A Busy Professor's Guide to Sanely Flipping Your Classroom

Cynthia M. Furse, *Fellow, IEEE*, and Donna Harp Ziegenfuss

***Abstract*—The Flipped Classroom has become a popular teaching method. Students watch video lectures before class, saving class time for active learning (problem solving, demonstrations, applications, etc.). This paper is a useful guide for busy professors who would like to try out the flipped classroom approach. Recommendations for four teaching components are given: (1) Planning the Flipped Classroom, (2) Video Lectures, (3) Active Learning, and (4) Student-Centered Formative Assessment. Recommendations are also given for how to get started with the flipped teaching method. Case studies from electromagnetics are given. Feedback from students on what resources are most useful, their comfort level asking questions, and their overall opinion on the flipped class over the semester are included.**

***Index Terms*—Flipped classroom, inverted classroom, teaching electromagnetics, assessment, pedagogy**

I. Introduction

One of the most promising and transformative trends in STEM education is the development of the "Flipped Classroom" (also called the inverted classroom), where lectures and homework are "flipped". Instead of lectures in class and homework out of class, students watch video lectures prior to class, leaving the in-class face-to-face (F2F) time for active and engaged problem solving. This effectively doubles the amount of organized contact time (as opposed to independent homework time) professors have with students. (In exchange, an equal amount of time must be removed from independent homework time.) The flipped classroom can increase student engagement, learning and retention of that learning, and in some cases increase retention in the program [1]–[3]. Most (but not all) students prefer the flipped classroom, and student teaching evaluations may be higher as well [4]. Data on increases in student success (exam, homework scores, long-term content retention, and retention in the program) are mixed [5]–[7] and seem to depend greatly on the specific learning activities and how well they align with the assessments (exams, for instance). Thus, it is very important to carefully design a flipped class (or any class, for that matter) to align learning activities with the class goals and assessments.

The trend in hybrid and flipped courses closely parallels the rise in online courses. This is due, at least in part, to the ease of developing and deploying online content via video (e.g. YouTube, MIT's OpenCourseWare (OCW) [8] (2001), the Khan Academy [9] (founded in 2006, videos released in 2012), Udacity [10], Coursera [11], edX [12], Canvas Network [13], and others. The first flipped STEM classrooms that used video lectures are arguably the high school chemistry courses of Bergmann and Sams in 2006 [14], and peer instruction in physics was using an inverted peer-instruction (PI) model with pre-class readings from 1991 [15]–[17]. Dr. Furse's Introduction to Electromagnetics (2007) [18] and Numerical Electromagnetics (2008) [19] courses, introduced at the Frontiers in Education Conference in 2009, and described in the *IEEE Antennas and Propagation Magazine* in 2011 [4], made electromagnetics a pioneer in the flipped classroom movement, as well. Now, more than a decade later, flipped and other blended/hybrid learning examples can be found in engineering [4], the sciences [20], business [21], teacher education, languages [22], political science [23] and a multitude of other disciplines. Examples in electromagnetics include introductory electromagnetics [5], [18], [24]–[26], Design of Electromagnetic Devices [27] , Advanced Electromagnetics [18], [24]–[26], Design of Electromagnetic Devices [27] , Numerical EM [19], and others.

This paper combines our experience over the past 12 years personally flipping classes, and helping other faculty flip theirs [28]–[34]. We provide a guide for busy professors who would like to try out the flipped classroom approach, but know they don't have time to record a full semester's worth of video lectures in order to do so. The paper provides the background and recommendations on planning the flipped classroom, creating online video lectures, active learning for the face-to-face classroom, and student-centered assessment approaches in Section II, and Section III gives suggested steps for getting started with the flipped classroom. Section IV gives three electromagnetics case studies of ways that faculty have incorporated all or some portions of the flipped classroom in electromagnetics courses, and we conclude in Section V.

II. Creating the Flipped Class

In this section, we will describe the four key things a professor needs to do in order to design and create a fully flipped classroom. Creating a flipped class is much more than just the technology we use. It is about a dynamic change from teacher-centered instruction to student-centered learning. With this change, the professor actually spends more time with the students (both virtually in the lecture and actively in the problem solving time), higher quality time (actively engaged), and there are more people to help teach (students actively teach each other). Thinking about where the professor is MOST valuable is where the design of the flipped class begins, and we will describe this in Section II.A. Creating video lectures is discussed in Section II.B, and active learning activities for the face-to-face class in Section II.C. And then, with student-centered learning, comes a new opportunity for more student-centered assessments. Section II.D goes beyond the traditional exam assessment and suggests ways to use formative assessment to improve learning outcomes.

A. Backward Design for the Flipped Course

Designing the flipped classroom involves planning what should be in the lecture, what active learning activities should be in class, what assignments may remain for outside of class, and where the professor's time with the students is most valuable. Backward design is a course planning approach that begins by defining the final outcomes (what students will know and be able to do at the end of the course)[35]. Then working backward, the assessments for each outcome, and the teaching and learning activities to accomplish them are defined. Several backward design models exist in the current literature for aligning outcomes with teaching and learning activities

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C.M. Furse is with the Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT 84112 USA ((801) 585-7234; e-mail: cfurse@ece.utah.edu).

D.H. Ziegenfuss is with the Marriott Library, University of Utah, Salt Lake City, UT 84112 USA (e-mail: donna.ziegenfuss@utah.edu).

Training materials for flipping your classroom (or helping others do so) are available online at http://teach-flip.utah.edu

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[35]–[37]. This backward design that focuses on the learning outcomes results in a student-centered learning approach [38], [39]. Deliberately considering multiple individual learning styles [40] in this design can create a very flexible, student-centered approach for which the flipped classroom is particularly effective.

The Quality Course Framework (QCF) shown in Fig.1 is an adaptation of [35] that is being utilized at our institution for designing online programs [41] and flipped instruction [28]. The QCF divides the course design process into four phases: *Design, Build, Teach,* and *Revise*. Six instructional elements are embedded across the four phase process. Instructors can come into the QCF at any stage to begin their course design process depending on if they are beginning a new course or just building new content or learning activities for an existing course.

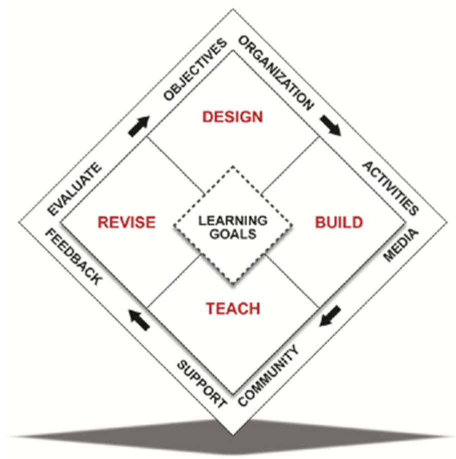

Fig 1. The Quality Course Framework (QCF) model for designing instruction. (From [41])

In the *Design* phase, instructors reflect on the purpose of the course and its situational factors, design course objectives/outcomes, and sequence and structure the course. During this process, an alignment grid is used to align the learning outcomes with the teaching and learning activities (see module 3 in [28]). The *Design* phase emphasizes two elements of the QCF: (1) course and lesson outcomes are stated as measurable objectives; and (2) the course organization simplifies navigation and enhances student learning. In this phase, the instructor should consider where their time with the students is most valuable. In the *Build* phase instructors create learning activities and the associated content they will use to teach the course. Two elements guide the process: (3) learning activities are designed to engage students in a complete learning process; and (4) the content format (video, in person, after class, etc.) is appropriate for communicating the course content. In the *Teach* phase instructors teach the course and focus on supporting student learning through effective communication and active learning. The fifth element is: (5) a sense of learning community is facilitated through specifically planned communication and student support. The final phase of the QCF process, or the *Revise* phase, focuses on analyzing course learning data and utilizing instructional design services to improve learning outcomes. The last QCF element is: (6) assessment, feedback and evaluation strategies are designed to measure student learning outcomes, as well as, overall course quality. These were, of course, *Designed* in phase 1.

When designing flipped courses, the integration of the pre-class online lectures and the in-class active learning activities requires extra planning and reflection. Problem solving that ties the pre-class videos to real-world applications (problem based learning) is particularly engaging [42]. Backward class design helps professors delineate what outcomes they seek, how they will assess those outcomes, what activities are needed to teach those outcomes, and where students will receive active practice for those outcomes. Planning where in this process the professor's contact time with the students is most valuable is key to planning the flipped classroom.

Another important aspect to consider in the *Design* phase is how to make the flipped classroom as inclusive for all types of learners as possible. Flipping the class enables the students to interact with the materials in their own way, creating a high level of personalization. Considering students with different learning styles [40], disabilities, motivations, prerequisite knowledge, and preferences can be both challenging and liberating for the instructor. For example, realizing that global learners need to see the big picture before understanding all the detail can remind an instructor to create a good summary at the start of a set of videos, that actually makes them better for all students. Closed captioning for hearing-impaired students is often used by other students who want to watch the videos in crowded or noisy situations such as on the bus. Captions can also be converted to most languages. Use of color to help dyslexic students understand circuit diagrams can help all students better understand nodes and voltages [43]. And, while most students prefer video lectures to reading material, they may present a challenge for visually-impaired students, and may require tailoring for their needs. When students access videos from a variety of instructors around the world (men, women, a variety of languages and cultures), they naturally increase their exposure to diversity in the field.

B. Creating Online Materials

Flipped classes most often use video lectures to replace in person lectures, thus opening up time in the face-to-face class room for active learning. In this section, we will discuss the technical aspects of creating video lectures, and best practices for the video creation. We will also discuss ways to overcome challenges such as technological limitations and video stage-fright, and the role of online readings, as well.

1) Best Practices for Video Lectures

Studies comparing video and in person lectures show that video lectures slightly outperform traditional in-person lectures [44]. Millennial and Generation Z students have an even stronger preference for online lectures [45]. This is an interesting observation, considering the intensely social nature of learning, and this study compares basic content transmission without active or interactive learning activities. It would be interesting to compare video lectures with interactive activities with a similar in-person lecture with active learning, but we are not aware of such a study. The challenge is that both lectures are inherently time-limited (videos by how much time you can get someone to spend, in-person by the class period), and thus both content transmission and active learning must happen within this period. The premise of the flipped classroom is that you can increase the amount of contact time by using the video lectures for content transmission and the in-class time for active learning activities to cement and apply understanding.

Video lectures should be short, quick, and non-repetitive. A traditional lecture designed for a 50-minute class will typically be about 15-20 minutes when recorded without the pauses and interruptions of a live audience. Lectures should be divided into shorter chunks (3-5 minutes each) so that they can be downloaded easily, and students can gather their thoughts and take notes in between. Making short video sections also helps the instructor, as it is easier to get through 5 minutes without messing up, or to restart a short section if needed, thus eliminating the need for editing.

Students tailor how they watch the video lectures to their personal preferences. They can repeat sections as needed (and typically do), speed up or slow down videos (students for whom English is a second language (ESL) often do this), or view them with closed captioning (which is available automatically through YouTube and other video hosting services). Giving an overview at the beginning and end is helpful, particularly for global learners [40] (those who need to see the big picture before understanding the details). Guiding students on what you want them to learn is helpful as well, such as assigning a "Question of the Day" [4] that summarizes the topic of the video (such as "How do you design a single stub matching circuit?). Making the online videos interactive improves learning [46], [47]. Adding short quizzes that test learning throughout the videos, asking the student to stop and try to work a short problem, anticipate the results of a simulation, or raising interesting questions throughout can improve interactivity. Several interactive online e-books and learning platforms have been developed in other disciplines [48], and with time may be seen in electromagnetics, as well.

2) Creating Video Lectures

There are numerous ways of creating video lectures (see Module 2 of [28]), and different ways to use them. The type of video should be chosen to best fit the lecture content. Tablets PCs with screen capture video recording software are very popular and effective for courses (such as electromagnetics) that are highly mathematical. Typically, the writing is seen, synchronized with the professor's voice, but the professor is often not seen, although there are split screen options that can enable this. A power point or similar document can combine blank pages for writing on as well as figures, tables, or photos that can be marked up. Notes made during the screen capture recording can be saved after the video is completed, and provided for the students to take additional notes on as they watch the video.

Another similar method is "hands writing" where a document camera [49] (sometimes just a cell phone [50]) looks down on a piece of paper, where the professor explains the derivation, writing and speaking as they go. Students typically choose the tablet lectures as their favorite video type, with "hands writing" a close second. The "hands writing" approach is perhaps the easiest, lowest barrier to entry for faculty. It is easy to use, inexpensive, and low tech while still being highly effective.

Many videos taken from the back of the room during a live, traditional lecture are available on YouTube, and it can be tempting to do this, because it is a relatively easy way of capturing lectures for a future class. However, most students do not prefer these videos. It is often difficult to see and hear the derivation, the professor seems very much removed, there are often numerous interruptions, and watching a full hour of video is very taxing for anyone. Instead, if seeing the professor is beneficial to the lecture content (such as teaching a foreign language, nursing and other hands-on activities, or if the professor is describing something without writing or figures), studio or on-site videos can be very effective. In engineering, this has been used effectively for lab and demonstration videos.

Video lectures should be professional yet personal and accessible. Small mistakes are inevitable (and students like getting extra credit for finding them), but audio and visual quality are most important. Wearing a microphone headset is generally essential to audio quality, and having a tablet with enough computing power to run the screen capture software and write in real time is essential to video quality. Cell phones are often a good alternative with both good audio and video quality. If using a camera, proper lighting, zoom, and focus are needed, many universities now have video studios (simple to complex) for this purpose.

3) Hosting Video Lectures

Videos can be hosted locally (most learning management systems now support video) or on sites such as YouTube and then organized and linked on the course website or learning management system. These can be made private or public. Public videos are often good publicity for the professor, department, and university and can have high impact for the electromagnetics community. In areas where students do not have access to the internet, alternatives must be considered. These include providing materials on DVD (if students have computers at home), school or library computers, or using reading materials rather than video materials for class preparation. A caution is provided here, however, that few students pick up as much material from reading as they do from video content. Many students use their cell phones or small tablets to watch the videos, mainly for convenience. Thus, it is important to keep the writing on the screen relatively large and legible, even if this means using more screens to complete a topic. It can also be helpful to provide screen shots or the original power point (with the written notes saved), so a student may print these out and take notes on them throughout the video.

4) Overcoming Video Creation Challenges

Creating video lectures is one of the perceived barriers to entry of the flipped classroom method. Cost of the technology can be minimized, as inexpensive tablets, document cameras, and cell phones can readily be used (see Module 2 in [28]). For instructors who prefer the simplest possible technology, "hands writing" with a document camera or cell phone is generally the simplest approach. (Dr. Furse's earliest videos were using a white board recorded with a pocket camera on a tripod.) Audio quality should not be neglected, so generally it is beneficial to use a headset microphone when video recording. Cell phones are notable exceptions to this, as most of today's phones have excellent video and audio quality. Most professors spend many hours (four or more) to record their first lecture video, but with practice get much faster. Typically, a traditional 50-minute lecture becomes a 20-minute video lecture broken into several 3-5 minute chunks, and it takes the professor 1-2 hours to record and upload this. If editing is desired, this takes much longer, so most professors find ways to avoid the need for editing. Keeping the video segments short (3-5 minutes) helps greatly. Keeping track of where in a set of lecture notes each segment starts (with post-it-notes, for instance) makes it so if you mess up in one of these segments, you can just start over with that segment. Once videos have been created and are being reused, most faculty find the overall preparation time for a flipped class to be significantly smaller than for a traditional lecture class [29].

Selecting and using videos created by others, called co-flipping [29], is a good alternative, but must be done with care. Instructors need to solve problems and teach in ways that are very similar to the videos they use, or risk confusing the students.

Another barrier to entry is the faculty member him/herself. Some faculty express the explicit desire for the positive feelings of being the "sage on the stage". Many of these faculty come quickly to the realization that they are even more important in the flipped model, and choose their in-class time to maximize their importance to their students. Others express reticence to create their own videos. Many people don't like hearing themselves on camera, let alone seeing themselves. Many find it hard to talk to an empty board. For this, we recommend that faculty create a few very low-risk high-reward videos such as doing example problems or exam solutions by video, and solicit feedback from the students. The vast majority (virtually all) students appreciate these sorts of resources in the class, and the reward to the faculty member is often enough to get them over the hump. Another trick is to provide a "face" to speak to. A small paper cutout of a familiar, jolly face (such as comic, Danny DeVito), taped so that it is peeking over the top of a laptop, may help create more animated lectures than talking to the laptop alone.

Copyright is an important consideration when using work by others (such as figures from a textbook) in your video and posting it online. Most universities have copyright librarians who can advise on this issue, and many textbook publishers are generous about giving permission to include figures, etc. in public online lecture videos.

5) Getting Students to Watch the Videos

The premise of the flipped class is that pre-class video lectures provide technical content that is essential for use during the in-class time. Students who haven't watched the videos will struggle and not get as much as they should during class. Thus, the first aspect of making sure the students watch the video is to ensure that the videos are actually valuable to them. Video lectures should be quick (not rambling), to the point (and tell the students what that point is), and at the right level (non-trivial, but not so confusing as to be frustrating). The next aspect of making sure the students watch the video lectures is to not repeat them during class. There is a fine line between giving a quick recap at the start of class, and effectively redoing the lecture, making it unnecessary to watch the video. Perhaps a student-driven recap (ask, "What did you learn last night in the video?") is better, as it gets everyone bringing out their notes and thinking back to the videos. Asking for a (voluntary) show of hands of how many students watched the videos, and quick verbal feedback on if they were useful provides a small amount of peer pressure to watch the videos before class. Using this approach, where the inherent value of the videos is the only incentive for watching, typical watch-rates are about 80%, which can be assessed or at least estimated through most learning management systems. Including interactive activities (short answers, short quizzes, short problems) throughout the videos can both assess and incentivize video watching.

Similarly, classroom attendance depends on the instructor's ability to make it inherently valuable to the students. Thus, repeating the lecture will generally decrease classroom attendance, as students know they can watch the video online. It is particularly important to assess the in-class activities and adjust their level as needed, very early in the semester, so as not to lose students who decide the class is either too easy (the examples or homework done in class are too simple) or too confusing. Like video watching, classroom attendance can be incentivized by having short quizzes or questions (classroom response systems have been used for this for many years) that basically mandate classroom attendances. However, (what not to do) effectively mandating that students attend class, but then not having the class be of sufficient value to them, will quickly alienate the students and make the class ineffective.

It is not yet clear in the literature if it is better to use an inherent value model or a small incentive model to get students to both watch the videos and attend class. It is likely this depends on the student body, local culture, and culture set by the professor. Continually assessing video watching and class attendance throughout the entire semester is important for the flipped approach to be successful, so we recommend designing that assessment into your classroom approach, and talking to your students about the importance of both.

6) The Role of Readings

In this section, we have emphasized how to create video lectures, but what about readings? Can a professor just assign the students to read the chapter, and expect to run the class as a flipped classroom? There are definitely examples in disciplines such as law and business where this has been the teaching norm for generations, but this has seemed somewhat more problematic in STEM disciplines, where students may have more difficulty understanding individual readings. This will clearly depend on the student and his/her background knowledge, and the level and quality of explanation in the reading (some books are easier to read than others). Some engineering graduate courses have, for instance, often relied on having students read journal papers before class, and basing discussion on these papers. Most students find watching a video easier than reading a book, and absorb the content more effectively in video format. As interactive e-books and interactive online learning platforms improve and reach electromagnetics, it is possible that readings of these types will match or replace video lectures. For now, we recommend providing video content, along with good quality written materials, thus enabling students to use both types of materials as they prefer. Even when video lectures are available, a small minority of students prefer to just read the chapter.

C. The Face-to-Face (F2F) Classroom

Active learning [4], [16], [51]–[54] -- engaging students in actively applying course knowledge rather than passively listening – has been shown to improve student engagement, learning, retention, confidence, and satisfaction with the class [55]–[57]. Active learning (also called engaged learning) is becoming the norm, either added to the traditional lecture, or displacing the in-class lecture entirely. This is arguably the most important aspect of the flipped classroom [55]. Active learning can be as simple as having students turn to their neighbor to discuss a question or as complex and in depth as group design projects. Active learning encompasses peer-assisted learning, problem based learning, collaborative learning, cooperative learning, and peer tutoring, all of which, in and of themselves, have been shown to increase student learning in various ways [2]. Activities can take a minute or two, the whole class period, or an entire semester. Active learning is certainly not new to engineering, and electromagnetics in particular. Labs are a regular part of most engineering curriculum, and use of numerical simulations (with their associated discussion time) have been a mainstay of electromagnetics education for decades. There are so many different types of active learning strategies, and we encourage instructors to review many options and choose ones that appeal most to them. Excellent resources include [52]–[54]. As starting suggestions, here are just a few simple and effective active learning strategies that are very useful in the flipped class:

1) Think-Pair-Share

Think-Pair-Share (which is a form of peer instruction) or just Pair-Share [16], [16], [58] is a very quick and easy method of engaging students in class. This works for any kind of class (regular lecture, flipped, online, etc.) and can be done in any type of classroom (stadium, tables, etc.) for any size of class (into the hundreds). The parts are:

THINK – Students think about a problem on her/his own;

PAIR – Students turn to their nearest neighbors, and share their ideas; and

SHARE – Student shares her/his ideas with a small group or the class.

This can be used in many different ways in an electromagnetic classroom. For instance, PAIR-SHARE is essentially the same method as think-pair-share without individual thinking time. A particularly effective PAIR-SHARE combo is instead of asking, “Are there any questions?” (to which the answer is inevitably no), instead ask “PAIR: Turn to your partner, and find the most confusing thing (the “muddiest point”) about today’s topic.” And then they SHARE with the class, which inevitably generates good questions and discussion [59, Ch. 23].

Think-Pair-Share can also be used very effectively for problem solving in class [4]. After a short student-driven review (“What did you learn from the video last night?”), the professor can pass out a sheet of problems for the day. Students most often struggle with the problem-solving strategy -- figuring out how to set the problem up, what steps to do to reach a solution, and which equation(s) and methods to use to get there. Having them discuss this with their neighbors and then share their approach(s) helps them develop that skill, see if there are multiple ways of approaching a problem, and it gives the professor an opportunity to discuss the general problem solving strategy with them as a class. Then students can work with their neighbors to try to solve the problem, and (usually after only a few minutes) when they bump into problems, the professor can help with an in-class discussion of the challenges and how to overcome them.

Peer instruction approaches, which use the Think-Pair-Share method to drive the in-class time, have been used very effectively in electromagnetics [5], [25]. Some of the critical aspects of this are to have the students commit to an answer in the Think stage, so they become emotionally invested, which encourages lively discussion when the Pair stage happens, especially if it's graded. The Think-Pair-Share questions should be hard enough that a large fraction of students get it wrong on their own, but get it right after pairing. Conceptual questions are better than calculation questions, in general.

2) Classroom response systems:

Clickers (from TurningPoint), TopHat, LearningCatalytics, Kahoot, and other classroom response system (CRS) allow the instructor to pose a multiple choice or short-text question, and each student to think about and answer that question. Some (Clickers) require special hardware. Others are mobile-phone enabled. These can be particularly nice for large classes, for getting the class started, and for encouraging and assessing class attendance.

D. Student-Centered Assessment

The flipped classroom’s student-centered approach warrants a more student-centered assessment approach. Summative assessments such as exams can tell how well the students have learned the material by the end of the course. Formative assessment such as self-checks, in class active learning activities and peer discussion, and course feedback throughout the semester can be used to adjust and improve both teaching and learning in real time [60]. Reflecting on their learning can help students become more proactive learners by helping them learn more about their personal learning style [40] and become more effective learners [26],[27]. Formative feedback strategies also helps professors adjust and improve the course in real time [62] and improve the culture of the learning environment [63]. A simple and easy-to implement formative assessment strategy for a flipped freshman circuits course is described in [33]. Below, we describe a student-centered assessment approach, and the feedback they have provided on the flipped class.

TABLE I
ASKING QUESTIONS VS. SCORES.

How have you asked questions?	Higher Scores (>75%) N=26	Lower Scores (<75%) N=21
To another student in class	46%	71%
Raising hand in class	27%	43%
Online discussion board	19%	19%
By email to instructor	15%	19%
To instructor face-to-face	31%	29%
In lab	73%	76%
In TA tutoring sessions	27%	15%
Never asked a question	27%	0%

TABLE II
RESOURCE USE VS. SCORES.

Which of these resources do you find valuable to help you learn?	Higher Scores (>75%) N=26	Lower Scores (<75%) N=21
Video Lectures	85%	76%
In class examples	85%	62%
In class problem solving	46%	48%
Textbook	58%	62%
Online resources	42%	24%
Labs	65%	43%
TA	35%	33%
Instructor’s office hours	27%	19%

1) Formative Feedback: How Students Experience the Flipped Classroom

Formative feedback should be used to improve both teaching and learning. The approach described here can be used for any type of class, but is particularly important for a flipped class, where the relationship between the professor and students and between the students themselves is more dynamic and interactive. Formative feedback on the course can be easily collected as online extra credit assignments every three weeks throughout the course, asking questions the instructor is wondering about for improving the course in real time throughout the semester. Example feedback questions for a freshman circuits course are given in Fig. 2 [33]. Responses were voluntary, and not anonymous. A small (insignificant) amount of extra credit was given, and many students wrote extensive reflections and responses anyway. Many specifically commented that they liked being asked for their feedback.

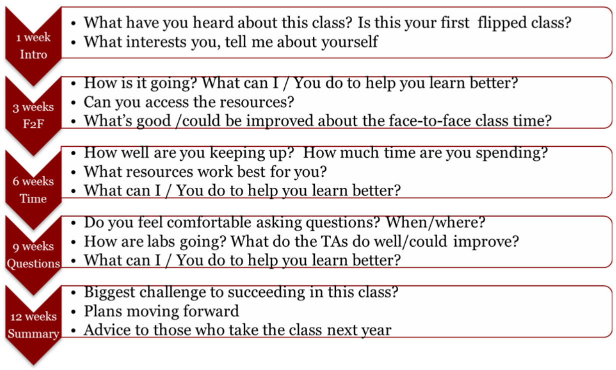

Fig. 2. Formative feedback helps the professor improve the course and the students improve their learning throughout the semester. Every assessment also includes: How can I help you learn better? How can you help yourself learn better? (From [33])

Table I shows students' comfort level asking questions, and Table II provides student feedback on how valuable the learning resources were. In an attempt to understand successful student learning behavior, feedback was divided between those who had scores above and below 75% in the course. Minimal self-reported differences were observed. Table III shows how the students' opinion of the flipped class changed over the semester. We have not yet asked these same questions in an electromagnetics course, but anticipate doing so in fall 2019.

Feedback on the flipped class [33] included comments about how useful the videos were, particularly being able to repeat them and go back to watch them again later: *"The lectures are online, which gives me ample time to absorb the information they have. If I need the information, I can go back and look at the lecture instead of having to go through my notes. I don't get bored in class because it is more interactive."* Another student said, *"When I am studying video lectures and other study materials before going to a class, I usually try to understand them and make some questions that I hope would be answered in class."*

In the in-class component of the flipped class students discussed how valuable it was to do problems, see examples, learn from peers and interact with the professor. They commented on how they felt the classroom climate made it safe to ask questions and learn with peers. The main recommendation from students was to do even harder problems in class so that they would be better prepared for exams.

Perhaps the most interesting feedback were the student reflections about what they could do to help themselves learn better. Students described how they prepared for class, worked through problems, used resources, watched videos and studied for exams. There was a wide range of methods by which they learned the material. Most watched the videos first, taking notes, then came to class and participated in the problem solving work with friends. Some read the book after the class, a few before class, and most used it as a reference resource. Although students rely on different learning resources at different times, and for different purposes, we realized that most students report using all the resources in some way. The wide variety of learning methods reminded us that there is a huge variation in how students learn best, and the importance of student-centered teaching. Also, it is important to delineate in the design of the class where students will gain their content information (video, readings, etc.), and to ensure they do (see Getting Students to Watch the Videos, above).

The majority of students say they prefer a flipped class, however, there are always a number of students who prefer a traditional lecture class. See Table III. One student explains it is not that they don't like flipping but, *"To be honest, even though I really like the flipped classroom, I think that the one thing that I wanted personally from this class was regular classroom lectures. Not that this teaching technique doesn't work, just that I feel like we have to go out and learn most of this information on our own."* Another student responded in a different way, *"I really like the flipped classroom I feel that it really benefits me and that I learn more and I learn the material easier. Also, because the lectures are videos if I don't quite understand something I can re-watch it instead of falling behind or having to go way out of my way to get help and then catch up."*

Another of our most important feedback observations was that challenges outside of course content often have a huge impact on how well a student is doing in the course. The single most significant concern of freshman electrical engineers was time management. [43] Nearly 60% of the respondents stated this as their biggest challenge. One student summed this up by saying, "*Time management because of my tough semester was probably my biggest challenge for this class. I wouldn't give myself that much time for the homework and I would focus on other projects for other classes, thinking that I could do it in the short amount of time I gave myself, but it always took longer than I thought. Some of the engineering concepts are still hard to wrap my head around."* Time management issues extend well beyond the freshman year, and numerous training methods have been effective in helping students manage their time better [64]. It is essential that instructors appropriately manage the work load expectations for all classes, and the flipped class in particular. If fully flipped, the time spent watching the video lectures should essentially replace an equivalent amount of out-of-class time doing homework. Instructors should design their flipped class so that it takes essentially the same amount of time as a traditional class. Starting the homework in class helps make this happen. It is also likely that the flipped class, with its emphasis on student engagement, student responsibility for their learning, and formative assessment, may help students recognize their time management issues and seek to improve them. Thus, providing recommendations and access to time management training (many universities provide short workshops or classes on this topic) could be particularly helpful for students in a flipped class. It is not necessarily that they have any more time management issues than those in a traditional class, but that they are in a position to recognize the issues they have.

TABLE III
STUDENT OPINION OF THE FLIPPED CLASS

Do you like the flipped class?	Week 3	Week 12
Positive	56%	65%
Unsure or neutral	35%	21%
Negative	9%	14%

2) *Muddiest Points*

Muddiest points [65] are concepts that remain confusing for students even after the lecture/class time. If many students express the same confusion, the instructor may need to provide additional resources or explanation. Sometimes, bottleneck concepts [66] (basic concepts that are fundamental to more advanced concepts) are identified that need further explanation. To help the students and professor understand the areas the students were struggling with each week, Muddiest Point [43] assessments were used. In an extra credit online assignment, students were asked, "What is the most confusing point this week? Try to answer it." A small amount of extra credit was given, and responses were not anonymous. The professor collected and collated the responses via the classroom management system to create a frequently asked questions blog (at this point responses were anonymized) as well as responding to individual concerns or confusions. This helped the instructor understand what the students were struggling with throughout the course, and it also helped the students reflect on their understanding.

Alternatively, muddiest points can also be collected on paper (8.5x11” sheets cut into 8 pieces works well), typically at the end of class, to help the professor gauge what additional help or resources the students may need, or to answer a few selected questions at the start of the next class.

In many cases, students expressed emotion such as curiosity, excitement, uncertainty, lack of confidence, anxiety, etc. along with the technical questions, and in these instances the professor tried to add a personal note of encouragement via the online learning management system. In many cases, these also enabled the professor to reach out to the student personally in and around class.

3) Exam Grading Strategy

Exams and other summative assessments are meant to determine how well students understand the material. Grades, given at the end of the semester, are meant to portray how well a student understands the materials at the end of the course. But integrating exam scores (midterm scores) from throughout the semester has some challenges in this regard. Some types of learners, such as global learners [40], need to understand the big picture before all of the details make sense. These learners may struggle with midterms, and then as they see the whole picture, do much better on the final exam. Other students may understand the material but do poorly on one exam or another for a variety of reasons. Often professors let students drop an exam to accommodate for these problems, but this effectively means the student doesn’t need to understand the material from the dropped test.

An alternative exam grading approach that uses the final exam as make up exams for the midterms can provide greater flexibility and motivation for the students, and less frustration and less grading work for the professor (see syllabus for [55]). Suppose a class has three midterm exams, which cover all of the material in the class (there is no new material covered after the last midterm). The final exam is then broken into three individual parts, each reflecting the content from one of the midterms. Students may take one, two, or three parts of the final, and will receive the best of either their midterm score or the final score on that part. Students who have done well on all three midterms may choose not to take the final. Students who did poorly on one or more midterms can make them up, demonstrating they know the material. Students are motivated throughout the semester to learn material they thought they understood but discovered they didn’t, and they like this grading method very much. On average, professors will have less than half of the final grading to do, which is generally appreciated at the end of a busy semester.

It is always important to have grading assessment (exams, assignments, etc.) align with the objectives of the course. This applies to both content and to how the course functions. For instance, if a major feature of the course is peer instruction and learning to work collaboratively and cooperatively in teams, grading individuals on a curve can significantly disrupt this process. Consider setting an absolute grading scheme, rather than a curve.

The example above highlights the importance of the backward design process and QCF design where outcomes, assessments, and learning materials are designed, in that order. It is also important to decide in advance if students learn more will you have higher grades, or is it essential in your department to have the same curve regardless of student achievement level. Furthermore, if you enhance the material taught in the class when you flip it, such as adding system-level design, open-ended problem solving, applications, etc. it is important that the assessment aligns with these new goals, as well. New assessments may be needed.

III. Getting Started in the Flipped Classroom

Most faculty don’t actually start at the beginning, planning their course from scratch, creating a full semester’s worth of online and in class content, and then starting out on the first day of class with a new program. Some faculty may flip a class from the start, and in the long run it likely saves them some time, but we would rarely suggest that. Rather, flipping a class may be a new experience for both the students and faculty. Taking small steps and refining your approach until you get good results in each step makes flipping your classroom a much more successful venture. One sane approach to flipping for busy faculty is:

a) Start with a class you have already prepared and taught before. This gives you a good set of lecture notes to start from, and experience with what students are likely to struggle with.

b) For the first third of the semester, experiment with adding active learning to your class. Try Think-Pair-Share and other active learning activities [16], [52] until you have found several that work for you and for your students. Also add regular assessments such as online feedback on the class and muddiest points. Use this to improve the class in real time.

c) In the second third of the semester, add in video examples. Record and post several examples for your students. Video solutions to exams, examples in or out of the textbook, homework solutions, etc. are popular, and little or no incentive is needed for students to access them. This will give you practice making and posting videos and the students practice accessing them. Get feedback from the students on the videos and make adjustments as needed.

d) In the last third of the class, create video lectures and in-class activities (often examples or homework problems). Flip the class for 2-3 weeks, getting feedback from your students daily-at-first, adjusting as needed. Expect a certain amount of naysayers (see Table III). Get feedback from peers and professionals during this time, as well. Typical time (per day) for faculty to flip a course are shown in Table IV.

e) The following year, flip the last 2/3 of the class, and in year 3, flip the entire course. Part of the reason to start flipping the end of the class first is that often students are unhappy if you are flipping a class and then stop.

We have collected resources for learning to flip into a (free) online course (Teach-Flip) [28] either in-person workshops and as an online course [32]. The course is based on three modules (designing the flipped class, video lectures, and active learning activities).

IV. Electromagnetics Case Studies

In this section, we will describe three examples of electromagnetics courses that have been flipped, and professors who have used material available from others to flip their courses. Re-using ones’ own or others’ content can significantly reduce the preparation time for a

TABLE IV
TYPICAL PREPARATION (HOURS) REQUIRED FOR THE FLIPPED CLASS (PER 1 HOUR OF CLASSROOM TIME)

Activity	Traditional	Flipped Year 1	Flipped Years 2+
Preparing or reviewing lecture notes (content)	1-2	1-2	0.5
Preparing in-class material	0.25	0.5	0.25
Preparing video material		1-2	
In Class	1	1	1
Office hours	1	1	1
Total Hours (approximate)	**3-4**	**4-5**	**2-3**

TABLE V
END-OF-SEMESTER STUDENT COURSE EVALUATIONS. VALUES ARE GIVEN ON A 1-6 SCALE WITH 6 BEING "STRONGLY AGREE"

Year	Effective Course	Effective Instructor
2002	5.07	5.38
2003	4.86	5.05
2004	4.65	4.89
2005	5.06	5.58
2006	4.88	5.18
2007	4.98	5.13
2009	5.68	5.85
2010	5.61	5.82

course, as shown in Table IV. There are three main ways this is done: (1) Faculty create and reuse their own materials, (2) Faculty use online materials created by others as supplementary materials for their course (which they teach in a traditional way), or (3) Faculty use materials created by others (online and/or in class materials) to flip their own class. This, we call, co-flipping [29]. The rest of this section describes three case studies of faculty who have shared materials in each of these ways, and describes best practices and lessons learned as a result.

Case 1: Faculty Creator Re-Using Materials

The flipped teaching method was applied in a junior-level required introduction to electromagnetics course [18] by Dr. Cynthia Furse at the University of Utah. Flipped teaching was started in the last third of the class in 2007, the professor did not teach in 2008, and the course was fully flipped in 2009, and essentially the same course materials were reused again in 2010. No significant difference (either positive or negative) was identified in the exam scores before or after flipping the class. The professor reported observing that students asked more questions in class and that many were at a higher level than prior to flipping. Student course evaluations increased substantially after flipping the class, as shown in Table V, and qualitative comments (which were extensive) were highly supportive of the approach. Feedback from students was almost unanimously positive about this method. It is worth noting that assessments such as these have serious limitations, bias, and variability [67], and this case, we are using them as a measure of student preference, not a measure of how well they learned the material.

The time frame for this change was:

2002-2006: No videos. Traditional class lectures. Active learning applied for about 5-10 minutes in each class.

2007: Video lectures recorded on a white board for the last third of the semester and posted after each class period. Regular lectures were given in class.

2009: The remaining two-thirds of the video lectures were recorded on a tablet PC. The professor is not seen in the video. Lectures for entire course were now complete and posted 1-2 days before the class. No traditional lectures were given in class, and class time was used for active learning and real-world applications.

2010: All videos posted on YouTube at the start of the semester. No traditional lectures were given in class, and class time was used for active learning and real-world applications. Substantial time savings was seen, as given in Table IV.

Case 2: Videos Used as Supplementary Material

Faculty can provide online materials created by other faculty as supplementary materials for their course. Alternatively, students find online materials (via YouTube, Google, etc.) and use them to augment their learning whether or not their faculty member provides them. Dr. Reyhan Baktur [68] at Utah State University used the videos from [18] as supplementary material. Students found the videos useful, particularly when she provided the link at the beginning of the semester.

Similarly, Michael Potter [69] at University of Calgary used a single video example (from [18]) and flipped the class for one day. 78.8% of the students self-reported that they watched the video, 96% found the video 'somewhat' to 'very' useful, and 75% thought it was either a 'great idea' or 'probably prefer' the flipped class format (15% said they preferred the traditional approach).

Case 3: Faculty Co-Flipping with Videos Created by Others

In 2012 a professor at a university in Pakistan used the lecture videos from [18] and other online sources and flipped the class, emphasizing real-life examples and intuitive/physical explanations of the concepts. Prior to this, a large proportion of students (approximately 50%) would drop the course before the midterm examination or change their program altogether. From 2009-2012, no student had done a final year project in this field. After flipping the course, no (0) students dropped the course, 9 students went on to work with this professor on various antenna design projects in their senior year project, and all of the students registered for Microwave Engineering as an advanced elective course. This example is particularly notable, as the lectures were not made by the professor teaching the course, and were in English, which was not the native language for most of the students.

In another example, a freshman circuits course [70] is now taught by three different faculty (different semesters), as well as two at a community college, all using the same set of video lectures (prepared by two of the faculty), all with similar success in the course. We have found that students do not object to having videos prepared by professors other than their teacher. However, if a professor chooses to use videos created by another, then they should adjust their teaching to align with these videos as much as possible. This is also important for a professor who is re-using their own videos, and who may update their teaching over time. As they change how they teach (such as a particular way of solving a certain type of problems), then it would also be important to update the videos to align with this new approach.

V. CONCLUSIONS

The flipped classroom uses pre-class lecture videos to free up class time for an engaging, active learning environment in the classroom. This effectively doubles the amount of organized contact time professors have with students. Recommendations for four teaching components are provided in this paper. (1) *Planning the flipped classroom* is more than just making video lectures and posting them on YouTube. Backward class design helps professors delineate what outcomes they seek, how they will assess those outcomes, what activities are needed to teach those outcomes, and where students will receive active practice for those outcomes. Planning where in this process the professor contact time with the students is most valuable is key to planning the flipped classroom. What not to do: Adding in out of class video lectures requires additional student time. If you plan to work examples in class and leave the out of class homework the same as in a traditional, students will have to spend too much time. Plan to reduce your out of class homework by about the same amount as you increase your out of class video watching, and get student feedback on this workload throughout the semester. (2) *Video lectures* are important, in order to free up time in the face-to-face classroom for active learning activities. They should be short, concise and non-repetitive. The most popular ways to create them are tablets or tablet PCs and "hands writing" on paper under a document camera or cell phone. More advanced video studios may also be utilized, but in classes where the mathematics and visual concepts are the dominant part of a lecture, keeping the bulk of the visual focused on them makes good sense. (Generally) what not to do: Videos taken from the back of an active classroom are less popular with the students than the close up, personalized-feeling tablet or "hands writing" videos. (3) *Active learning* in the face-to-face class time is key to the success of the flipped classroom. In class problem solving and real world examples are good activities in electromagnetics courses, and there are many other options as well. Think-Pair-Share activities can be used easily in these activities, and "Muddiest Point" activities help both students and professors understand what they do not understand. What not to do: The in class time must be of high educational value to the students. Don't waste their time. If you require them to watch the video lectures, then do not repeat the lecture in class. Keep examples and homework problems at a high enough level that they can't trivially work through them alone. Asses this level regularly (though formative assessment), and adjust as needed. (4) *Student-centered formative assessment* is an important teaching tool in student-centered teaching such as the flipped classroom. "Muddiest Point" assessments help both the professor and students learn what concepts they are missing or struggling with, well in advance of the summative assessments (exams, final grades). Regular (every 3 week) feedback on how the class is going can help the professor improve the course in real time, and is appreciated by many students. Asking "What can I do to help you learn better? And What can you do to help you learn better?" provides an opportunity for student reflection that can, for many individuals, consciously improve their learning behaviors or reach out to the professor for advice. What not to do: Don't ask for feedback and then ignore it, or worse yet, blame the students for it. Talk about the assessment results briefly in class, and seek to make changes to help the students, or at least tell them why you aren't doing what they ask.

Combining these four elements can help professors create an engaged learning environment for their students. Whether or not student learning increases depends on the situation. Professors often find they can cover the same topics more deeply, or in some cases more topics at the same level. If topics are covered more deeply, this may not show up in exam scores, particularly if the exams are written to test the same level of learning as they were before the flipped classroom. Professors often report more and deeper questions in class, and student satisfaction with the class is often higher. A majority (but not all) students prefer the flipped class, and that preference increases as the semester progresses.

We provide online resources for professors wanting to move forward with this approach in [28], and a five-step recommendation for getting started: (1) Start with a class you have already prepared and taught before, so that you are familiar with the course content and where students struggle with it. (2) Add active learning activities in the first third of the semester, helping both you and the students become comfortable working together in this way. (3) Add video examples in the second third of the semester. Working exam solutions, homework, or other examples by video are almost always popular with the students, and they give both the professor and student experience creating and accessing video content. (4) In the last third of the semester, choose a 2-3 week segment to fully flip. Use pre-class video lectures and in class active learning activities. Get extensive and regular feedback from your students, and also from professionals such as other faculty who have flipped and/or teaching and learning center professionals to improve your activities in real time. (5) In subsequent years, fully flip more of the class, starting from the back and working forward. The reason for this is that since most students prefer the flipped method, they would be less satisfied if you start flipped and then leave it and return to traditional lectures.

One of the opportunities flipped teaching provides is for faculty to re-use videos they previously created or those of others. Important considerations for professors re-using their own materials are to make sure they teach the same courses multiple times so they can re-use and refine their materials. Materials from other professors can be provided as supplementary materials in a class, and the students prefer they be provided at the time they are learning the material originally, organized along with their course content. Video materials shared by other professors who then provide the in-class support can be very effective, but must be used with care. Similarly, some videos used from a previous course may need to be updated as the professor finds better ways to help the students learn a concept. It is important that the video content properly reflect what is taught in the class and how it is being taught. What not to do: Do not require videos that teach a topic one way, and then you do it a different way in class.

And finally, the biggest "what not to do" of all. Don't be afraid to try a new teaching method. Approach this like a research project – learn what others have done through reading the educational literature and talking with experts in the field, consider your own course and experience, and your goals and objectives. Plan a path to reach your objectives, and assess and adapt as needed along the way. The flipped class provides a format to incorporate more active and engaged learning in your classroom. Consider what you could do with that….

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Cynthia M. Furse is a Professor of Electrical and Computer Engineering at the University of Utah and has been a leader in the flipped classroom.

Donna Harp Ziegenfuss, EdD, is an associate librarian at the University of Utah Marriott Library with expertise in instructional design and teaching.