Three Approaches to Flipping CE Courses: Faculty Perspectives and Suggestions

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Abstract

Classroom inversion or “flipping” is one of the latest models designed to actively engage students during class times. The model involves moving traditional lecture material outside the classroom and practical application of newly learned ideas into the class meeting times. In the inverted model, the course concepts, theory, or equations are presented in various media – videos, readings, notes – prior to the class contact time. Application of those new ideas is cultivated during the class time through faculty-directed problem solving, brainstorming and discussions as well as field trips and guest speakers.

This paper offers specific suggestions for improving classroom time management by implementing an inverted classroom model. The authors have incorporated this approach in three distinct settings – a medium/large (50) enrollment senior-level foundations design course, a small-enrollment sophomore-level mechanics course (22) and a large enrollment junior-level environmental engineering course (90). Successes and lessons learned are documented for each of the settings. The authors provide suggestions based on their experiences for faculty considering a transition from a traditional lecture-style presentation to a strategy that transforms the classroom into a more active educational experience.

The paper summarizes both the advantages and disadvantages of the classroom flip from the instructor’s perspective.

Introduction

The current challenge facing engineering educators goes well beyond conveying technical information core to the discipline. While information transfer remains a part of the task, the need to develop creative and innovative thinkers ready to engage in the challenging professional marketplace evolving due to “globalization, sustainability requirements, emerging technologies, and increased complexity”\(^1\) is paramount.

Instructors must then consider the most effective classroom approach not only to transmit technical subject matter, but also to foster creative and inquisitive minds that can someday research complex problems and arrive at innovative solutions. It is critical that university programs strive to prepare students for a lifetime of learning, educating them in critical and creative thinking skills, and develop strong team members and leaders. This paper details three approaches to classroom flipping that provide the time-management flexibility necessary to incorporate pedagogies that develop these skills.
Motivation

Active Learning

Many of the techniques commonly advocated for instructing students in lifelong learning, creative thinking, and teamwork skills fall under the broad umbrella of “active learning.” “Active learning is generally defined as any instructional method that engages students in the learning process. In short, active learning requires students to do meaningful learning activities and think about what they are doing”\(^2\). Approaches to active learning generally fall into the categories of collaborative learning (group-based learning), cooperative learning (cooperation is stressed over competition) and problem-based learning (relevant problems provide context for the instruction). Prince\(^2\) summarizes literature supporting each of the methods; the benefits are many. Active learning leads to a deeper level of thinking and cultivates creative, motivated engineers. Furthermore, since the students are active in their own learning process, they acquire the skills needed to be a life-long learner.

Time constraints

One primary obstacle is often blamed when the types of active instruction necessary to build lifelong learning skills, creative thinking and teamwork practice: TIME.

Time is problematic on two levels. First, faculty sense that introducing several active learning strategies to their course may sacrifice the extent of technical content that can be covered. In other words, the perception is often that the pedagogical methods themselves take up too much time. Many instructors are reluctant to part with lecture time, which they perceive to be more efficient, for methods that may, at first, appear to compromise the amount of technical information that can be covered. This is a reasonable concern, and one that this paper attempts to address through model cases presented later.

Time is also critically important when considering the faculty member’s workload and the effort necessary to prepare for a course. A straight lecture course – especially if that is the mode of instruction most familiar to the faculty – likely requires the least initial preparation of all approaches. Incorporation of active learning strategies requires considerable initial effort and time investment from the faculty when preparing the course for its first offering. However subsequent offerings of the same course normally require less faculty time.

Expected Benefits of Flipped Classrooms

Flipped classrooms are inherently active

At least some of the obstacles to active learning – particularly related to time – can be solved by a deliberate course management strategy. The idea of an inverted or flipped classroom\(^3,4,5\) involves restructuring the sequence in which material is delivered and student work is completed. Classroom flipping is a highly flexible classroom time management strategy that creates opportunities to incorporate the methods commonly thought to promote self-directed learning skills, creative thinking and problem solving, and team building exercises. When applied to
fullest advantage, the total technical material covered in a flipped course can even exceed that of a traditional lecture formatted course.

At its most basic level, classroom flipping involves a switch between the material covered in class and work done outside of class in the traditional lecture format. This means that new material is conveyed prior to class meetings and new concepts are practiced and applied during class meetings. Many models exist for accomplishing this flip, three of which will be described in this paper.

If course material is effectively conveyed to students prior to class (through readings, videos, audios, etc.) it affords significant flexibility to the in-class time and any number of active learning strategies can be implemented. Such exercises can involve collaborative or cooperative learning as students work through well-defined practice problem sets or challenging students to apply the concepts to a higher level problem or case study (i.e. problem-based learning) that encourages creative thinking. The format also creates the flexibility to use class time for activities such as demonstrations or field trips that are otherwise difficult to fit into the schedule.

The merits of flipped classrooms against traditional lecturing

First a definition of “traditional” is in order because the term is relative and interpreted differently by faculty. For the purposes of this paper, a traditional course is one that is taught primarily in a lecture format. Hallmarks of the method include a largely one-directional dialogue during class meetings. Often the lecture presentation pre-supposes the concept under discussion is entirely new to the students. That is, aside from pre-requisites and topics earlier in the course, students are normally not specially prepared for the lecture presentation. Out-of-class work typically involves computationally solving problems that require application of a new concept recently presented in class. Students may have a lengthy window, perhaps a week, to complete the assignment.

The following sections highlight some of the key characteristics where traditional and flipped classrooms may differ.

Student Engagement

Traditional lecture presentations often are not fully engaging and may not hold student interest effectively. Flipped classrooms are inherently flexible and are able to bring many experiences into the classroom, including dynamic problem solving sessions, case studies, guest speakers, and field trips.

I think that getting the boredom of lengthy engineering lectures out of the way at home made it easier to concentrate on key concepts and problem solving techniques during class (student feedback, Velegol).
Student Attention Span

Traditional lectures frequently carry a line of thought for a lengthy period of time, normally 50 minutes or 75 minutes. An uninterrupted lecture of this length is well beyond the typical student’s attention span of 5 – 15 minutes. Therefore, much of the information conveyed during the lecture presentation is not adequately absorbed by the student solely due to the long, static nature of the experience. A hallmark of flipped classrooms is the clear organization of material into smaller time segments. For instance, pre-class assignments may include viewing a previously recorded lecture. The pre-recorded lecture is normally segmented into small, 10 to 15 minute time periods, based on the topic, and specifically formatted for this pre-class experience. Recorded lectures are often much shorter than the same material would require in class, and students have the flexibility to view it multiple times if necessary. Further, the in-class time is inherently more active when using a flipped approach, so many of the attention span issues with traditional lecturing in class are overcome.

The online video lectures were nice because you don’t have to watch them all in one sitting. Because they are so short and there are so many you can watch a few and take a break before you become very bored and start zoning out (student feedback, Velegol).

Active Learning

In the traditional lecture environment students are often passive receivers of information and may not be regularly challenged to think and apply concepts. When active learning strategies are used within the traditional lecture setting without making other adjustments, they may come at the expense of covering more technical information. Flipped classrooms often specifically structure the in-class time for active and critical thinking exercises. And because the core technical information is conveyed outside of class, there is no compromise in the amount of material covered.

[The flipped] method has forced me to think about the material twice as much as I would normally if class were only lectures and homework. Although the [pre-class] assignment is painful at first, once it is explained and there are more examples in class the [post-class] assignment is straight-forward (student feedback, Swartz).

Self-Directed Learning

In order to build effective lifelong learning skills, students must take responsibility for their own learning, practice conceptualizing topics independently, and learn to self-evaluate their understanding. In a traditional lecture setting, the information is “given” to the students, and in some cases perhaps made too accessible. Students cannot actually learn the concepts until they have invested some intellectual effort themselves. Flipped classrooms more closely simulate the engineering student’s future work environment and build the skills necessary for self-directed and lifelong learning.
[With the flipped approach] I feel more of a responsibility to learn the material ahead of time; otherwise I’ll be behind in the [following] class. I also appreciate the lecture-at-your-own-pace videos (student feedback, Swartz).

Teamwork

Traditional lecture courses generally leave students to learn the material entirely independently. Most of the so-called team-building experiences in traditional courses are really problem sets or even projects that are assigned to a group of students. It is normal for student groups to partition the assignment so that individual students can work independently on a distinct portion. In a flipped environment, students often work cooperatively during class time. The instructor is then available to facilitate healthy team-building discussions and peer teaching to help students build meaningful skills in this area.

I liked the flipped course for many reasons. The main one is because we were able to work on the homework in class with other students. Being able to ask questions to the teacher is also a huge help (student feedback, Velegol).

Talking with classmates and discussing answers was beneficial (student feedback, Velegol).

Review and Study

As noted in the discussion related to student attention span, a student can intellectually miss large portions of the traditional lecture presentation. When classroom flipping is employed, students generally have opportunities to return to the original presentation – whether readings, recorded videos, etc. – to review and study a concept as much as needed to reach complete understanding. In the traditional format, students often study from their own notes, which may be incomplete, and the method itself may lead students to highlight ideas likely to be on the exam without truly conceptualizing the content.

I like the flipped [method] because when I watch the videos on my computer, if I miss something or if I just go into a daze for a minute, I can go back and watch that part again (student feedback, Velegol).

Learning Process

Traditional lecturing does not often address the student’s learning process, giving her tools to self-assess along the way, and being sensitive to challenges with the subject. Often material is presented in lecture, a few homework assignments may be given, and the student waits to see if her exam performance is satisfactory. The very nature of the approach emphasizes exam performance over fundamental learning. The flipped classroom affords the students numerous opportunities to self-assess, review pertinent information, and apply ideas to increasingly complex problems.
[The flipped approach] has a little bit of everything. If you don’t fully understand the alpha (pre-class assignment), which I usually don’t, the first five minutes of class can catch you up in time for the quiz. I feel that alpha assignments kind of just warm you up for the lecture so that the information is familiar. Then the [post-class assignment] hits and makes sure you really know what you are doing. (student feedback, Swartz)

“Challenging us to figure out the alpha assignments is more work, but it causes us to really look deeper to understand the concepts rather than just listening to you do problems and being lost when we’re on our own.” (student feedback, Swartz)

Three Approaches

The authors applied the flipped classroom concept to three distinct courses, and worked almost entirely independently of each other. Table 1 highlights key similarities and differences in the three cases. The following sections further detail each approach.
<table>
<thead>
<tr>
<th>Course</th>
<th>Enrollment</th>
<th>Class Year</th>
<th>Pre-Class Assignments</th>
<th>Accountability “Gate”</th>
<th>Class Time</th>
<th>Flip Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brian Swartz, <em>Mechanics of Materials</em></td>
<td>22</td>
<td>Sophomore</td>
<td>Lecture video – audio explanation added to PDF of traditional class notes</td>
<td>Handwritten, self-graded quiz at the start of class</td>
<td>Review of new information as directed by quiz and pre-class assignment struggles</td>
<td>Entire course</td>
</tr>
<tr>
<td>Stephanie Velegol, <em>Introduction to Environmental Engineering</em></td>
<td>90</td>
<td>Junior</td>
<td>Weekly 90 minute video module in approximately 10 minute “chunks”.</td>
<td>Web-based quiz prior to class</td>
<td>10 – 15 minute review of video content. Begin work on the post-class assignment, asking questions as needed. Guest speakers On-campus field trips</td>
<td>Entire course</td>
</tr>
<tr>
<td>Jeff Laman, <em>Structural Design of Foundations</em></td>
<td>50</td>
<td>Senior</td>
<td>Focused reading and review of worked example problems</td>
<td>Web-based quiz prior to class</td>
<td>Work through a comprehensive design problem, stopping occasionally to ensure all students are maintaining pace and reaching reasonable results</td>
<td>Gradually transitioned to the flipped format at the ¾ point of the semester</td>
</tr>
</tbody>
</table>

**Table 1. Summary of key characteristics in the three flip approaches discussed in this paper**

**Approach 1: Brian Swartz, University of Hartford “Mechanics of Materials”**

Swartz’s model may be somewhat short of what others will term a “full flip.” In other words, there were still occasionally formal presentations in class, and students were expected to do work after the class period in addition to their work before the class period. The model implemented by Swartz is best illustrated by Figure 1. The center row loosely describes the learning spectrum – new information is introduced, that information is processed or “learned”, then the concepts can be applied to real or realistic problems. Generally speaking the emphasis of the traditional lecture approach (top row in Figure 1) is on delivering new information during class time. The
students are often asked to process that information so that they can apply it to solve a real problem on homework assignments after class.

The model used by Swartz essentially slides the timeline of the course delivery along that learning continuum. The assignment prior to class emphasizes delivery of new information. The in-class time is dedicated to helping students process the new information and ensuring that they comprehend the concepts. After class students are asked to follow through by applying the concepts to real problems. Each of the three approaches discussed in this paper includes some sort of “accountability gate” to ensure the student was successful with the out-of-class work and to help the instructor target problem subjects, as necessary, in timely classroom presentations.

![Conceptualized timeline of the inverted classroom approach used in Case 1.](image)

Swartz has applied this classroom concept in a small-enrollment (22 students) sophomore-level Mechanics of Materials course. In this instance students were provided with completed lecture notes related to new concepts and equations. Swartz prepared videos that introduced the material. The video was a voice-over explanation of the lecture notes created using commercially available screen capture software. He scanned the completed lecture notes into a PDF file and used various mouse tools (pointer and basic drawing tools) to highlight the points being discussed in the voice-over.

Prior to most class days students were asked to review the provided lecture notes while watching the corresponding videos – usually about 15 minutes total – and attempt to solve a simple problem that involved the new concept. This made up the alpha assignment. The alpha assignment practice problem was reviewed and graded quickly at the start of class – based primarily on effort and completeness – while the students took a brief quiz related to the video or the problem they attempted. Students self-graded the quiz immediately after it finished allowing them to quickly self-assess their understanding. On most days a two-directional dialogue (an “active lecture”) transpired for about 20 minutes as questions arose when grading the quiz and reviewing the problem assigned as part of the alpha assignment. This time and discussion offered the students a sort of “beta test” of their new knowledge – *Am I on the right track with*
The way I’m thinking about this? The second portion of the class involved the more challenging problems intended to close out the lesson on the “omega” assignment. On some days the students would begin work on the omega assignment itself, often in pairs or groups. More commonly, however, the instructor guided the students to first develop an outline of the steps to solution so that they could self-assess their understanding of each step and ask questions on the topics least clear to them while still in class.

The feedback through surveys and focus groups from the cohort of students in the course was generally positive. They acknowledged that the flipped approach led them to more thorough thinking about the subject matter and felt that they understood the material better. On a mid-semester survey, of 21 students responding, 15 voted in favor of maintaining the flipped approach the second half of the semester. To be fair, however, a few students spoke out strongly against the flipped approach. Their primary concern was a perception that this approach was more demanding on their time.

**Approach 2: Stephanie Velegol, The Pennsylvania State University “Introduction to Environmental Engineering”**

Velegol used pre-recorded video lectures to convey technical content in a large (90 student) required Introduction to Environmental Engineering course. In total the students watched 11 self-contained video lecture modules. The videos were created in a technology room and involved the instructor writing on notes in outline format. The students were encouraged to print out these notes ahead of time and follow along as the instructor filled in the notes on a tablet screen. Most of the time the students could see a video of the instructor in the bottom right of the screen. Each module was approximately 90 minutes long but was broken down into titled 5 – 20 minute video sections. This allows students to go back and review particular video segments.

In this case the Alpha assignment was to watch the module at home and complete an on-line assessment before coming to class on Monday morning. Part of the on-line assessment included writing down any questions or clear and muddiest points (for credit). The on-line assessment was fairly straightforward and addressed qualitative understanding and simple quantitative concepts. Class time was mostly used to address misunderstandings and problem sets that were due on Fridays. During class on Monday the instructor would discuss the questions on the pre-class assessment and go over any commonly-made mistakes. The rest of the class on Monday and Wednesday would be free for problem solving in class. The students could choose to work alone or in groups, however, most chose to work in groups. The instructor and teaching intern would walk around and answer questions. If there was a common struggle, the instructor or teaching intern would address the concern to the entire class.

In this case the Omega assignment is to finish the problem sets (started in class) by Friday and to study for a weekly quiz in class on Friday. The students preferred the weekly quiz vs. 2 mid-term exams as they were less likely to fall behind in the material.

Class time was also used to go on four field trips. With a class of 90 students this is usually prohibitive. Because of the class flip, the class could split into 2 or 3 groups and visit a LEED certified building, a wastewater treatment plant, a Morningstar solar home and the recycling and
composting facilities on campus. Guest speakers also came to class to discuss indoor air quality and the environmental impacts of Marcellus Shale drilling.

**Approach 3: Jeff Laman, The Pennsylvania State University “Structural Design of Foundations”**

Laman gradually proceeded to a completely flipped classroom over the first 10 weeks of a 15 week semester. Because many students are not familiar with a flipped classroom, and Laman was also new to the method, it was decided that gradually acclimating students was a better strategy. The course is a senior-level *Structural Design of Foundations* course with approximately 50 structures-focused students enrolled. The instructor worked with the Penn State College of Engineering Leonhard Center for the Enhancement of Engineering Education to design an active learning environment within CE441 that: 1) better promoted group activities and peer interaction; 2) shrank the perceived size of the course enrollment for students; 3) offered extended open-ended problems to promote development of creativity and innovation skills; and 4) included writing within coursework to stimulate a broader world view. The redesigned course adopted a strategy of gradual warm-up activities to full classroom flip, moving lecture content to outside the classroom through the integration of student-centered activities. Consequently, students are ready to solve design problems in class in a highly participatory and engaged environment.

The initial goal of the course gradual flip was to strongly encourage student preparation for class, a hallmark of the flipped classroom. This was accomplished through selected readings and carefully prepared example problems followed by an online quiz open during the 24-hour period prior to class. The concise, short readings and examples were designed to convey new information prior to class, rather than recorded lecture videos. Online, short, multiple choice quizzes served as a low risk gate to both test reading comprehension, but also to reinforce important points of the reading. As the semester progressed, students were responsible for pre-class assignments, normally initial portions of examples to be worked in class. Pre-class assignments were completed in student pairs and submitted at the start of class. The pre-class assignments were then reviewed by Laman to evaluate student understanding before proceeding with the in-class example.

Each week during the first 10 weeks the instructor emphasized the importance of preparing for class in advance and actively engaging in their own learning. The mantra forwarded by Laman was “Learning results from what the student does and thinks and only from what the student does and thinks. The teacher can advance learning only by influencing what the student does to learn”. Gradually this statement was embraced by the students as the semester progressed. It was clear that students needed to be warmed up to the idea of taking responsibility and educated on how learning really occurs.

At the conclusion of the tenth week students were required to complete more extensive out-of-class reading and example review of the next topic covered. In preparation of the first full flip class, students initiated the solution of the assigned, open ended design problem. This initial solution was submitted for grading and returned to ensure that all student pairs were off to a solid beginning and had prepared adequately. In class management of the flip required full engagement of the students, nearly in unison, as they proceeded with the design problem. The
instructor guided the process by leading the discussion of each subsequent step, prompting discussion of the engineering process to some consensus, and then initiated a design period of a few to several minutes with students permitted to ask questions regarding that step. Wherever a theme developed with a significant number of students having the same questions, the instructor stopped and asked the students to work the issue out in discussion. In this way, the design problem solution proceeded over the course of three 50-minute classroom periods through completion.

Faculty observed benefits of flipped classrooms

Students are prepared for class: With a pre-class assignment and an accountability gate, students are coming to class having already been exposed to the technical content. This allows them to ask better questions and engage in deeper level thinking. Faculty are then able to address “just in time” questions.

Faculty can use class time to discuss applications and deeper level thinking instead of mundane topics. In engineering classrooms technical content is of paramount importance but can become monotonous when faculty have to cover the same content semester after semester. Flipping the course allows this content to be covered once by the faculty in the videos. Faculty can then use class time to bring in their expertise (for example through more detailed analysis or current events).

Faculty can use class time for any number of activities without worrying about covering content. With the content removed from the class time, faculty can use that class time for more engaging activities. This could include projects, guest speakers, field trips, laboratory experiments or demonstrations.

Class can be better organized without concern about not covering enough material in class. In a traditional lecture format the material must fit within the class time. If not, the schedule (e.g. dates for homework assignments, quizzes, exams) needs to be re-arranged. With a flipped course the pre-class material does not need to conform to a specific time frame.

Learning becomes student-centered, not instructor-centered. The instructor becomes more “guide of the side” rather than “sage on the stage”. Although this could at first feel uncomfortable for faculty, the authors have found that being more engaged with students during class time is more rewarding than speaking to a sea of partially engaged students.

Challenges in flipping a course

There is an initial investment of time for faculty to create out of class material. A flipped course requires that out of class material is prepared and well organized. For some faculty this may mean converting their notes to powerpoint or pdf (although the advent of “smart pens” allow faculty to narrate a lecture with pen and paper.).
The class must be well organized and carefully mapped out. In a traditional lecture format, the instructor has some flexibility in changing due dates based on the amount of content covered. When the learning is student-directed, there needs to be clear organization to make sure students stay on track with the course material.

It is often more difficult to re-create the out of class material. This is especially true for the creation of on-line videos. Although these can be re-taped to correct mistakes, it is more difficult and challenging. For this reason the flipped approach may be better for faculty who have taught a course many times.

Faculty may struggle with letting go. For faculty accustomed to and comfortable with the lecture approach, it can feel as if flipping the classroom involves releasing some control of the course. In some respects, this transfer of control is one of the virtues of flipping. A student-centered learning environment is desirable. The faculty should maintain control of the course content and structure, but a willingness to be flexible in class is necessary. A marked advantage of this environment is the ability to address a group of students, perhaps the entire class, on points of common confusion right when they are ready to hear it. This does mean, however, that planning every minute of the class period before it begins is simply not possible.

Suggestions for a first-time flip

The authors’ experiences have led to a few lessons learned that any faculty planning to flip a course for the first time should heed:

Get Buy in from Students. The faculty should carefully explain the benefits of the flipped approach to the class so that the students buy into the method. Without some salesmanship, students are likely to reject the approach just because it is different.

Do Not Over-Flip. A flipped classroom is more a time management strategy than a pedagogical approach. The improved time management facilitates better pedagogy, but be mindful of the differences. Specifically, note that it is not essential for everything in the course to be “flipped.” It does not mean that you cannot ever deliver a traditional lecture or assign traditional homework. If the subject content or the mentality of the students demands a lecture from time-to-time, it would be unwise to cram that material into the flipped model.

Do not use this as an opportunity to give the students more assignments. It may be tempting to use the extra class time for additional assignments or projects. This may lead to frustration for the students. A flipped class should be truly flipped and not add any more time for students in the course.

Be Organized. It is essential that the entire course be thoroughly planned when implementing a classroom flip and related pedagogies. This may be an insurmountable challenge when teaching a course for the first time without prior observations of the most difficult technical points and the amount of time necessary to cover each subject. While many faculty have proven reasonably
successful in teaching a lecture-based course while planning only one week at time, that approach may prove more difficult in the flipped environment.

**Remain Flexible.** One of the hallmarks of classroom flipping is flexibility, so embrace it. This is not to suggest that you regularly accept assignments late or decrease your expectations in other areas – not that kind of flexibility. Rather embrace the opportunity to move course content around to best serve the students and meet them at their point in the learning process. This may involve such things as impromptu in-class presentations on topics planned for the out-of-class preparation materials or spending twice as much time as planned on an in-class problem just to maximize a teaching moment. Those are the opportunities that make inverted classrooms so attractive.

**Conclusions**

The authors have implemented a classroom flip strategy in three distinct settings. The approach greatly enhances the faculty’s flexibility to use class time to achieve various objectives beyond conveying technical information. For example, the authors have enhanced their courses with guest speakers, field trips, active problem solving sessions, and self-directed learning exercises never possible in their traditional classrooms.

From a faculty perspective the benefits are many. Students are more come to class prepared, ask better questions and are more actively engaged in class time,

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