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Evolution of a Flipped Classroom: From Prototype to Personalized Learning

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Abstract

The flipped classroom is an innovative pedagogical approach where students complete preclass preparation outside the classroom and then use class time to actively focus on answering conceptual questions and solving procedural exercises in individual and group settings. This paper chronicles an instructor's experience teaching a core undergraduate course in Numerical Methods using flipped learning, implemented for one topic in 2006 and eventually for the entire course in 2013 and beyond. These offerings included face-to-face and remote instruction during the COVID-19 pandemic. Each of the teaching experiences is outlined with subsections on preclass learning, in-class activities, post-class work, and assessment, providing a framework for readers who may wish to incorporate flipped instruction in their STEM courses. Furthermore, some tips for successful implementation beyond the established are also described.

Keywords

Flipped classroom, active learning, adaptive learning, remote instruction

1 Introduction

As opposed to the traditional lecture, where most students passively listen to the instructor, take notes, and ask or are asked an occasional question, active learning is an instructional method meant to engage students in the learning process. In one of the most comprehensive metastudies [1] done in undergraduate STEM education, where 225 studies were analyzed, the average examination scores increased by 6% (0.47 SD) under active learning over traditional lecture. Students also were less likely to fail in the active learning classes. In a follow-up metastudy [2], active learning was also shown to narrow achievement gaps for underrepresented students. Achievement gaps between majority and underrepresented students were reduced by 33%, while the passing rates were narrowed by 45%. One of the popular ways to incorporate active learning is the flipped learning classroom.

So, what is flipped learning? As per flippedlearning.org, "Flipped learning is a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter" [3, 4].

The first formal mention of the flipped modality was in the book *Effective Grading*, published in 1998 [5]. In that book, flipped learning was defined as an approach in which students are

introduced to topics before class so they can focus on the higher-order thinking skills in the classroom. For the pre-class learning, they assigned writing and problem-solving work to the students and then set activities in the classroom that required argument and analysis. Teachers would give feedback to the students right in the classroom. Then in 2000, Lage, Platt, and Treglia [6] called the same approach an "inverted classroom" and applied it to an introductory economics class. Their motivation was to reduce lecturing as they believed talking could not cater to students' learning styles. Their pre-class learning included multiple formats, such as audiovisual lectures, PowerPoint presentations, and textbook content. Although the myth of learning styles [7] has since been refuted, their motivation seems aligned with the first principle of universal design for learning (UDL), which is having multiple means of representation [8]. What made the flipped modality popular was the movement started by the high-school teacher duo of Bergman and Sams [9], who implemented the flipped modality in a chemistry class.

Implementing the flipped classroom in engineering has been an increasing trend in the last decade. A meta-study [10] showed over 4,000 articles published on flipped classrooms between 2008 and 2017. Their study showed a slight effect size improvement over the traditional lecture in engineering courses. Another meta-analysis by Lag and Seale [11] found an average effect size of d=0.24 (n=272)**.** Although these effect sizes may seem small, they need to be interpreted knowing that an average effect size for education interventions is d=0.38 for published research [12] and d=0.18 for unpublished research [13], and considering the investment made for the intervention. Examples of investment made in a flipped classroom are the time and expense required to create and upload lecture videos, pre-class quizzes, in-class exercises, and extra teaching assistants needed in the class.

In this paper, we discuss the evolution of the flipped classroom for a course in Numerical Methods – one which started as a prototype with video lectures on CDs in 2006 and now is an entirely flipped course with adaptive learning and accessible on multiple platforms, devices, and operating systems.

This core course is taught at the junior level in the mechanical engineering department at the University of South Florida (USF). The course is offered three times a year, and typical enrollment varies from 40-120 students per semester. The course's main objective is to develop and use numerical methods for the following mathematical topics: Differentiation, Nonlinear Equations, Simultaneous Linear Equations, Interpolation, Regression, Integration, and Ordinary Differential Equations. The calculation of errors and their relationship to the accuracy of the numerical solutions is emphasized throughout the course. Programming is conducted via MATLAB to reinforce the course's fundamentals and solve intractable and real-life problems.

2 The Evolution

In 2001 and 2003, NSF funded [14, 15] the first author's project to develop open education resources (OER) [16] for a course in Numerical Methods, including textbook content, PowerPoint presentations, multiple-choice tests, historical anecdotes, real-life applications, and lecture videos. These resources were implemented and assessed to compare the traditional

lecture course with a course where web-based resources were available to the students and were used actively in and outside the classroom.

A typical flipped classroom has three components: 1) pre-class learning, where the student prepares for the class using several resources, which could include video lectures, textbook content, simulations, and assessments, 2) in-class activities that include conceptual and procedural exercises and short lectures, 3) post-class work that might include higher-order thinking exercises, projects, etc.

2.1 Web-Based Self-Study/Discussion (2006)

The first author was not aware of the terminology of "flipped" or "inverted" classroom in the Summer of 2006 when he assigned students to independently study one of the eight topics of the Numerical Methods course, namely, Solution of Nonlinear Equations, while he traveled to go to the ASEE conference for a 4-day trip. The primary motivation for the self-study was the many instructional days that were being missed. Unlike the 16-week traditional semester, the summer semester lasts only ten weeks.

Pre-class learning: The resources given for pre-class learning included textbook content, web-based multiple-choice questions, and video lectures. Because these were pre-broadband days, students could access the videos on the local network at the university. Others had DSL connections at their homes. For many living in rural areas or not on campus during summer, the videos were provided on compact disks. Students were assigned homework as part of the grade where they had to answer nine brief questions – three each on three subtopics of nonlinear equations. These questions were based on the lower levels of Bloom's taxonomy [17].

In-class activities: The self-study was followed by a mandatory discussion session upon my return from the conference. During this class, they were encouraged to ask questions but were not required to do so. Nonetheless, enough questions were asked by students to last the duration of the discussion session. Several questions needed the instructor to go through the solution process.

Post-class work: The discussion class was followed by post-class homework, where they had to answer nine more questions based on the higher levels of Bloom's taxonomy.

Assessment Summary: We called this modality "Web-based self-study/discussion." In a paper written by Kaw and Hess [18], this modality from the Summer of 2006 was compared with the "web-enhanced lecture" modality for the same topic used in the Summer of 2003. In the "web-enhanced lecture" modality, prior knowledge was checked in the class via the multiple-choice questions developed for the OER. The class lecture was done via a PowerPoint presentation and whiteboard using the Socratic method, including student questions. Students were paired to do a portion of several problems suggested by the instructor. They would either start a problem or finish one. The resources given and the assigned homework were the same for both modalities. The comparison was made by measuring student performance on a multiple-choice final exam based on lower and upper levels of Bloom's taxonomy and students' satisfaction via a survey.

The "Web-based self-study/discussion" showed a positive effect size for both the lower-level (d=0.122) and upper-level questions (d=0.142) on the topic of Solution of Nonlinear Equations. A survey on the quality of the class presentations with seven questions rated on a 1-7 Likert scale (1 being truly inadequate and 7 being truly outstanding) was given to students. Questions covered the topics of concepts learned, formulation of problems, development of higher-order thinking, etc. The "web-enhanced lecture" modality was found to have a more favorable rating than the "web-based self-study/discussion" modality. Open-ended questions were also asked in the survey. With the self-study resources, some responses included a student identifying themselves as learning-disabled and mentioning that they addressed their neurodivergent needs, while many other students pointed out the flexibility of studying. The complete details of the assessment are given in Ref [18].

2.2 Flipped Modality (2013-2016)

Until 2012, the first author continued to teach the class as a web-enhanced lecture, which nowadays may be called an active-learning blended class. It was in 2013 when he teamed up with two other universities, Arizona State University (ASU) and Alabama A&M University (AAMU) to teach the Numerical Methods course in flipped modality and compare its effectiveness with the blended classroom.

Pre-class learning: Several resources were assigned to the students to prepare for the classroom and were curated in the learning management system (LMS). These included YouTube lectures and complementary textbook readings. Students were required to take online quizzes with three questions each via the LMS. The number of quizzes depended on the number of modules assigned that week, which varied between 1 and 3. The total number of modules for the course was 30. Most of the questions in the quizzes were algorithmic; the questions had the same template but with different numbers. The students were also asked to respond to an open-ended question in which they identified the most challenging concept in the module.

In-class activities: Students responded to conceptual questions via hand-held clickers from Turning Technologies [19]. This personal response system was chosen as it was an add-on to PowerPoint. All features of Office, such as inserting images and using the Equation Editor, were available. Students would answer a question and pair with another student if more than 25% of the students chose the distractors. They would respond again, and that was followed by an instructor-led discussion. These conceptual questions were followed by students responding to free-response procedural questions. Students were paired to check their solutions with one another and continue working on them. During the activity, the instructor and two graduate assistants helped students if they faced difficulty. Higher-level problems were also solved in class, where students would have to model the problem as well as write a computer program. Mini lectures during class were informed by what students struggled with during the pre-class learning. There also were several complex topics in the course, which were best left to an introduction by the instructor. These complex topics in the course included untransformed nonlinear regression models, spline interpolation, and Gaussian quadrature rules. More details about the in-class activities can be found in Ref [20].

Post-class work: Contrary to the widespread belief that the flipped classroom ends with in-class activities, post-class work is critical to students' success in the course. The students were assigned problem sets but were not graded to avoid assessment fatigue. However, computer-based programming projects for higher-level skills acquisition were graded.

Assessment Summary: In general, there were slight differences between flipped and blended classrooms in the final examination and combined classroom environment data from the three universities. Based on the combined data, *blended instruction* was associated with slightly better average performance on the final exam's multiple-choice (MC) questions across multiple demographic segments. However, the differences were not statistically significant, and the effects were minor. However, flipped instruction was individually associated with slightly better average MC scores at USF and ASU. Conversely, at AAMU, blended instruction was associated with significantly better average MC scores for all students. With the free-response (FR) questions, the average scores were slightly better with blended instruction at USF and AAMU, although the average FR scores were better for flipped instruction at ASU. However, after combining the free response data, the differences were insignificant, and the effect sizes were small. The results from the College and University Classroom Environment Inventory (CUCEI) were like those from the FR questions [21]. At USF and AAMU individually, the *blended* classroom was the preferred environment based on average scores. However, at ASU, the flipped classroom was the preferred environment. When combined, average data from the three schools did not indicate a preferred classroom environment.

Students perceived both benefits and drawbacks of flipped instruction. Only 26% of all respondents combined preferred flipped instruction, and 48% said they did *not* prefer it. However, 54% liked problem-solving versus listening to lectures during class time. The students identified demanding expectations with flipped instruction, with 71% reporting the need for more effort and 80% reporting increased responsibility placed on them. Based on a content analysis of open-ended survey responses, the perceived benefits of flipped instruction were as follows based on the combined data: enhanced learning or learning processes (41% of respondents); preparedness, engagement, and professional behaviors (34%); and alternative use of class time (23%). This aligned with the focus group results, in which the most frequently discussed benefits occurred in the same order. The focus group results indicated load, burden, or stress with flipped learning as a frequently discussed drawback. Given the lack of significant differences, it was concluded that it might be possible to use either instructional approach with the expectation of similar exam and classroom environment outcomes, keeping in mind the students qualitatively identified key benefits with flipped instruction. The complete details of the assessment are given in Ref [22].

2.3 Flipped Modality with Adaptive Learning (2016-2019)

Flipped classrooms face student resistance, especially regarding pre-class learning. Poor pre-class preparation then impacts student engagement in the classroom, which is crucial to the success of a flipped classroom. We wished to address this concern by using adaptive learning for pre-class learning. As an exploratory project, adaptive lessons were developed for half of the eight topics of the course. The lessons were designed on the adaptive learning platform (ALP)

called Smart Sparrow [23]. The results from using these adaptive lessons in the flipped classroom were compared to the results from the prior flipped classroom without the adaptive lessons.

Pre-class learning: The resources that were assigned to students for pre-class learning in Section 2.2 for the flipped classroom were now delivered via the ALP platform Smart Sparrow [23]. Fifteen of the 30 modules of the course were deployed to the ALP since this was an exploratory grant. Each module was broken into nodes (average of 2.66 nodes per module and median of 2 per module), and each node had five sections – Introduction, Learning Objectives, Videos, Textbook Content, and Assessment. The difference between delivering a module via the LMS versus the ALP was mainly that the ALP selected an optimal learning path for the student. Based on a proprietary algorithm, the ALP may ask the student to practice a few questions from a previously presented node or ask them to practice the module again. The student could override these paths, and they could choose their way as well. The only restriction was that a minimum score of 59% had to be achieved for a node that was a prerequisite for the next node. The score was based on going through the lesson (i.e., knowledge covered) and proficiency in content (i.e., knowledge state); hence, the 59% mark was not hard to achieve. Moreover, help was just a discussion board, email, or office visit away. More details about using adaptive learning for pre-class learning are available in Ref [24].

In-class activities: The activities remained the same as for the flipped modality mentioned in Section 2.2.

Post-class work: The activities remained the same as for the flipped modality mentioned in Section 2.2.

Assessment Summary: Based on direct and indirect assessment outcomes, the flipped classroom with adaptive learning was the preferred instructional method. The average score on the free-response (FR) questions on the final exam earned by all participants were almost seven percentage points higher in the flipped classroom with adaptive learning (FA) versus in the flipped classroom without adaptive learning. This improvement suggested the potential of adaptive learning concerning more open-ended problem-solving in the flipped classroom. The classroom environment based on the CUCEI was also rated higher for the flipped classroom with adaptive learning (versus without adaptive learning) across all seven environmental dimensions. In addition, there were significant differences at $p < 0.05$ for four of these dimensions. One of these was the Individualization dimension ($p = 0.01$), which measures individual or differential treatment, a primary objective of adaptive instruction. In a closed-ended question about preference for flipped instruction versus usual methods of instruction, there was an increase at USF from 29% to 42% with the introduction of adaptive learning. This increase corresponded to an odds ratio (OR) of 1.81 (i.e., a small to medium effect). There were also associated decreases in the perceived effort required and responsibility imposed when adaptive learning was introduced to the flipped classroom at USF. Seventy-four percent (74%) of respondents said more or much more effort was required with flipped instruction when adaptive learning was *not* used, versus 59% who felt this way when adaptive learning was used, representing a medium effect size of $OR = 2.01$. There was a decrease from 82% to 73% for the perceived responsibility imposed with the introduction of

adaptive learning, which represented a small effect of *OR* = 1.66. The complete details of the assessment are given in Refs [25, 26].

2.4 Flipped Modality during Remote Instruction (2020)

In the Fall of 2020, we continued to teach the course in a flipped manner but taught remotely because of the COVID pandemic. The sudden change in the middle of the Spring 2020 semester to remote instruction and teaching remotely during Summer 2020 informed teaching going forward. The pre- and post-class work stayed the same as in the face-to-face flipped classroom, but we had to rethink the in-class activities because they had to be done online synchronously.

Pre-Class Learning: The activities remained the same as for the flipped modality mentioned in Section 2.2.

In-class activities: Class was conducted via an online conference tool called Blackboard Collaborate Ultra (BBCU) [27].

a) First, to do the clicker activities online, we could no longer use personal response systems (PRS) as they were physical devices. Although several paid cloud-based options, such as Top Hat [28] and Turning Technologies [19], were available, we did not wish to increase the burden on our students, especially during unpredictable times. We settled on Microsoft Forms [29] as an online PRS replacement as it was free. It had several limitations, but it served its purpose. More details on how to use MS Forms as a PRS are given in a blog [30].
b) Second, for the in-class problem solving, we distributed the pdf file with the free-response questions to the students via the chatroom. About 15-20 minutes were allotted for individual problem-solving, and then students were assigned to breakout rooms to work in groups, which the instructor and two TAs monitored. We dropped into the breakout rooms; however, many were found to have no activity. The instructor then reviewed the questions and outlined the solutions.
c) Third, when a lecture was required, such as for an inherently complex topic or a challenging area, as evidenced by responses in the ALP lessons, OneNote on a tablet was used and served as a virtual whiteboard.

More details about conducting the in-class activities can be found in Ref [20].

Post-class work: The activities remained the same as for the flipped modality mentioned in Section 2.2.

Assessment Summary: Data gathered in the remote, online environment suggested positive changes in the perception of the flipped classroom compared to pre-COVID (on-campus) times (Section 2.2). These included the perception that the flipped classroom imposed lessened load, burden, or stress, as evidenced by a significantly decreased proportion of students who discussed load, responsibility, and anxiety (from 40% to 24%) in an open-ended question posed in the online, remote environment ($p = 0.004$). This reduction may have resulted from the "mainstream use" of

videos and recordings during the COVID period, situating them as more conventional in higher education. In a closed-ended question that corroborated this result, the proportion of respondents who perceived more effort with flipped instruction decreased from 71% to 58% ($p = 0.015$) with the switch to remote instruction. The complete details of the assessment are given in Ref [31].

2.5 Flipped Modality during Remote Instruction with Adaptive Learning (2021)

In the Spring of 2021, we still taught in a completely remote fashion as COVID continued to dictate the method of instruction throughout the nation. We followed the same procedure as for the Fall 2020 semester (Section 2.4), except that the pre-class learning was done via the ALP lessons.

Pre-class learning: The activities remained the same as with the flipped modality with adaptive learning mentioned in Section 2.3. However, the ALP lessons were now available for the whole course. They had to be moved to a different ALP - RealizeIT [32] - because a major publisher acquired [33] Smart Sparrow, and they discontinued supporting current external clients. More details about the development, implementation, refinement, and revision of the adaptive lessons are given in Ref [34].

In-class activities: The activities remained the same as for the flipped modality during remote instruction mentioned in Section 2.4. Lessons learned from the Fall 2020 semester about the breakout rooms and several tips offered by a *Chronicle of Higher Education* article [35] were implemented. The significant changes included having larger breakout groups with shorter-length sessions to increase the chances of student engagement in the breakout room.

Post-class work: The activities remained the same as for the flipped modality mentioned in Section 2.3.

Assessment Summary: Data from the remote (i.e., online) flipped classroom suggested positive changes in classroom environment perceptions, preference for flipped instruction, perceived responsibility imposed, motivation for independent learning, and perceived learning when adaptive learning was introduced. Specifically, there was a desirable increase in all seven of the CUCEI classroom environment dimensions with the use of adaptive learning in the remote flipped classroom, with a significant increase for the Innovation dimension that measures novel teaching ($p = 0.007$ and Cohen's effect size $d = 0.54$). Preference for the online flipped classroom increased from 23% to 43% of respondents when adaptive learning was available ($p = 0.011$ and $OR = 2.41$, which is a medium to large effect size). In addition, the percentage of respondents who perceived more responsibility with online flipped instruction decreased significantly from 78% to 63% when adaptive learning was used ($p = 0.040$ and $OR = 2.07$). An open-ended question partially corroborated this reduction. Specifically, there was a significant decrease in the proportion of students who experienced load, burden, or stressors in the online flipped classroom when adaptive learning was available versus not. This proportion dropped from 31% to 16% ($p = 0.036$, $OR = 2.4$).

Moreover, adaptive learning was associated with enhanced student motivation in the online flipped classroom. The percentage of students who reported having the necessary motivation outside of class increased from 32% to 47% with adaptive learning ($p = 0.044$ and $OR = 1.94$). The increased motivation was a significant result for the COVID remote classroom in general. Thirty-eight percent (38%) reported more substantial learning gains with online flipped instruction when adaptive learning was used versus just 19% when adaptive learning was not used in this setting ($p = 0.009$, $OR = 2.55$). Multiple-choice final exam and concept-inventory scores were slightly higher with the adaptive lessons in the online flipped classroom, although not significantly so. The complete details of the assessment are given in Ref [36].

2.6 In-Person Flipped Modality with Adaptive Learning (2021-22)

Starting in the Fall of 2021, our classes returned to in-person face-to-face (F2F) instruction. We implemented the pre-class learning via the adaptive platform for all course topics and continued to do so in Spring 2022.

Pre-class learning: The activities remained the same as for the flipped modality mentioned in Section 2.5.

In-class activities: The activities remained the same as for the flipped modality mentioned in Section 2.2. The only change was using the Poll Everywhere [37] audience response system for the conceptual questions, as the university subscribed to the service. Poll Everywhere is cloud-based and accessible via any Wi-Fi mobile device.

Post-class work: The activities remained the same as the flipped modality mentioned in Section 2.2.

Assessment Summary: The results of this F2F flipped modality with adaptive learning are currently being collected and will be compared with the F2F flipped modality without adaptive learning from Section 2.2.

3 Tips Beyond the Established Models for the Flipped Classroom

Several models delineate how to conduct a flipped STEM classroom [3, 38-40]. This section gives some categorical tips beyond the established models for the flipped classroom.

- Initially, the classrooms associated with these studies were highly conducive to active learning. The classrooms included portable flat tables and chairs. However, the university started believing "there is no front to an active classroom" and removed whiteboards and replaced them with glass boards in these active-learning classrooms. These boards were hard to write on and reflected the classroom lights. The boards also had limited writing space, even for short lectures. The first author moved the class to a "regular" auditorium with many more seats than students, for example, having 80 students in an auditorium that seats 140. The effectiveness of active learning did not suffer much. Leaving every other row vacant allowed the instructor and the teaching assistants to move around fully

and access every student. The only drawback was during programming assignments, as the furniture setup felt cramped and uncomfortable.

- Groups of two students were randomly made for in-class activities at the beginning of the semester. These groups of two remained the same throughout the semester. Students individually solved the prescribed questions first. This solo activity was followed by pairing up with their group member. To avoid a student being without a partner due to absence, two groups worked together as a distinct group of up to four members.
- During the group activities, the instructor and two teaching assistants circulated around the room to gauge the student's progress and answer any questions the students had. To avoid students having to keep their hands raised if they had a question, a card (red on one side and green on the other) was given. The default was the green side (i.e., they were not seeking help) while turning it over to the red side indicated they needed help. This card served two additional purposes. First, students continued working on a different problem while waiting for assistance. Second, the card alleviated the anxiety of introverted students.
- MS Forms [27] is a good personal response system among the freely available options. Several new features [41] have been added since the first author used it during the pandemic in 2020 and 2021, including converting Word and PDF files to MS Forms, integration with Teams, rating and ranking, and dynamic poll results.

4 Concluding Remarks

Flipped learning remains one method of introducing active learning and improving student engagement in STEM classrooms. Flipped learning is an approach in which students are introduced to topics before class so they can focus on higher-order thinking skills in the classroom. This article took the reader through the evolution of the flipped classroom from teaching just one of the eight topics of a typical Numerical Methods course to where it is now, in which all eight topics are covered using the flipped modality. The pre-class learning, based on video lectures on compact disks, major publisher textbook readings, and homework assignments submitted on paper, is now done through online adaptive learning platform lessons accessible via multiple platforms, operating systems, and devices. The in-class activities have remained similar over the years, except for the changes in the personal response system from hardware-based to cloud-based and the significant adjustments that had to be made during the remote instructional period of the pandemic (i.e., 2020-2022). The components of the post-class work have remained similar, including assigning selected textbook problems and programming projects. Assessment of each of the different experiences was summarized to provide results relative to students' cognitive and affective outcomes.

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