were well integrated into the teaching and learning processes to achieve the advantages of the inverted classroom.

That being said, we are not arguing that use of educational technology itself will produce a difference in student learning experiences and outcomes. Instead, use of technology is only part of the strategy utilized to achieve certain educational purposes. In the process of using the inverted classroom approach, students' motivation for learning as well as faculty's instructional skills, including design of lesson videos and in-class management incorporating active learning activities, are both important.

As with any educational innovation, the use of the inverted classroom approach is not a solution in and of itself. It is a tool, a vehicle that can enable students to create long-lasting meaning for themselves through the supportive guidance of their instructor and peers. It must be applied carefully, with consideration given to the holistic experience of the students and the fact that it is still an emerging teaching and learning technique for both students and instructors. More lessons for its effective implementation need to be learned and shared. Yet as the technology and architecture that allow for the implementation of the approach become more widely available, it is expected that both students and educators will come to be more adept at learning and facilitating under the model, and the potential of this approach will be realized more fully.

References

Astin, W. (1991). *Assessment for excellence: The philosophy and practice of assessment and evaluation in higher education.* New York: Maxwell Macmillan.

Bates, S., & Galloway, R. (April 2012). The inverted classroom in a large enrolment introductory physics course: a case study. *Proceedings Higher Education Academy STEM Conference.* London, England.

Bishop, J. L., & Verleger, M. A. (2013). The Flipped Classroom: A Survey of the Research. *Proceedings of 2013 ASEE Annual Conference & Exposition.* Atlanta, GA.

Bloom, B. S. (1956). *Taxonomy of educational objectives : The classification of educational goals.* New York: D. McKay.

Campbell, W. E., & Smith, K. A. (1997). *New Paradigms for College Teaching.* Edina, MN: Interaction Book Company.

Chasteen, S. V., Pollock, S. J., Pepper, R. E., & Perkins, K. K. (2012). Transforming the junior level: Outcomes from instruction and research in E&M. *Physical Review Special Topics – Physics Education Research, 8*(2).

Chickering, A. W., & Gamson, Z. F. (1987). *Seven principles for good practice in undergraduate education.* Retrieved from http://wwwtemp.lonestar.edu/multimedia/SevenPrinciples.pdf

Choi, E. M. (2013). Applying Inverted Classroom to Software Engineering Education. *International Journal of e-Education, e-Business, e-Management and e-Learning, 3*(2), 122-125.

Crouch, C. H., & Mazur, E. (2001). Peer Instruction: Ten years of experience and results. *American Journal of Physics, 69*(9), 970-977.

Craig, M., Campbell, J., Gries, P., & Zingaro, D. (2014). Comparing outcomes in inverted and traditional CS1. *Proceedings of the 2014 conference on Innovation & technology in computer science education (ITiCSE '14)* (pp. 261-266). Uppsala, Sweden: ACM.

Ding, L., Chabay, R., Sherwood, B., & Beichner, R. (2006). Evaluating an electricity and magnetism assessment tool: Brief electricity and magnetism assessment. *Physical Review Special Topics – Physics Education Research, 2*(1), 1-7.

Educause (n.d.). Things you should know about: Flipped classrooms. Retrieved from http://net.educause.edu/ir/library/pdf/eli7081.pdf

Felder, R. M., & Soloman, B. A. (n.d.). *Index of Learning Styles Questionnaire*. Retrieved from http://www.engr.ncsu.edu/learningstyles/ilsweb.html

Felder, R. M., & Spurlin, J. (2005). Applications, Reliability and Validity of the Index of Learning Styles. *International Journal of Engineering Education, 21*(1), 103-112.

Felder, R., & Brent, R. (2005). Understanding Student Differences. *Journal of Engineering Education, 94*(1), 57-72.

Findlay-Thompson, S., & Mombourquette, P. (2014). Evaluation of a flipped classroom in an undergraduate business course. *Business Education & Accreditation, 6*(1), 63-71.

Fink, L. D. (2003). *Creating significant learning experiences.* New York: Jossey-Bass.

Fitzpatrick, J. (2004). Evaluating teaching effectiveness. *Nursing Education Perspective, 25*(3), 109.

Foertsch, J., Moses, G., Strikwerda, J., & Litzkow, M. (2002). Reversing the lecture/homework paradigm using eTEACH web-based streaming video software. *Journal of Engineering Education, 91*(3), 267-274.

Gagne, R. M., Wager, W. W., Golas, K., & Keller, J. M. (2004). *Principles of Instructional Design.* Belmont, CA: Wadsworth.

Hake, R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(64).

Hamdan, N., McKnight, P., McKnight, K., & Arfstrom, K. (2014, September 30). *The Flipped Learning Model: A White Paper Based on the Literature Titled A Review of Flipped Learning* . Retrieved from http://www.flippedlearning.org/cms/lib07/VA01923112/Centricity/Domain/41/WhitePaper_FlippedLearning.pdf

Harrington, S. A., Bosch, M. V., Schoofs, N., Beel-Bates, C., & Anderson, K. (2015). Quantitative Outcomes for Nursing Students in a Flipped Classroom. *Nursing Education Perspectives, 36*(3), 179-181.

Harris, D. N. (2009). Teacher value-added: Don’t end the search before it starts. *Journal of Policy Analysis and Management, 18*(4), 693-699.

Hays, W. (1994). *Statistics*. Fifth ed. Fort Worth, TX: Harcourt Brace College Publications.

Horton, D., Craig, M., Campbell, J., Gries, P., & Zingaro, D. (2014). Comparing outcomes in inverted and traditional CS1. *Proceedings of the 2014 Conference on Innovation & Technology in Computer Science Education (ITiCSE '14)* (pp. 261-266). Uppsala, Sweden: ACM.

Humber College (n.d.). Flipped Classroom. Retrieved from http://humber.ca/centreforteachingandlearning/instructional-strategies/teaching-methods/course-development-tools/flipped-classroom.html#ScrollHere

Lage, M., Platt, G., & Treglia, M. (2000). Inverting the classroom: A gateway to creating an inclusive learning environment. *Journal of Economic Education, 31*(1), 30-43.

Lane, J., Lane, A., & Kyprianou, A. (2004). Self-efficacy, self-esteem, and their impact on acdaemic performance. *Social Behaviour and Personality, 32*(3), 247-256.

Lape, N., Levy, R., Yong, D., Haushalter, K., Eddy, R., & Hankel, N. (2014). Probing the Inverted Classroom: A Controlled Study of Teaching and Learning. *Proceedings of 2014 ASEE Annual Conference & Exposition.* Indianapolis, IN: ASEE.

Litzinger, T. A., Lee, S. H., Wise, J. C., & Felder, R. M. (2007). A Psychometric Study of the Index of Learning Styles©. *Journal of Engineering Education, 96*(4), 309-319.

Love, B., Hodge, A., Grandgenett, N., & Swift, A. W. (2013). Student Learning and Perceptions in a Flipped Linear Algebra Course. *International Journal of Mathematical Education in Science and Technology, 45*(3).

MacPhee, D., Farro, S., & Canetto, S. S. (2013). Academic Self-Efficacy and Performance of Underrepresented STEM Majors: Gender, Ethnic, and Social Class Patterns. *Analyses of Social Issues and Public Policy, 13*(1), 347-369.

Marra, R. M., Rodgers, K. A., Shen, D., & Bogue, B. (2009, January). Women Engineering Students and Self-Efficacy: A Multi-Year, Multi-Institution Study of Women Engineering Student Self-Efficacy. *Journal of Engineering Education, 98*(1), 27-38.

Mayer, R. E. (2005). The Cambridge Handbook of Multimedia Learning. Cambridge: Cambridge University Press.

McClelland, C. J. (June 2013). Flipping a Large-enrollment Fluid Mechanics Course – Is it Effective? *Proceedings 2013 ASEE Annual Conference & Exposition.* Atlanta, GA.

Menekse, M., Stump, G., Krause, S., & Chi, M. (2013, July). Differentiated Overt Learning Activities for Effective Instruction in Engineering Classrooms. *Journal of Engineering Education, 102*(3), 346-374.

Morin, B., Kecskemety, K. M., Harper, K. A., & Clingan, P. A. (June 2013). The Inverted Classroom in a First-Year Engineering Course. *Proceedings 2013 ASEE Annual Conference & Exposition.* Atlanta, GA.

Notaros, B. M. (2002). Concept Inventory Assessment Instruments for Electromagnetic Education. *IEEE Antennas and Propagation Society International Symposium.* San Antonio, TX.

Ossman, K. A., & Bucks, G. W. (2014). Effect of flipping the classroom on student performance in first year engineering courses. *Proceedings of 2014 ASEE Conference & Exposition.* Indianapolis, IN.

Papadopoulos, C., & Roman, A. (2010). Implementing an inverted classroom model in engineering statics: Initial results. *Proceedings of 2010 ASEE Annual Conference & Exposition.* Louisville, KY.

Post, J. L., Deal, B., & Hermanns, M. (2015). Implementation of a flipped classroom: Nursing students' perspectives. *Journal of Nursing Education and Practice, 5*(6), 25-30.

Prince, M. (2004). Does Active Learning Work? A Review. *Journal of Engineering Education, 93*(3), 223-231.

Rockoff, J., & Speroni, C. (2010). Subjective and objective evaluations of teacher effectiveness. *American Economic Review: Papers & Proceedings 100*, 261-266.

Shah, D., French, J., Rankin, J., & Breslow, L. (2013). Using Video to Tie Engineering Themes to Foundational Concepts. *Proceedings of 2013 Annual ASEE Conference & Exposition.* Atlanta, GA.

Sherry, B., & Skillen, P. (2013, February 21). Flipped Classroom – The Basics. Retrieved from http://www.otffeo.on.ca/en/learning/otf-connects/resources/flipped-classroom-the-basics/

Sousa, D. A. (2011). *How the Brain Learns*. Fourth ed. Thousand Oaks, CA: Corwin.

Stickel, M. (June 2014). Teaching Electromagnetism with the Inverted Classroom Approach: Student Perceptions and Lessons Learned. *Proceedings 2014 ASEE Annual Conference & Exposition.* Indianapolis, IN.

Stickel, M., Liu, Q., & Hari, S. (June 2014). The Effect of the Inverted Classroom Teaching Approach on Student/Faculty Interaction and Students' Self-Efficacy. *Proceedings 2014 ASEE Annual Conference & Exposition.* Indianapolis, IN.

Tabachnick, B.G., & Fidell, L.S. (2007). *Using Multivariate Statistics.* Boston, MA: Pearson/Allyn & Bacon.

Talbert, R. (2011). Inverting the Classroom, Improving Student Learning. Retrieved from http://www.slideshare.net/rtalbert/inverting-the-classroom-improving-student-learning

Talbert, R. (2014, April 30). *Flipped Learning Skepticism: Can Students Really Learn on their Own?* Retrieved from http://chronicle.com/blognetwork/castingoutnines/2014/04/30/flipped-learning-skepticism-can-students-really-learn-on-their-own/

Talley, C., & Scherer, S. (2013). The Enhanced Flipped Classroom: Increasing Academic Performance with Student-recorded Lectures and Practice Testing in a" Flipped" STEM Course. *The Journal of Negro Education, 82*(3), 339-347.

Watters, A. (2012, November 28). *Top Ed-Tech Trends of 2012: The Flipped Classroom*. Retrieved from http://hackeducation.com/2012/11/28/top-ed-tech-trends-of-2012-flipped-classroom/

Winter, J. (2013). *The effect of the flipped classroom model on achievement in an introductory college physics course.* Mississippi State University.

Higher Education Quality Council of Ontario

An agency of the Government of Ontario