Flipping a First Course on Cyber-Physical Systems - An Experience Report

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ABSTRACT

The flipped classroom format involves swapping activities traditionally performed inside and outside the classroom. The expected effects from this swap include increased student engagement and peer-to-peer interaction in the classroom, as well as more flexible access to learning materials. Key criteria for successful outcomes from these effects include improved test scores and enhanced student satisfaction. Unfortunately, while many researchers have reported positive outcomes from the approach, some instructors can still encounter difficulties in reproducing this success.

In this paper we report our experiences with flipping a first course on Cyber-Physical Systems at Halmstad University. The course is required for a Masters level program and is available as an elective for undergraduates. The focus of this report is on three separate editions of the course taught over three years. In the first year, lectures were recorded. In the second, the same instructor taught the course using the flipped format. In the third, new instructors taught it using the flipped classroom format.

Our experience suggests that flipping a classroom can lead to improved student performance and satisfaction from the first edition. It can also enable new instructors to take over the course and perform at a level comparable to an experienced instructor. On the other hand, it also suggests that the format may require more effort to prepare for, and to teach, than the traditional format, and that a higher level of attention to detail is needed to execute it with positive outcomes. Thus, the format can be demanding for instructors. It is also the case that not all students preferred this format.

Keywords

Flipped Classroom, Cyber-Physical Systems, Embedded Systems.

1. INTRODUCTION

Over the last five years, we have been developing a first course on Cyber-Physical Systems (CPS) for Masters level and upper undergraduate levels [TC+13, TC+14]. The syllabus [T11], lecture notes [T15], modeling, and simulation environment [A16], are all publically available under liberal re-use licenses (CC and BSD).

1.1 The Flipped Classroom

As the content of the course began to stabilize, we considered ways in which we could improve student performance and satisfaction with the course. Various sources suggested that the flipped classroom approach might be beneficial. While the body of relevant research is larger than can be summarized here, a recent survey by Bishop and Verleger of research on this teaching format makes numerous points consistent with our understanding of the state of the art [BV13]. Several factors are simultaneously catalyzing new research into better teaching methods at higher education institutions. These factors include increased tuition costs and the availability of cheaper technology for sharing information. This dynamic is reflected in (and was further energized by) internationally visible milestones such as MIT OpenCourseWare (2001), Khan Academy (2006), and the various MOOC providers (2011).

Bishop and Verleger observe that research shows that recorded lectures, online assignments, and intelligent tutoring systems can improve learning; however, developing intelligent tutoring systems along these lines can be prohibitively expensive. In light of these developments, the flipped classroom is seen as a unique combination of learning theories, where the basic manifestation is the 'flip' between activities performed inside and outside the classroom.

They also find that, unfortunately, most studies use single-group study designs and focus on student perceptions. Results are mixed but generally positive. Anecdotal evidence suggests that learning is improved, but there is very little work evaluating it objectively. The survey authors recommend that future work investigates learning outcomes objectively, and that researchers consider the theoretical framework used to guide the design of in-class activities. It is challenging to find a universally accepted definition for the flipped classroom. In their survey of work on the topic, Bishop and Verleger define the flipped classroom as being characterized by interactive group learning in class, and computer-based individual instruction outside. They view online videos as a key component while remaining unclear on the importance of traditional reading materials.

Technically, our course does satisfy this definition, because our main study materials (and most secondary references) are available online. We see reading lecture notes as essential training in a fundamental scholarship skill, and a way to offer deeper exposure to the material.

Regarding the reporting of several studies on student reaction to the flipped classroom, Bishop and Verleger report: "Despite differences among studies, general reports of student perceptions were relatively consistent. Opinions tended to be positive, but there were invariably a few students who strongly disliked the change." Surprisingly, despite their extensive survey, Bishop and Verleger identify only a single study that performed a control experiment comparing the performance effects of a flipped classroom technique [DF06]. The improvement on the final exam averages was about four percent.

The survey authors also recommend "researchers clearly describe the activities used for both in-class and out-of-class activities".

We do this partly in this paper, by describing the operation of the classroom with a high level of detail, and in even more detail in the guidelines for future instructors.

1.2 Problem

To explore this new technique, we were aware of three basic questions:

- How hard is it to transition to the flipped classroom?
- How hard is it for a new instructor to take over a course that uses this format?
- What type of effort (and how much) is needed to teach a course with this format?

As a backdrop to this exploration, we were aware of only one prior attempt at applying this method, but it was not continued, and was not documented.

1.3 Contributions

The primary contribution of this work is to share an experience with the flipped classroom format. This consists of describing the development of the video materials (Section 2), outlining the execution of the flipped classroom (Section 3), and summarizing the measured student responses from this experience (Section 4). It is the execution of the flipped classroom that we have come to believe is the most demanding aspect, especially in attention to details. Reflecting on the overall experience yields a secondary contribution in the form a set of potential benefits and tradeoffs that can be considered when choosing to adopt this format (Section 5). To address some of the shortcomings evident in the responses, we describe certain remedies that should be applied in future editions of the course (Section 6).

2. RECORDING THE LECTURES AND PRODUCING THE VIDEOS

Lectures were recorded in the first year of this study program (Nov-Dec, 2013). Our goal was for the instructor to prepare and execute the lectures in a manner that was as close as possible to the normal lecture form. One logistic difference was that he prepared a one-page lecture outline, which was provided to the recording team before the start of the class. Classes consisted of two 45-minute lectures, with a 15-minute break in between. With the aim of producing recordings no longer than 15-20 minutes each, the instructor included three components in the outline for each lecture, with a clear title that would be used as the title for the video. An effort was made to use high-contrast colors for writing on the whiteboard; the teacher wore a microphone and was asked to repeat questions so that they were audible. Unfortunately, it proved hard to fully comply with this request, possibly because it was hard for the instructor to carry it out without disrupting the class and increasing the students' awareness of the recording process.

The recording facilities consisted of a moveable TV-studio in broadcast quality built around PC-based video and audio mixing and recording software (Tri-Caster). The live recording was done with two HD-video cameras: one unmanned camera (at the back of the room) with a fixed angle of view covering the whole podium with whiteboard; and a second camera operated by a cameraman and closer to the podium, following the lecturer and zooming in on the whiteboard. The video/audio recording console positioned on the right-hand side (from the student´s view) was operated by a producer/sound engineer, who was live cutting between the two cameras to get a more cinematic production. Sound was recorded by a wireless lavalier microphone. The whole lecture was of publishable quality as soon as it was finished, due to the "live" video recording technique; but, in this case, a title needed to be added, along with the Halmstad University logo, and the recording needed to be compressed from 40 GB to less than 2 GB to be published on Kaltura, which was the official choice of the university at that time.

The lectures took place at the start of the week, and production of the videos was typically completed during the week or early the following week.

3. RUNNING THE FLIPPED CLASSROOM

The two new editions of the course were delivered using the flipped classroom format (Nov-Dec 2014 and Nov-Dec 2015).

3.1 Preparation Before the Start of the Course

In addition to the preparatory activities for classes taught in the traditional format, each offering of the course required work both in the Learning Management System (LMS) and outside of it.

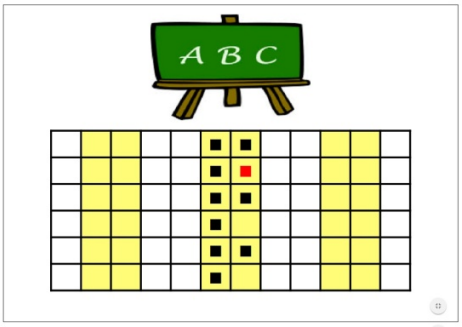
Work in the LMS consisted of:

- Ensuring that all students had LMS accounts that allowed them to watch the videos from the very start of the course.
- Providing clear instructions about the special nature of the flipped classroom format - with no lectures, but work to do (including an online quiz) before coming to class.
- Preparing timed release of lectures - so that they are made available primarily during the week when the lecture is given.
- Preparing online quizzes to test students on the videos and reading materials before the start of class.

Work outside the LMS consisted of:

- Reviewing the content, stated teaching outcomes, grading scheme, and logistics document provided to the students.
- Preparing an initial template for a weekly survey that students could optionally complete to provide feedback on the progress of the course.
- Providing a mechanism to ensure that students were seated in a "randomized" fashion in class - to increase the chance that students sat next to someone they did not know well (see bit.ly/LNCPS-seating).

Since this course involves many group activities, we wanted to ensure that students did not form "cliques". To do this, we created a protocol whereby a carefully arranged sequence of seat assignments was handed out in order to students as they arrived at class. Assuming that students arriving together have a higher chance of knowing each other, one function of the sequence was to seat these students further apart. Another goal was to make sure that as many students as possible were paired (that is, sitting next to another student who would be a designated partner for the class), no matter how many students showed up. To achieve the latter, it helped to have a good estimate of the typical number of attendees. The cards look like this:



The board represents where the teacher usually stands; the red box is the seat assigned to the student; the black boxes are the previously filled seats (before this student is seated). Two adjacent seats are paired when they are in a band of the same color (white or yellow). Once most students have arrived, a little rearrangement is required. The protocol means more "risk" of ending up with unpaired seats at the start but, as the room fills up, the risk is reduced.

3.2 Conducting the First Class

The first class requires special care because students may not be aware that it is taught in the flipped format, and that they should watch the video, read the lecture notes, and do the quiz before coming to class. It is also highly likely that they have not heard of the flipped classroom format. Therefore, the main activities in our first lecture consisted of:

- A brief introduction by the instructor and co-instructor(s).
- A very brief introduction to Cyber Physical Systems (CPS) and their significance.
- A very brief introduction to the flipped classroom format.
- A specially prepared 26-minute video (bit.ly/flipped-format). (Note: at around minute 15 of this video, a short survey was handed out to the students to help the instructor better understand the strengths and needs of the students).
- The short URL for the lecture notes was given to students (e.g. bit.ly/LNCPS-2016).
- A reminder of the importance of timely starts (the class starts on the hour, not 15 minutes past the hour).
- An explanation of the card-based seating arrangement (everyone picks the top card in the deck and sits in the set specified by that card).
- A reminder of the importance of reading the Logistics chapter, which covers teaching outcomes and how final grades are calculated.
- A study problem that students could work on without special background knowledge. This asked about the challenges of building a CPS such as a robot that could play ping pong.

3.3 Preparations Before Each Class

A key quantitative difference for the instructor between the traditional and the flipped classroom format is the significantly higher number of different events in the latter. Such events include different types and amounts of interactions with students. As a result, it became particularly important to pay special attention to timing and timeliness in both planning and executing the lecture. So before each class it was necessary to:

- Review lecture materials and videos.
- Review and update the online quiz prior to release (Its goal is to test that students have watched the videos and done all the reading).
- Prepare and print study problems for the lectures and bring extra pens for students.
- Prepare a summary of results for the quiz for each student, highlighting any points that appear to merit special attention.

3.4 Conducting Labs

When this course was flipped, there were no significant changes made to the way in which the lab was conducted. The focus of the lab in this course is to provide some hands-on experience with the modeling and simulation environment (Acumen) used to support the theoretical aspects of the course and for the course project. Typically, each session started with the instructor using Acumen to illustrate some key points relating to the lecture (and which is related to the course project). Students then had a chance to work on solving a small problem using Acumen, a process that was injected with discussions of the project, as needed.

3.5 Conducting Regular Classes

Classes consisted of two 45-minute sessions with a 15-minute break in between. As mentioned earlier, attention to timing and timeliness are critical to proper management of the flipped classroom. In the two editions of the course, students worked on 2-3 study problems. By the end of the first offering we settled on a target of two problems per class, to make best use of the available time. These problems were very similar in structure to those in the lecture notes and on the final exams. Each consisted of multiple parts that built on one another, and that often became more challenging near the end.

Students were asked to work on given problems in one of three configurations: individually, in pairs, or in groups of about 5-6 students. Combinations of these configurations were used on the same problem.

Over the course of the two offerings, we experimented with different stagings of how students worked with a given problem. A typical example was to ask students to work in pairs in all stages. In one staging, the first step was for each student to solve the problem independently. Second, students turned their answer sheets down, as the class worked with the instructor to develop a rubric consisting of key points and a (generous) point scheme. Third, students graded the problem for each other. Fourth, students discussed the grading and a note was made to the instructor if there was any dispute. The idea of this staging was to encourage deeper analysis and discussion. Eventually, it became clear that the idea of mutual grading was not popular, even when the instructor determined the final grade, after reviewing all results. It is conceivable that other stagings or variations of the approach could make this work, but operationally this just seemed too difficult.

Close to the end of the second edition of the course, we noticed that students reacted differently to different sequencings of configurations (such as pair-then-group, or group-then-pair).

While these sequencing variations were tried only once in the second edition of the course, it appeared that it was helpful for students to start with a group problem where they worked in groups of five, and afterwards on a problem where they could work in pairs.

3.6 Conducting the Final Lab

This consisted of:

- A review session and discussion of the final exam.
- Presentation of the final results of the tournament and awards.
- A return to the study problem posed in the first class, concerning the challenges in building a CPS such as a robot that could play ping pong. This was a time for the students to reflect on what the course had taught them about how to overcome these challenges.

4. STUDENT RESPONSE

This section presents key indicators of student test performance and student satisfaction over the course of the three offerings of the course. The goal here is to document the indicators that we saw as relevant to evaluating the effects of flipping the classroom. Our interpretation of the data will be presented in the next section.

4.1 Student Matriculation and Performance

The following table summarizes the matriculation, passing from first exam, student satisfaction aggregate percentage, and average final exam grades:

Table 1. Student Performance over the Three Years

Edition	Number of Students	Passed First Time	Student Satisfaction (%)	Final Exam Average (%)
2013 (Regular)	42	23	59 a	40
2014 (Flipped)	57	29	73 a	46
2015 (Flipped)	54	24	49 b	40

Students were allowed to take the exam at different times. Those that did not pass first time were allowed to take it multiple times until they passed. Here we consider only this indicator for ease of data gathering, and because passing from the first sitting is desirable.

Student satisfaction is an aggregate, based on the university survey that students can elect to complete at the end of the course. It is important to note that the survey changed dramatically between the 2014 and 2015 edition and, for this reason, the markings “a” and “b” are added to the reported numbers in this table. This denotes that only the first two numbers can be safely compared.

It is also important to note that the final exam uses a grading scheme that makes full use of the grade scale. Thus, it is not a direct indicator of the percentage of the materials that students show they have mastered, nor is it a direct indicator of the percentage of the learning outcomes that students have achieved.

4.2 University Course Evaluations

The university offers students optional surveys at the end of each course to provide feedback about their experience. We have reported on the experience with the 2013 edition elsewhere [TC+14], where it is referred to as the “Winter 2013” edition, so below we present the findings from the last two years.

4.2.1 Second Year (2014)

In response to the set questions, most of the 24 respondents agreed with, or were neutral on, the following points: A clear idea early on in the course about 1) Learning outcomes (84%), 2) Course structure (84%), 3) Course content (71%), 4) Coursework (88%), 5) Assessment criteria (84%), 6) Examination requirements (88%). Most also agreed that 7) Activities were related to learning outcomes (80%), 8) Literature was related to learning outcomes (84%), 9) Examination was related to learning outcomes (84%), 10) Course structure created good conditions to achieving learning outcomes (80%), 11) Teaching and working methods created good conditions for achieving learning outcomes (80%), and 12) The examination was relevant in relation to teaching outcomes (88%). All students agreed with, or were neutral to: 13) Their own efforts created a good chance to achieve the learning outcomes. A majority of students agreed that 14) Other students’ activities created a good opportunity for them to achieve learning outcomes (59%) and 15) The teacher’s efforts created a good chance for them to be able to achieve the learning outcomes (67%).

The standard survey then provides an area for free-form comments. Several comments complimented or criticized various aspects of the course. One student saw the course as being focused on Acumen, “a tool not used in the real world”, and suggested that it would be better to focus on “deeper modeling and control”. It is useful to note here that this tool is not used at all in most lectures. Another student didn’t like the flipped classroom format, but thought it could work if the student “did not lose so much time waiting for the other students to answer his questions.” He was clearly frustrated by the perceived inefficient use of time, waiting for individual students to respond. Another felt that the course structure was good but that the content could be better explained. Three students voiced an interest in seeing the course cover less topics but with more depth. At least one student asked for more intermediate-level questions (between what was done in class and what appeared in past final exams). There was an interesting variation in the response to the Game Theory chapter: some thought the presentation was remarkably elegant, and others saw it as shallow and wanted more detail.

In a question that lists various aspects of the course and asks students to comment on them, most respondents gave sparse answers. But one gave the following detailed response:

- Lecture notes - very good material
- External reading - generally very good
- Lecture videos - very good
- The flipped classroom - very good idea
- Study problem - very good
- Seating arrangement - new and very good
- Quizzes - very good
- Surveys - very good that shows caring about student’s opinion

- Project - very good
- Acumen - new and interesting
- Peer interaction - very good especially changing because seating arrangement

Another student, however, expressed great dislike with the idea of the seating arrangements, frustration that some study problems were not "completed in class" and recommended that the teacher better manage class time. This student also thought that the lectures were OK, but preferred traditional lectures. The student felt that, with the flipped classroom format, "what is the point of having a teacher?". At least two students noted that "the videos were not so clear" or that the resolution could be improved.

There were also several heart-warming responses from various students, which we omit here, as our goal is to reflect on the kinds of things that can go wrong and how to mitigate them.

4.2.2 Third Year (2015)

In response to the set questions, most of the 15 respondents agreed with, or were neutral, on the following points: 1) Course design (68%) and content (62%) enabling them to attain teaching outcomes, 2) Giving them access to research of relevance to the field (74%), 3) Developing their ability to think critically (60%), 4) Actively searching for and learning new knowledge/abilities/skills (67%). The number of 'neutral' respondents varied between 0% and 12%.

In the open feedback section, student suggestions included the following: 1) Include solutions to study materials (presented at the end of the week) to use in reviewing the material, 2) Not being graded on everything that they do [a switch in this direction was made mid-course], 3) Preference for working in smaller groups than in larger ones [concern was about how all 4-5 people would participate in a group of that size], 4) Frustration with lab/project exercises lacking instructions, 5) Part of the project was simply changing of certain parameters, 6) Bugs in the model and other players exploiting these bugs, 7) No need to spend class time on the quiz [in the previous year results were summarized by email], 8) Don't care to learn about how long others are studying, 9) High course load from another course, and the many project problems led them to skip the project work because it did not seem to yield significant knowledge (Others, in contrast, said the project part was very interesting), 10) Instructors did not follow their own template on grading projects, 11) It was unnecessary to learn Acumen, as there were no users outside class (others thought it was very practical).

For the question that lists various aspects of the course and asks students to comment on them, most responses were not informative. However, one student provided the following detailed response:

- Problem sessions - very convenient problems
- Group problems - good for everyone to participate and hear how other solved the same problems
- Pair problems - good to have someone else to discuss a problem with, both might have different solutions
- Individual problems - good also to check if you have really understood the relevant chapter
- Standing up during class - a good idea, especially if we've been sitting a lot
- How problems were graded - Some lab problems were graded weirdly
- Randomized seating - good to mix everyone so we have different groups for the group problems
- Quizzes - nice quizzes to check your understanding
- Weekly survey - good to check how the majority thinks about some stuff

In response to the question "Did this course change your understanding of the world and (or) the importance of innovation in the future?" one student simply wrote "Surely"; but another responded "Understanding of innovation process, how to start from idea to reach the production stage and the importance of simulation will help us in future career." In response to the question "What did you find most rewarding in the course?", one student wrote "To use old known physical equations we've learnt long time ago in programming and to model it in 3D objects. And also to do the [project ping pong player] mascot."

4.2.3 Special Question During the Last Two Years (2014/2015)

The university survey system allows instructors to pose specific questions to students. Among the questions asked in the two flipped classroom format offerings there was a specific question asking "How well did the flipped classroom work?" The following table presents the multiple choice responses (only one could be selected) in the past two years of the course:

Table 2. Student Reaction to Flipped Class

Student Choice	2014	2015	Total	Total %
Much better than normal classes	11	4	15	40
A bit better than normal classes	5	3	8	21
About the same as normal classes	3	2	5	13
A bit worse than normal classes	1	1	2	5
Much worse than normal classes	3	5	8	21
Total Respondents	23	15	38	100

The column Total adds the numbers for both years with the hope of providing a more stable indicator.

4.3 Student Comments in the Final Meeting

As noted above, we have reported on the experience with the 2014 edition elsewhere [TC+14], so we present only the last two years here.

4.3.1 Second Year (2014) Comments

Note: only a total of 24 students in attendance in this study sessions. Numbers below such as (23/24) mean that 23 out of those 24 students agreed. The first noted number is problematic, since the count was 25. Hence, a question mark was added after that number.

Elements that worked well:

- Flipped classroom works very well (25?/24)
- Reading materials (in general) (23/24)

- Teacher reactions to questions was encouraging (23/24)
- Random seating arrangement was perfect (21/24)
- Study problems worked very well (20/24)
- Quiz being time-limited (20/24)
- Workload was manageable [Weekly surveys]

Elements that could be improved:

- No notification on quiz answer availability (22/24)
- Lack of feedback on study problems (maybe the solution) (20/24)
- Lecture recording video quality for whiteboard content (17/24)
- Lack of audibility of student questions/answers in videos (13/24)
- Inability to randomly form teams (10/24)
- Lack of audibility of other student questions (9/24)
- Lack of feedback on project (9/24)
- Difficulty of forming teams (7/24)
- Inability to backtrack in quiz (which would help deal with network connection problems and managing the time limit) (7/24)
- Inability to see equations in RTF or PDF when notes are downloaded (6/24)
- Inability to change teams/divisions during the course (5/24)
- Noise volumes in class (until the last few weeks) (3/24)
- Presence of Acumen-specific items in the videos with the old syntax (Unknown votes)
- Inability to ask questions during the video (Unknown votes)

4.3.2 Third Year (2015) Comments:

Fifteen students (15) participated in this final class session.

Elements that worked well:

- Online lecture notes helpful (14/15)
- Randomized seating (15/15)
- Flipped approach (10/15)
- Coffee (12/15)
- Group discussions (12/15)
- Following the project with tournament
- Separate lab and lecture

Elements that could be improved:

- Lab: what to do was okay, but where [in the models] was unclear (13/15)
- Videos could not be played full-screen (1/15)
- Text syntax format - earlier version was better (3/15) ➔Difficult to write complex conditions
- Lack of solutions for problems in lecture notes (14/15)
- Lack of model exams with solutions (15/15)

4.4 Instructor's Observations and Additional Remarks

In the first year, the instructor had the impression that tension was building in the classroom as the course progressed. The presence of the recording crew and the camera was very clear. This seemed to create simultaneously an atmosphere of excitement and undesirable self-awareness.

In the second year, both the instructor and the students were quite concerned about the flipped classroom experience. For the instructor, this was not due to lack of prior experience by other educators and researchers, but rather, concern about one's own ability to perform in this new setting.

In the third year the original instructor served in an assistive role, and two new instructors with no prior experience took the primary responsibility for teaching the course. One of the two instructors only led the first lecture, and the other instructor led the rest.

5. ANALYSIS AND INTERPRETATION OF STUDENT RESPONSE

This section presents our analysis and interpretation of the measurements and observations presented in the previous section.

5.1 Transition to the Flipped Classroom

The final exam grades and the university survey reflect an improvement in student test performance and level of satisfaction when the classroom is flipped and the same instructor teaches the course. In preparing the final exam for the flipped edition, care was taken to ensure it was at least as challenging, and it was graded at least as strictly, as the previous year. Student response to the specific question about their view on the flipped classroom indicates that they were mostly positive (about 75 percent), although there were students that were not satisfied with this format. The presence of a few students who did not view this format positively appears to reflect the findings of previous studies [BV13]. We deduce from these indicators that the change to the flipped classroom is justifiable, and that it is possible to achieve affirming measurements from the first time teaching such a course using this format. An important caveat to this interpretation is that a different group of students (cohort) was measured each year, and we have not carried out any analysis that would allow us to normalize learning between these two groups.

The special question in the university survey (presented in the table in the previous section) gave one indicator of the level of student satisfaction with the flipped classroom format. On the positive side, and despite a drop in response rate in the second year (class size in both cases was about 50), 61 percent of respondents saw the new format as better than the traditional class. About 13 percent of the respondents were neutral. On the negative side, 26 percent of respondents saw it as being either a bit or much worse than the standard class format. It is worth noting that in the second edition the teacher also changed, and that in the first edition of the course only 17 percent responded that way. Further, if all students reacting negatively to the format responded to the survey, the total negative response may be as low as 10 percent across the two years.

The in-class discussions at the end of the course gave a different indicator of student reaction to the flipped classroom format, with 87 percent of the students present viewing it as a success.

5.2 Handover to New Instructors

When the flipped course was then taught by a new instructor, final exam grades went down to the same level as the traditional classroom edition, and student satisfaction levels appear to have

dropped. It is important to note here that the university changed the student survey, and so the numerical values are only loosely comparable. It should be noted here that the new students also had significantly less experience than the original instructor for the course.

5.3 Level and Nature of Instructor Effort

Our particular realization of the flipped classroom requires at least as much effort from the instructor and the institution as the traditional classroom does. In the traditional setting the instructor prepares the lecture, study problems, final exam, and does the grading. In the flipped classroom, the instructor still does all of these things. While preparing for the lecture is somewhat different, the instructor must come to class ready to deal with a wide range of questions that students may have. The development of the study problems also requires additional attention to timing, as does the execution of the class.

6. PLANS FOR FUTURE EDITIONS

The next edition of the course at the Masters level will be in September-October of 2016. Based on the experience from the last year of this course, we believe that the most important improvement to the course in the flipped format can be through improving the study problems.

6.1 Improving Study Problems

The main improvement is to present a group problem first and then an individual or pair problem. We are also considering the introduction of a short series of quick questions that use an online clicker (a device for collecting answers from students in real-time) at the start of the lecture, which would follow a similar form to the original work of Mazur [M97]. We would expect this to increase the flow of information from students to teacher, increase interaction between students, and bring out some key advanced ideas introduced in the course. Our hope is to introduce this quickly as part of the first lecture, and then move on to group and pair questions in the rest of the lecture. We would also expect to reduce the time needed for working on those questions by asking different groups to explain only different sub-parts of each question. We will also explore the use of an appropriate technology to speed up the collection of the results of all types of assignments, to make the class more efficient.

We see that a key idea introduced by Mazur is increasing student thinking in class by encouraging "Peer Instruction" [M97]. He observed the inefficiency of the traditional format for science classes, where the instructor uses a textbook as a source; then distills it to students in the form of lecture notes or slides; and then delivers a lecture based around these notes. He postulates that the tradition of lecturing may predate even the printing press. To address this problem, he began exploring an approach where students were required to do the reading before class, are then given a short quiz on the reading at the start of each lecture, and then the rest of the class is divided into 10 to 15-minute periods that focus on addressing each of the main concepts in the reading. Individual periods may start with a very brief lecture on the point, followed by student activities. The activities might start with a multiple choice question (called a ConcepTest) that students first answer themselves, and then try to convince their neighbors of the answer. Answers in the second round are generally much better than in the first, and there is significant discussion between students between the two rounds. Additional time can be spent on the problem if results are lower than 80 percent accuracy, with the ideal goal of reaching levels of 90-100 percent. Questions build on one another, and gradually increase in demand. For clarity, all questions use words and avoid equations. For a class of about 250 students, this led to improved attendance, attention, involvement, instructor awareness of student level, and test results.

6.2 Other Planned Improvements

Further planned improvements for the course are as follows:

- Addressing the logistical issues raised by students in the course evaluation and during the end-of-course discussion. Some issues can be addressed directly in the lecture notes by setting the right expectations and providing clearer instructions; others will require changes to the LMS.
- Improving the descriptions of the labs, so that they are clearer to instructors and students. In particular, there will be stronger connections to the lecture materials and the project work, and more specific goals for lab activities will be specified.
- Supporting the lab and project activities with an automatic grading server. This server will reduce the work that students currently have to do to have the players they build compete with those of against other teams.
- Updating the official description and the logistics documents using the idea of Constructive Alignment by John Gibbs. This includes aligning the stated teaching outcomes of the course more closely with what students are evaluated on in the final exam.
- Moving the videos to a platform that allows variable speed replay. We also hope to make the videos open to the public and to link to them from the lecture notes.
- Reintroducing a chapter about Communication, which is facilitated by a change to the number of calendar weeks available for the course.
- Exploring the idea of identifying groups of students with extreme performance (either high or low) and offering them special support.

Another edition of the course will be offered at the doctoral level. That course will not be flipped; it will use the same materials, but classes will be used for traditional lectures on more advanced topics.

7. CONCLUSIONS

This report documents our experience in developing materials for, conducting, and transitioning to a new instructor within, a flipped classroom format. Student response to these changes was measured in terms of final exam questions, university survey results, and feedback solicited in the final lab with students. From this response, we suggest that transitioning to a flipped classroom can produce positive results from the first offering, although 10-25 percent of the students may not initially look favorably on the transition to the flipped format. Our experience is remarkably consistent with the main findings of Bishop and Verleger [BV13] from the analysis of several studies. In particular, student perception was generally positive, and there can be notable improvement on final exam grades. Additional information from this work includes that the number of students opposing the flipped classroom can vary significantly by instructor, and that the

flipped classroom may help new teachers step in without dropping below the baseline established by the teacher that developed the flipped classroom materials.

The experience also drew our attention to the fact that this format appears to be more demanding on the instructor than the traditional lecturing format. There is a large number of details, and the instructor must manage timing in the presence of several variables that can have large variability. An example is the time it takes students take to solve a study problem, which can be affected by the problem itself, by student preparedness, by group size, and so on.

In future work we would like to see whether the flipped format can enable students to achieve significantly better results than those achieved to date. Upon reflecting on the experience reported here and reviewing various related work, Mazur's work reminds us that a key benefit of the flipped classroom is to catalyze constructive student interaction. Mazur's work, combined with Gibb's notion of Constructive Alignment, encourage us to use simple questions at the start of each lecture to foster such interactions, and to aim to achieve a very high and quantitatively measured level (among students) of understanding of key concepts by the end of each class.

On a more technical note, we would also like to explore other ways of creating and recording videos, such as using a "digital blackboard" for creating the content. This could avoid the need for scheduling a class to create the content, as well as the need for significant audio/video recording equipment.

For teachers interested in flipping a course, an important practical consideration is the possibility of finding simpler and more efficient ways to record and distribute the lectures. The basic issues are to ensure quality of the sound, precise capture of what is written on the whiteboard, and post-processing to eliminate errors. Creating videos from lectures seems to provide a natural feel to the content, but it can be disruptive and/or distracting to the course that is running at that time. Reducing the disruption and distraction, as well as delivering the recorded videos quickly to the students, can reduce the negative effects on that course.

ACKNOWLEDGEMENTS

This work would have not been possible without the support of the School of Information Technology at Halmstad University, especially the support of Jörgen Carlsson and Stefan Byttner. Equally essential has been the support of the US National Science Foundation (NSF) through the NSF CPS Project #1136099, and the Swedish Knowledge Foundation (KK) Project FAR-EIS. We would also like to thank the organizers and participants of the WESE from 2013 to 2016, whose insights and advice have deeply influenced the development of this course.

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