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CONCEPTUAL RESEARCH

The Flipped Classroom of Operations Management: A Not-For-Cost-Reduction Platform*

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ABSTRACT

By delivering lectures online using screen capture technology, students can learn course material at the time and location of their choice, when they are in control to pause, rewind, and fast forward the professor. Class time is no longer spent teaching basic concepts, but rather focused on more value-added activities such as problem solving, systems thinking and active learning, as well as potential collaborative exercises such as case studies, web-based simulation games, and real-world applications. A flipped classroom is an online course because its online components must compete with the best of the online courses. It is also a traditional course since not even a single class session is cancelled while all the lectures are delivered online. This core concept is reinforced by a network of resources and learning processes to ensure a smooth, lean, and synchronized course delivery system. Our pilot statistical analysis indicates that a flipped classroom, when implemented in a quantitative and analytical course, can outperform its alternatives.

Subject Areas: Course Design, Management, Science/Operations Research, Operations Management, Teaching Style.

INTRODUCTION

One of the most binding constraints for business school students—from admission to graduation—is their low level of quantitative and analytical skills. According to the CEO of American Express, the low level of quantitative capabilities of graduates in the United States has kept them from outperforming graduates of rising countries such as China and India (Zakaria, 2011). The Organization for Economic Cooperation and Development (OECD) Skills Outlook (2013) compares the literacy, mathematics, and computer skills of U.S. residents with those of

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residents of other OECD countries. In mathematics, the United States trailed 18 countries, and beat just Italy and Spain.

The operations management (OM) course at our institution is a quantitatively oriented course in which students are presented with a structured, data-driven, and analytical approach to learn the basic concepts of OM (adopted from Anupindi, Chopra, Deshmukh, Van Mieghem, & Zemel, 2012). Believing that managers cannot go far with quantitative and analytical capabilities below a certain threshold, we have flipped our course to improve students' capabilities in these areas.

A flipped class aims to best utilize technology outside the classroom to enable students listen to lectures, solve assignments, and take quizzes. By delivering lectures online using screen capture technology, students can learn the material at a time and location of their choice, and when they are in control of pausing, rewinding, and fast forwarding the professor. Live face-to-face in-class discussions not only retain the human side of traditional classrooms, but offer a more active learning environment that is a result of better-prepared students. Class time is no longer spent teaching basic concepts, but rather on more value-added activities such as problem solving, answering questions, systems thinking, and potentially on collaborative exercises such as case studies, Web-based simulation games, and real-world applications.

A flipped classroom is an online course because its online wing must compete with the best of the online courses. It is also a traditional course since not even a single class session is cancelled while all the lectures are delivered online. Over time, the flipped classroom can actually turn into a problem-based learning workshop where students can collaborate and have an active role in understanding course concepts. Based on in-class questions and discussions, the course can renew itself each semester—in both the in-class wing and the online wing.

In addition to the low average level of quantitative capabilities in business school students, there is also a large gap in capabilities across students. The grade distribution for the prerequisite of our OM class in Fall 2012 was 10% A or A−, 15% B+ or B, 22% B− or C+, 32% C or C−, and 21% D+ or lower. A key question is thus how to position a course for students with such varied quantitative backgrounds.

Another characteristic of a flipped classroom is its differentiating power. If an online course can be considered a make-to-stock production line, the flipped classroom produces both make-to-stock products by providing what is needed for average and below average students via online components, and make-to-order products through a flexible in-class production system that processes a group of well-prepared students.

Some may think a flipped classroom is a teaching method in which the instructor records lectures in a classroom one semester, puts them online indefinitely, and partially uses future semesters' class time for other purposes. Nothing could be further from the truth. When thinking of a flipped classroom, it is necessary to understand that an intense amount of preparation is needed to make it successful. One objective of this manuscript is to describe the characteristics of a flipped classroom and thus define the required network of resources and learning processes to ensure a smooth, lean, and synchronized course delivery system. In addition, based on empirical data, we compare a flipped classroom with both traditional and online classes, and provide statistical evidence to support the use of flipped classrooms in quantitative-based courses.

The remainder of this manuscript is organized as follows. The related literature is reviewed in the following section. Resources and learning processes for a flipped quantitative-based course in business schools in general and for our OM course in particular are then presented. This is followed by empirical analysis of a pilot assessment of flipped classrooms, and conclusions that can be drawn from the analysis.

LITERATURE REVIEW

There is a limited amount of literature on flipped classrooms. Lage, Platt, and Treglia (2000) argued that if an instructor wanted to lecture for those students who learn best via lecturing, conduct experiments for experimental learners, give group assignments for collaborative learners, and oversee self-directed study for independent learners, student contact time would need to increase fourfold. Both the proliferation of students' access to multimedia and the ease of multimedia development have created an environment in which alternative learning methods can be integrated without increasing contact time or sacrificing course content. According to Herreid and Schiller (2013), the flipped classroom not only benefits from materials developed by the instructor but from the availability of audio and video resources on virtually any subject, frequently narrated by some of the world's outstanding authorities. Lecture captures of a flipped classroom can in turn contribute to the online repository of assets of open-to-the-public OM classrooms, or what are generally known as Massive Open Online Courses.

Baker (2000) described the evolution of online instructional materials that allow students to spend class time on active learning and peer-collaboration. Zappe, Leicht, Messner, Litzinger, and Lee (2009) reported that students of their large flipped undergraduate architectural engineering course enjoyed watching lecture videos outside of class, and that the discussions are more effective than in-class lecturing. Strayer (2012) compared traditional and flipped versions of an introductory statistics class, and reported that students in the flipped classroom were more open to cooperative learning but less satisfied with online tasks.

Based on a survey of 200 teachers, Herreid and Schiller (2013) completed the list provided by Fulton (2012) on the advantages of a flipped classroom. These advantages included (i) students can watch lectures online and progress at their own pace; (ii) classroom time can be used more effectively and creatively; (iii) students are more actively involved in the learning process; (iv) teachers get better insight into students' difficulties and learning styles when doing homework in class; and (v) students like flipped classrooms. According to the authors, teachers have long struggled to get students to study on their own, either ahead of time or through homework, yet that is when real learning happens, not when the teacher is lecturing.

Before the advent of flipped classrooms, educators have used a variety of pedagogical techniques including autotutorials, team-learning, peer-instruction, inquiry-learning, and just-in-time teaching. A central theme in all these techniques is that active learning works best. For more information on these techniques, the reader is referred to Abbott (1970, Auto Tutorials), Kasl, Marsick, and Dechant (1997, team learning), Crouch and Mazur (2001, peer instruction), Novak (1999, just-in-time teaching), and De Jong (2006, inquiry learning). In the next section, we refer to several pedagogical tools and techniques. For more information on these topics, the reader is referred to Toppin (2011), Euzent, Martin, Moskal, and Moskal (2011) and He, Swenson, and Lents (2012) for discussion of lecture capture, Hillman (2012) for online quizzes, Bonwell and Eison (1991) and Johnson, Johnson, and Smith (1998) for active and cooperative learning, Faria, Wellington, Hutchinson (2013) for business simulation games, Duch, Groh, and Allen (2001) and Savery (2006) for problem-based learning, and to the National Center for Case Study Teaching in Science (2013) for using case studies in problem-based learning and active learning.

THE NETWORK OF RESOURCES AND LEARNING PROCESSES

As we learn from great directors such as Stanley Kubrick, whose films like A Space Odyssey broke new ground in cinematography, and David Lean, who is remembered for big-screen epics such as Lawrence of Arabia, it is never enough for a film to have just one solitary excellent element. A great film is recognized by its skillful integration of several differentiating components. Similarly, for a flipped classroom to succeed, it needs a well-integrated network of resources and learning processes to reinforce the core concept. The resources and learning processes include standard academic tools such as textbooks, PowerPoint slides, assignments, tutoring, and exams. There are also resources and processes that are tailored for a flipped classroom such as recorded lecture captures, step-by-step animated-solved assignments, after-lecture-before-class quizzes, after-class quizzes, Web-based simulation games, online learning management systems (LMS), and academic honesty control systems. These components and their relationships are depicted in Figure 1, and some are described further in the following subsections.

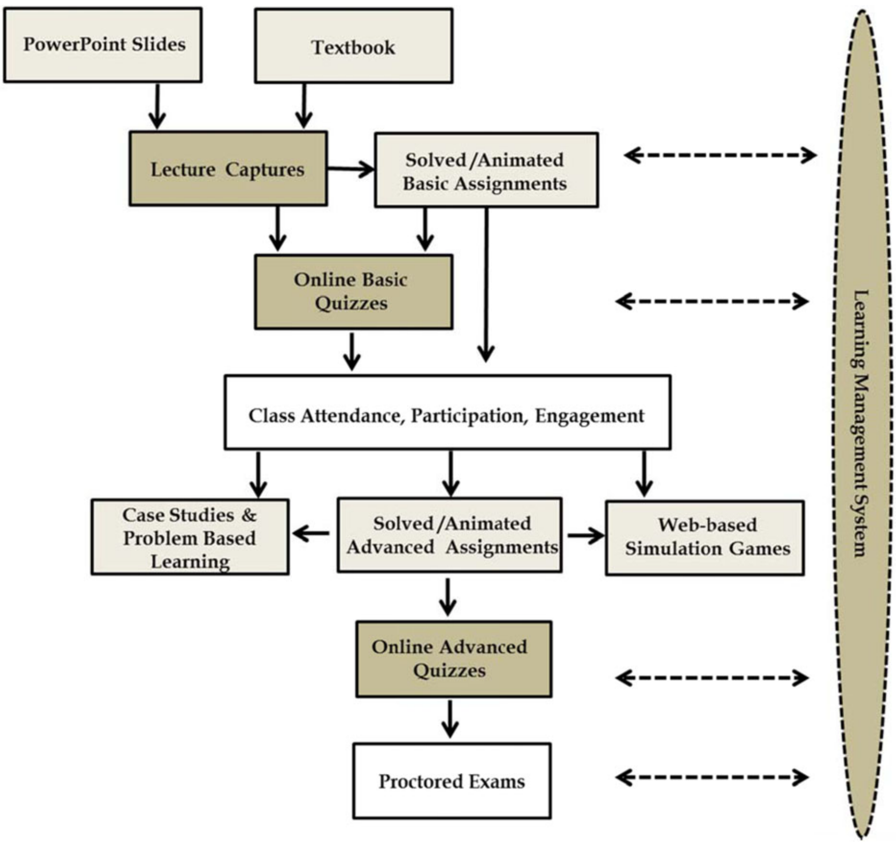
PowerPoint Slides

We have prepared a set of detailed, step-by-step lecture slides with simplified notations to facilitate understanding of the seeds of each concept. The slides are based on questions students have asked in live class sessions over time. After each in-class discussion, we collect questions students have asked and insert animated answers to the questions at appropriate points in the lecture slides for use in future semesters. These slides are different from the ready-to-use generic slides that accompany textbooks because they fit with the capabilities of our students.

Recorded Lecture Captures

The impact of lecture capture technology on education is analogous to the impact of the Internet on communication. Two technologies that enable lecture captures are screen capture software such as CAMTASIA STUDIO (TechSmith, 2013) and touch screen smart monitor hardware such as SYMPODIOUM (Smart Technologies, 2014). Using screen capture software, the voice of the instructor is recorded

Figure 1: Basic resources and learning processes of a flipped classroom.
White blocks represent in-class activities, while dark blocks represent online activities. Intermediate shading refers to a combination of the two types of activities.



simultaneously with what is happening on the monitor, including animations on the presentation slides, and what the instructor writes or draws on the smart monitor. There are significant differences between preclass lecture captures (in-office recording) and in-class recording (also referred to as lecture captures) because they serve two entirely different purposes. We rely on in-office recordings to ensure a controlled environment in which all the effort is focused on creating an effective and time-efficient learning atmosphere for an average student. In an office setting, the strongest or weakest students cannot distract the continuity of the learning process of an average student as they can during in-class recordings of lectures. The fact that lectures can be viewed more than once is helpful for improving the learning of below average and international students, and those with concentration disabilities. Instructors also benefit from lecture captures because they do not have to repeat themselves every semester. This by no means implies that one may record an in-class lecture and leave it for a decade online. Flipped classroom professors need to use feedback from face-to-face in-class discussions, and close the loop by bringing the outcomes of these discussions into the lecture slides and in-office lecture captures. An average lecture age of less than 2 years, i.e., recapturing 15% of lectures per semester, seems to be a reasonable renovation strategy. Only through a set of well-designed and well-staged lecture captures can one assure that the learning process is smooth, i.e., the workload is uniformly paced over the weeks of the semester.

After-Lecture-Before-Class Quizzes

We have developed a large test bank of basic quantitative multiple choice quizzes. These online quizzes ensure that students have reviewed the lecture slides and watched the lecture captures before they come to class. Students do not need to do anything other than listen to the lectures. Basic quizzes have the same problems as those covered in lectures with the exception that the numbers are changed. We elaborate later on the generation process of quizzes. Only through a continuous set of before-class and after-class quizzes can one assure that the learning process is lean, i.e., students do not have the opportunity to postpone the learning tasks.

Animated-Solved Assignments

Following the after-lecture and before-class basic quizzes and prior to coming to class, students are expected to go through a set of presolved, step-by-step animated assignments. Students put solved assignments in a slide show mode and attempt to solve them. If a student needs help, it is just one mouse click away. It may require 2–8 mouse clicks to go from one slide to the next. This is profoundly different from a slide show in which a bundle of quantitative relationships appears on the screen in a single drop. We have observed that by watching the lecture and going through this step-by-step process, a below-average student can independently learn the basic concepts of OM before coming to class. It is also why in spite of the availability of extensive tutoring hours only about five percent of the students take advantage of tutoring.

Class Sessions

We encourage students to go into a state of meditation few minutes before class starts to leave all distractions behind. Similar to an actor following Stanislavsky's Method (Carnicke, 2008), as students meditate before the lecture starts, they clean the slate and enter a state of being ready to learn at their very best. In a quantitative course, if students come to class with a blank mind, there will be little common ground for communication and discussion between the teacher and the students. What can be accomplished is merely a monologue from a speaker to a class of not-necessarily prepared students. Freeing up class time for live communications by having students undergo an online preparation phase can replace the monologue with active dialogue between a class of prepared students and a professor who is quick on his/her feet to react to students' questions. In such an environment, there is enough time for a classical approach to solving (or resolving) assignments and answering questions as well as open and free-flow discussion that allows students to actively contribute to the teaching process. The atmosphere should allow for frequent interruptions and challenges, creative thinking, and other digressions in real time. This environment also directs the instructor to rethink what improvements can be made in the lecture slides and lecture captures and to revise them accordingly.

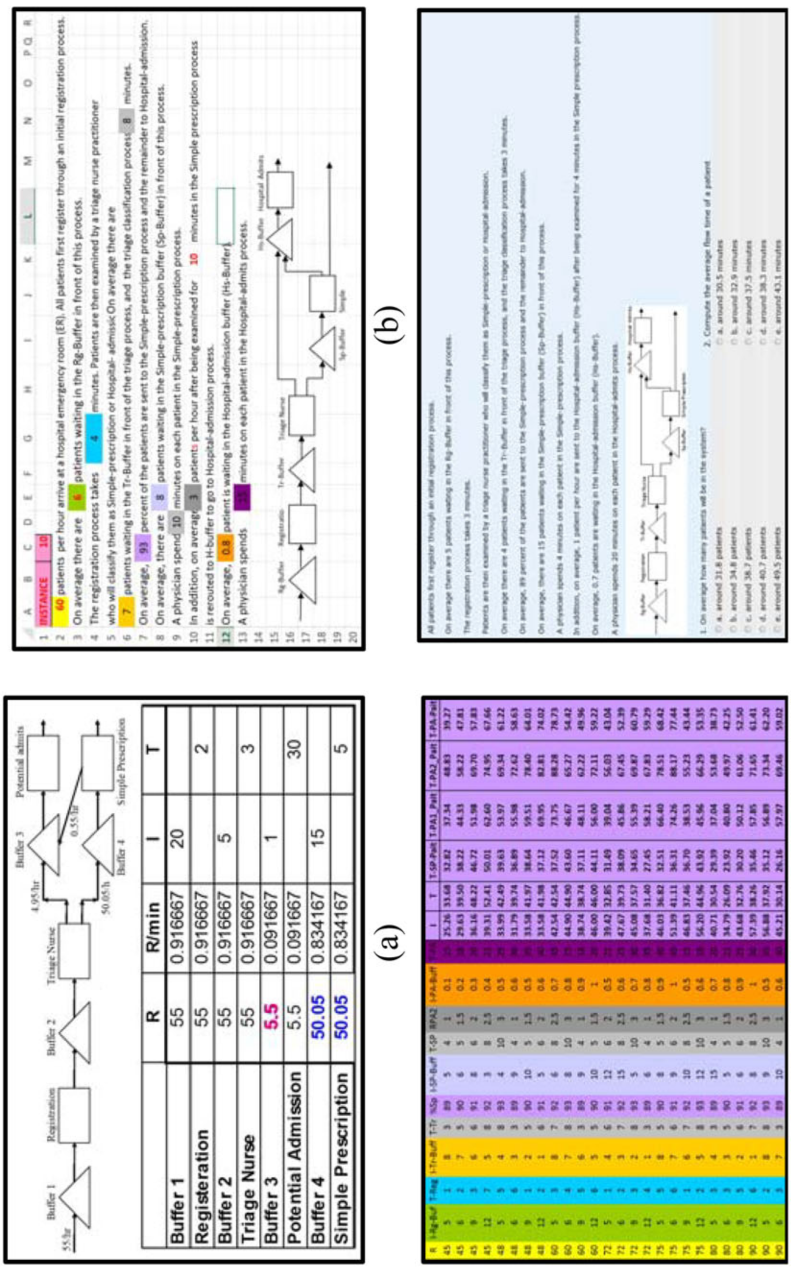
Flipped classrooms also ensure that the so-called Carnegie requirements for class hours per course unit awarded are followed. In the Carnegie unit definition, one unit of credit requires 50 minutes of instructor-led activities and 100 minutes of independent work per week over a 15-week semester. Our flipped classroom provides about 150 minutes of instructor-led sessions outside the classroom since about 150 minutes of lectures are delivered online using screen capture technology. Students watch these lectures since they have to take a quiz before coming to class. Fully understanding the online lectures, practicing presolved assignments, taking online quizzes and other out of classroom activities (such as Web-based games) also requires 150 minutes. Our flipped classroom also provides for 150 minutes of in-class discussion per week since not even a single class is canceled. Given all the preparation required before coming to class, the 150 minutes of face-to-face interaction in the classroom is no longer instructor-led but is interactive. We also allocate some class time to broadening students' skills by using tabular and schematic representation and information visualization, teamwork, alternative software tools, and examining social responsibility. The links between the online lectures and in-class discussion need to be continually renewed to ensure a synchronized process. By synchronized, we mean that online resources and learning processes should facilitate in-class discussions, and vice versa.

After-Class Quizzes

After each class session, during which questions regarding the online lecture and the presolved assignments have been addressed, students complete already solved, step-by-step animated assignments. They then take another online quiz, but this time at a more advanced level. Both basic and advanced online quizzes have been designed and implemented by the author of this manuscript. They are algorithmic, e.g., have identical contexts and questions, but have different numerical parameters as illustrated in Figure 2.

Each quiz is a replica of a presolved assignment (Figure 2a). The statement of the problem is copied from a PowerPoint slide and pasted into an Excel worksheet. An Excel cell is then allocated to each parameter of the problem so that by changing cells one can create a new instance of the seed problem (Figure 2b). Next, the changing cells are linked to a table using the Excel VLOOKUP function (Figure 2c). Each row of the table corresponds to one instance of the problem, and there are usually 25–50 instances. Each row contains the set of parameters of a specific instance on the left side, and the solution to the sub-questions on the right side. Parameters are generated using the uniform and normal distributions by means of RAND and NORM.S.INV functions in Excel. Solutions are computed using other Excel functions. The statement of the problems, the table of parameters, and the table of solutions are linked using RANGENAME, VLOOKUP, INDEX, and MATCH functions. By changing instances of the problem, all parameters in

Figure 2: Steps in the quiz generation process.



the statement of the problem and answers in the multiple-choice questions are changed.

An Excel MACRO is applied to change the instance number in the seed-page and copy the specific instance into a new worksheet, thereby generating 25–50 new worksheets based on the seed sheet, each containing a random instance of each quiz. The Excel file is then copied into a Word file. The copying process can be time consuming since a large set of empty spaces of different kinds—such as different types of TABs—are created in the word file, and which cannot be removed in one or few steps. (To understand the process, the reader is encouraged to create a problem with changing cells in a single Excel worksheet, copy it into a Word file, and then try to organize it for an exam). To resolve this difficulty, we copy the Excel file into a LaTeX file. LaTeX does not differentiate between one and several spaces or different types of TABs, they are all recognized as a single space. The LaTeX file is transformed into a PS file, then into a PDF file, and finally written on a Word file that is now well organized. In addition, all HTML instructions are embedded in the original Excel file, thus the final Word file has all the features needed to be uploaded to Moodle as a CLOZE type quiz in XML format (Figure 2d). This process is fully automated and is done in one step.

Our quizzes differ from those available from publishers or educational service providers for several reasons. First, they are not generic but fit the capabilities of our student population. Second, they allow the instructor to virtually partition and decentralize the class and approach each layer of students separately. As soon as a weakness is observed in one layer of students in a live classroom, and after going through the subject in class, a quiz is designed using the quiz-generation process and implemented online to address that specific weakness. Currently, all students take the quiz, but we plan to create a mechanism that enables only a subset of the students to take it. Third, incorrect answers for each instance of a problem are not random and unrelated; they are pulled from the correct answers to other instances of the same problem. This feature increases the likelihood of capturing potential instances of academic dishonesty. Finally, students do not pay a fee for using these services.

Web-Based Simulation Games

We have implemented simulation games (Responsive Learning, 2014) in which students act as operations managers of a manufacturing or service system. Students examine the tools, techniques, and methodologies they have learned through the course in a virtual environment. Our experience shows that after playing the first game, students realize that understanding the course material plays a significant role in their performance. Accordingly, they allocate more time to learn the course material and recognize their potential applications in the second game.

Case Studies and Real-World Applications

Freeing up class time also enables the instructor to discuss more real-world applications and close to real-world case studies to improve the quantitative and analytical skills and systems thinking capabilities of students. We elaborate on the use of case studies, real-world applications, and simulation games in a subsequent section.

In-Class Exams

A flipped classroom allows proctored exams to be used to validate nonproctored quiz grades. This capability does not exist in online courses. By comparing student performance on nonproctored online quizzes with that on proctored midterm and final exams, we later report on the implications for academic integrity in our flipped classroom.

Learning Management System

One of the main purposes of a LMS is to make sure students have watched lectures, taken quizzes, and worked on assignments. We send e-mail messages to students who have taken basic quizzes instructing them to proceed to solve related assignments and be prepared for class discussions and advanced quizzes. Forums are opened allowing students to discuss course material and search for teammates. The LMS (our institution uses Moodle) also enables the instructor to play the role of Big Brother. The instructor has access to data such as the time and duration each student spent on each activity, and the IP address of the computers on which online quizzes were taken. Regression analysis of the time spent on quizzes and grades earned and analysis of variance of grades achieved on different quizzes are conducted in the background to ensure academic integrity.

While there is no single model for a flipped classroom, piecemeal implementation of the network of resources and learning processes does not yield a lasting competitive edge. All the components of the network need to work in harmony as a total system.

OBSERVATIONS AND STATISTICAL ANALYSIS

In this section, we present empirical data illustrating the characteristics and effectiveness of the flipped classroom, and the learning gains from its implementation.

Evaluation of the Resources and Learning Processes

A survey of 84 students in Fall 2013 provided feedback regarding the effectiveness of the resources and learning processes of our flipped classroom. On a scale of 1–5, the average score for the relative impact of lecture slides, the highest ranking resource/learning process, was 4.7 (Figure 3). It is not an exaggeration to say that each slide, over time, has consumed 2–3 hours of the author's time. Step-by-step animated assignments and recorded lecture captures ranked second and third with scores of 4.4 and 4.2, respectively. Before-class quizzes, after-class quizzes, and face–to-face discussion all had a score of 4. We expected the last of these to have a higher score. The fact that it did not is mainly because we have not been successful in motivating lower layers of students to fully comply with their before-class online responsibilities so that they are well prepared to benefit from in-class discussions. If we can improve on this, we will not be too worried about not covering 100% of course content as students can learn concepts not taught in class on their own.

Figure 3: Relative impact of resources and learning processes.

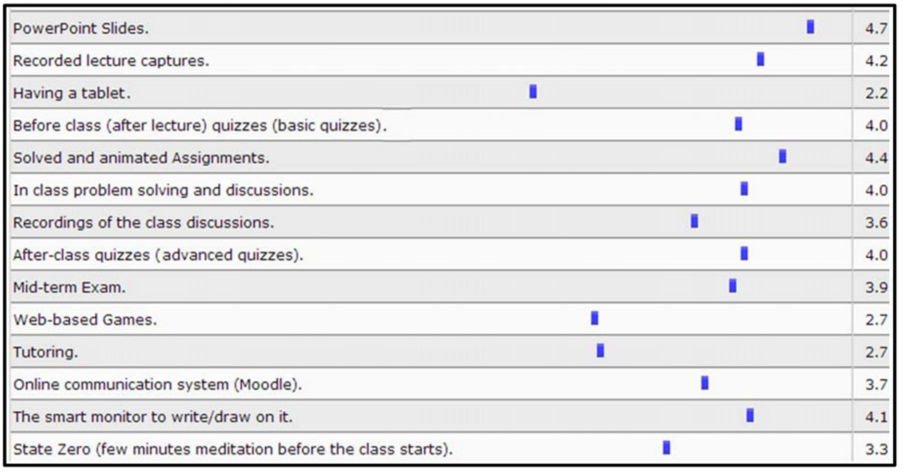


Table 1: Descriptive statistics of midterm grades.

Statistics	Spring 11	Fall 11	Spring 12	Fall 12	Fall 13
Sample size	160	160	154	141	157
Mean	12.1	11.6	12.4	14.0	14.0
Median	13.0	12.0	13.0	14.0	15.0
Mode	14.0	14.0	15.0	16.0	16.0
Coefficient of variations	.29	.34	.27	.29	.31
95% confidence interval	11.6–12.7	11–12.2	11.9–13	13.4–14.7	13.7–14.9

Comparison with Traditional Classes

When implemented in a quantitative and analytical course, a flipped classroom can outperform its traditional version. The specific learning goal measured in this study is students' knowledge of basic OM concepts. Proctored exams and online quizzes were the tools used to measure students' knowledge. The author's OM classes were fully flipped in Fall 2012 and Fall 2013. The class was partially flipped in Spring 2012, and was taught in a traditional format in Spring and Fall 2011. All midterm exams contained 20 similar short problems. Figure 4 shows the cumulative grade distribution. The horizontal axis shows the percentage of students who correctly answered a number of questions greater than or equal to the number on the vertical axis. The difference in grades between the flipped and traditional classrooms taught by the same professor is noticeable. As shown in Table 1, the mean, median, and mode of students' grades improved by switching from a traditional to a flipped classroom.

One-tailed hypothesis tests were carried out to determine if differences between mean grades achieved in the traditional and flipped classes are statistically significant. Specifically, the objective was to find whether there is statistical

Figure 4: Cumulative percentage of students correctly answering questions. For example, more than 40% of the flipped class students have answered at least 16 questions correctly.

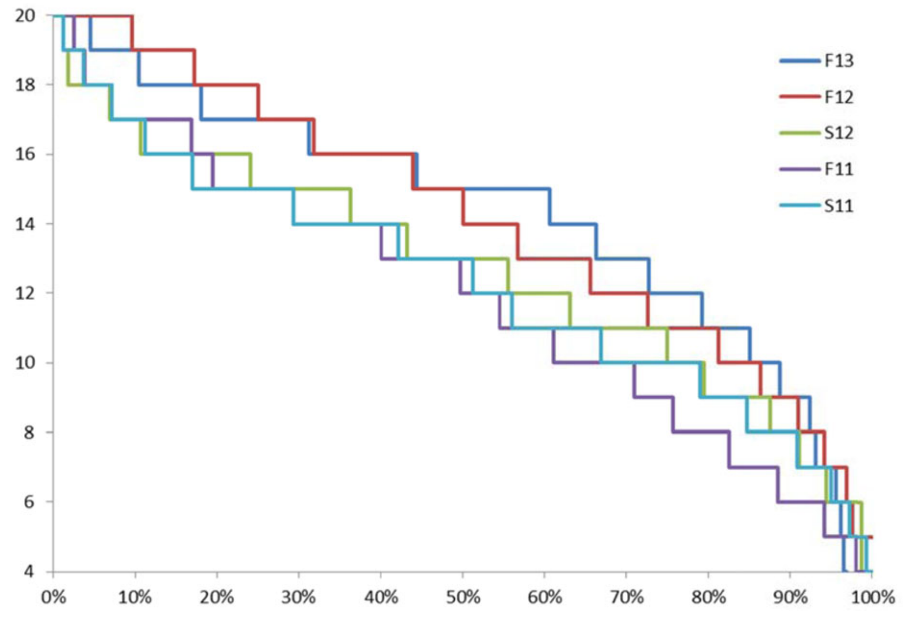


Table 2: Hypotheses Tests comparing performance of flipped and traditional classrooms.

Null Hypothesis	t-Stat	p-Value	K	K/μ
μ(grades in Fall 12) $\leq$ μ(grades in Spring 11)	4.37	8.8E-06	.89	7.4%
μ(grades in Fall 12) $\leq$ μ(grades in Fall 11)	5.26	1.4E-07	1.37	11.8%
μ(grades in Fall 13) $\leq$ μ(grades in Spring 11)	4.35	9.3E-06	.88	7.3%
μ(grades in Fall 13) $\leq$ μ(grades in Fall 11)	5.24	1.5E-07	1.35	11.6%

evidence to reject the null hypothesis that the average grade of the flipped version of the course is lower than or equal to the average grade of a traditional version of the course. For example,

H_0: μ (grades in the flipped class of Fall 2013) $\leq$ μ (grades in the traditional class of Spring 2011)

H_a: μ (grades in the flipped class of Fall 2013) $>$ μ (grades in the traditional class of Spring 2011)

The resulting p value was $< .001$ thus the null hypothesis is rejected. Columns 2 and 3 in Table 2 show t-statistics and p values for four null hypotheses comparing mean grades in Fall 2013 and Fall 2012 classes with those of traditional classes taught in Spring 2011 and Fall 2011. All null hypotheses are rejected ($p < .001$), thus the following conclusions are supported

μ (grades in the flipped class of Fall 2013) $>$ μ (grades in the traditional class of Spring 2011)

μ (grades in the flipped class of Fall 2013) $>$ μ (grades in the traditional class of Fall 2011)

μ (grades in the flipped class of Fall 2012) $>$ μ (grades in the traditional class of Spring 2011)

μ (grades in the flipped class of Fall 2012) $>$ μ (grades in the traditional class of Fall 2011)

Additional hypothesis tests were conducted of the form

H_0: μ (grades in a flipped classroom) $\leq$ μ (grades in a traditional classroom) $+$ K

H_a: μ (grades in a flipped classroom) $>$ μ (grades in a traditional classroom) $+$K

The objective of these tests was to determine if there is significant evidence to support the hypotheses that the average grade in the flipped version of the course was K units greater than the average grade in its traditional version. By increasing the value of K in the above hypotheses, one can identify the maximum value for which the null hypothesis can still be rejected. According to Table 1, average grades in the flipped class of Fall 2013 and traditional class of Spring 2011 were 14.0 and 12.1, respectively. The largest value of K for which it is possible to reject the null hypothesis H_0: μ (grades in a flipped classroom) $\leq$ μ (grades in a traditional classroom) $+$ K at $\alpha = .01$ is .88. One can therefore conclude that

The average grade in the flipped classroom in Fall 2012 was 7.4% higher than the average grade in the traditional class in Spring 2011.

The average grade in the flipped classroom in Fall 2012 was 11.8% higher than the average grade in the traditional class in Fall 2011.

The average grade in the flipped classroom in Fall 2013 was 7.3% higher than the average grade in the traditional class in Spring 2011.

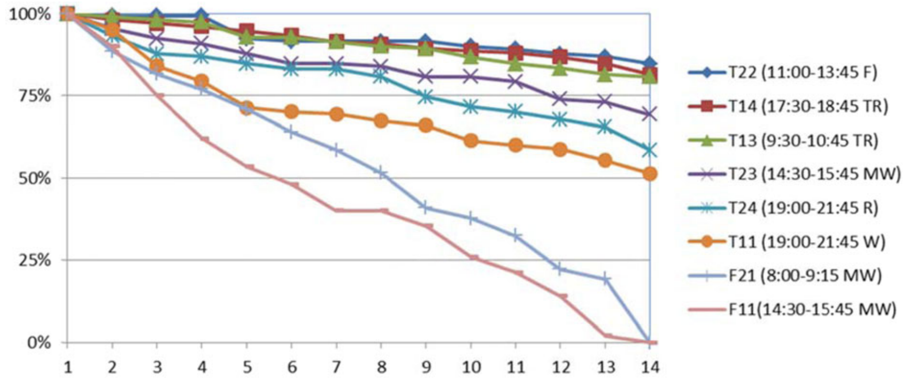
The average grade in the flipped classroom in Fall 2013 was 11.6% higher than the average grade in the traditional class in Fall 2011.

Registration Rate

To assess students' interest in a flipped class, the registration rates of the flipped and the traditional sections of the same course offered in the same semester were compared. Figure 5 illustrates the registration rates of eight class sections, each with a capacity of about 150 students, in Fall 2012 and Spring 2013. The vertical axis shows the unfilled capacity in percentage terms. The horizontal axis is a counter of the number of times the available capacities were checked. The time interval between counts was two to three days. As illustrated, when the flipped sections were fully filled, the most highly filled of the traditional sections still had about 50% available capacity.

Demand for a specific class section may be a function of the following: (i) class time, (ii) ease of grading on the part of the specific instructor; and (iii) quality

Figure 5: Registration rate in eight OM courses in Fall 2013 and Spring 2014. All sections had the same capacity of 150 students. T and F refer to traditional and flipped class respectively. The second digit is 1 for Fall 2012, 2 for Spring 2013. The third digit identifies the professor. The time and day of each class is shown inside the parentheses.



of the professor and course content. The average grade of the flipped sections was slightly higher than the average grade of all sections. Based on a survey of 148 daytime students, evidence suggests that the high demand for the flipped version of the course is not necessarily due to convenient class hours or perceived ease of grading. According to the survey, 64% of students were motivated to take a specific section of a course based on the quality of the professor and course content, 21% indicated they selected a section based on class time, and 15% did so based on the ease of grading on the part of the specific professor.

Class Attendance and Class Participation

Based on 16 random headcounts, the percentage of students who attended class in Fall 2012 was between 82% and 97%. In other words, while all teaching materials were online, students still attended class. Ten percent of the final grade was due to class participation. However, based on conversations with colleagues, 10% for class participation is not believed to be an adequate motivation for students to attend class. Students who choose not to come to class or miss classes receive a participation grade equal to the average of their midterm and final exams. For more information on the impact of in-class lecture capture on class attendance, the reader is referred to Traphagan and Kucsera (2010).

Class attendance (physical presence) and class participation (mental presence) are requirements in a flipped classroom. However, the main goal of a flipped classroom is to encourage student engagement that fosters active learning and systems thinking. Choosing online and hybrid courses is student initiated rather than institution initiated. It is justified when either the student market requests it or the level of class attendance and class participation falls below a certain threshold.

Table 3: Average score and 95% confidence intervals for online components of flipped classroom compared to average and best online courses.

Statistics	Compared to an Average Online Course	Compared to the Best Online Course
Sample size	84	84
Mean	78.4	66.8
Median	80	65
Mode	90	40
Standard deviation	16.4	22.6
Coefficient of variation	.21	.34
Standard error	1.79	2.47
95% confidence interval	74.8–82	61.9–71.7

Comparison of Quizzes and Exams

By comparing nonproctored online quizzes with proctored midterm exams, there is evidence that a flipped classroom yields a high level of academic honesty. In Fall 2012, the average grade for 11 quizzes before the midterm exam was 77.6%, and the average score for the midterm exam was 69.8%. The higher average score for non-proctored quizzes compared to proctored exams can be attributed to the following: (i) quizzes are open book; (ii) students have more time for quizzes; (iii) quizzes are taken at the time when the corresponding topic is learned and discussed; (iv) the lowest quiz grade is dropped; and (v) students are under less stress during quizzes compared to during exams. It is important to note that in online courses, there is no similar basis to examine the issue of academic honesty by comparing non-proctored and proctored tests. It seems that when students have face-to-face communication with their professor (as is the case in a flipped classroom but not in an online course) combined with a large set of random algorithmic problems, the likelihood of academic dishonesty in online quizzes (in flipped classes) diminishes. However, a thorough analysis of this hypothesis deserves separate study. For a discussion of the importance of student-instructor relationships on academic honesty, the reader is referred to Christe (2003).

Comparison with Online Courses

By providing well-designed animated lecture slides, in-office lecture captures, presolved and step-by-step animated assignments, and before-class and after-class online quizzes, online components of a flipped classroom can compete with the best online courses. To provide evidence to support this claim, at the end of the Fall 2013 semester, students were asked what score they would assign to the online components of the flipped course if they assigned a score of 50 to an average online course they had taken. The average score was 78.4 with a 95% confidence level of 74.8–81.9 (Table 3). Students were also asked what score they would assign to the online components of the flipped course if they assigned a score of 50 to the best online course they had taken. The average score was 66.8 with a

95% confidence level of 61.9–71.7. In other words, the online components of the flipped classroom outperformed the best of the online courses the students had taken.

Classroom Observations

We now report on three examples of active learning observed during the Fall 2013 flipped classroom. The first example comes from an in-depth discussion of systems thinking and the concept of trade-offs. Without prior planning, the interactive discussion led to where one should position a firm in the three dimensional space of (i) customer waiting time—the longer the customer wait the lower the revenue; (ii) product waiting time—the higher the inventory the higher the operational cost, and (iii) capacity waits—the higher the capacity the higher the investment cost. The discussion created a basis upon which to link revenue management, inventory management, and waiting line management models through the concepts of safety inventory and safety capacity and the impact of variability.

The second example comes from the application of problem-based learning using a Web-based simulation game. Each day in the game took one hour in real time, and the game ran for 168 days (one week in real life). Students were required to access the game several times each day to monitor the system they were managing, and to make decisions over the course of the week to maintain or improve system performance. In addition to the 168 day duration of the game there were additional 50-day periods at the beginning and end of the 168 days during which students could not access the game. These periods ran in a few minutes. The students played the first and last hour of the main 168 hours in the classroom. During these sessions, they made initial (to start day 51) and final decisions (for the last 50 days) regarding capacity and safety capacity, the type of orders they would process, order quantities, reorder points, and the optimal service level (through analysis of the news vendor problem). These two sessions provided perfect examples of problem-based learning in which students had to acquire the essential concepts of the course, find and use appropriate tools and methods, integrate different functional areas to gain a systems view, and exercise their quantitative and software skills. This opportunity was not afforded by the traditional version of the course offered by the author. At the end of the game, student groups prepared three-page reports in which they elaborated on how they played the game, what operations management tools and techniques they used, what good and bad decisions they made, and what they learned throughout the game. Many students expressed a positive opinion about the game, explaining that the pseudo-real-world of a computer game enabled them to better understand and implement their knowledge in real-world situations.

The final example comes from a real-world application in which monthly import and export data from the ports of Los Angeles and Long Beach over the past 16 years (a total of 192 rows each with four columns of loaded import, loaded export, empty inbound, and empty outbound) were used as a case study to exercise alternative forecasting techniques. In another experiment we used an origin-destination data set containing about 40,000 records. Each record also contained about 10 attributes such as origin, destination, address, phone number, industry, weight of the shipments, volume of the shipments, number of trips, etc. The use of these datasets represented our first attempt to approach big-data in the course. During the analysis, students were introduced to the task of cleaning the data and removing inconsistencies. In another real-world application, we addressed the graduation rate and time to graduate at our institution as a case study to address systems thinking and strategic decision making. These types of learning are hard to replicate in either online courses (due to the lack of face-to-face interaction) or traditional classes (due to shortage of time).

CONCLUSIONS

Many educational institutions have become attracted to online courses as a cost cutting initiative. The cost of switching a traditional course to an online course is bound by the total cost of the course. Cost reduction goals of hybrid (50% traditional and 50% online) courses to save direct transportation costs and the indirect costs of travel time spent on going to and from campus are not realized unless 2–4 hybrid courses are bundled together. A flipped classroom is positioned differently, as it focuses on improving the teaching environment and the limits of student learning. An intense amount of preparation is needed to develop a well-integrated network of resources and learning processes. As we have discussed, the main components of this network include the instructor's ability to be quick to react to students' questions. We provided statistical evidence to show that a flipped classroom, when implemented in a quantitative and analytical course, can outperform its traditional counterpart, and that a well-designed online component of a flipped classroom can compete with the best online courses. Even if online classrooms are the ultimate goal, to ensure desired learning outcomes, they need to incorporate the strengths of flipped classrooms. The goal of future research is to examine which types of courses, traditional, hybrid, online, or flipped, best fit classes given course level (freshman, sophomore, junior, senior) and type (quantitative, mostly quantitative, mostly qualitative, and qualitative).

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