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Flipping the Differential Equations Classroom: Changes Over Time

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Abstract

Traditional lecture style courses use class time to deliver new material to students and homework to provide practice. Flipped classrooms, on the other hand, provide new material outside of class and students are then given opportunities to work actively on problems during class time. A flipped classroom design combines active, problem-based learning activities with direct instruction methods, and is seen by many as a teaching method that results in higher student satisfaction, greater retention of knowledge, and increased depth of knowledge [1] .

The initial implementation of a flipped classroom can be difficult for teachers. Time is needed to develop instructional materials for students to view outside of class, in addition to the time required for developing constructive in-class activities. Teachers who have persisted with this teaching method often report that their classrooms are not optimized until the third or fourth implementation. This paper describes the three-year progression from traditional lecture style to flipped classroom design of a large enrollment differential equations course at the University of Louisville's J. B. Speed School of Engineering. The discussion section of the paper reflects on specific implementation difficulties of flipping a classroom, and gives strategic suggestions for instructors who are beginning to design this type of curriculum.

Introduction: Course Administration, Content, and Context

Differential Equations for Engineers (DE) at the J. B. Speed School of Engineering is the fourth course in a sequence of required mathematics courses for engineering students. The series consists of topics in calculus I through III followed by differential equations, with each course including theory paired with engineering applications and analyses. The first three courses are four credit-hours, and DE is a two credit-hour course.

The engineering school has three semesters per year: Fall, Spring, and Summer. Several sections of each engineering mathematics course are typically offered each semester. Though taught by multiple faculty, the sections are coordinated; the faculty team uses the same text, materials, assignments and exams. All sections take the same exam at the same time. A team of student graders, supervised by one or more faculty members, scores the exams. Graders are students who have taken the courses previously and performed well. Faculty members grade parts of the final exam along with graders.

Like the other calculus courses offered in the engineering school, DE was designed specifically for engineering students. For every theoretical topic, students are also exposed to common engineering applications. There are five course units (for details, see Appendix A). Upon completion of DE, learners should be able to:

1. Identify the order and type (linear or non-linear) of a given ordinary differential equation and solve it by an appropriate solution technique.
2. Solve first and second order linear difference equations.
3. Demonstrate the application of each of the methods of undetermined coefficients, variation of parameters and Laplace Transforms by solving ordinary or systems of ordinary differential equations.

4. a. Develop and solve an appropriate first or second order differential equation (or system of differential equations) that models each of the following one-dimensional dynamic systems encountered in engineering: mechanical vibrations, electrical circuits and mixing problems. b. Interpret these mathematical models by specifying assumptions and limitations, and articulating why the models provide a reasonable characterization of the system.
5. Use Euler's and Runge-Kutta (4th order) numerical methods to approximate the solution of a first order differential equation with initial condition.
6. Apply the Method of Separation of Variables technique for solving linear second order partial differential equations (PDE) to create two ordinary differential equations from a given second order linear PDE.

Since there are three semesters per year, and DE is the last of four required math courses, students most commonly take DE in the fall semester of their sophomore year. Students in all disciplines take several other challenging courses this semester. A typical schedule for a bioengineering student includes dynamics, physics, organic chemistry, and thermodynamics in addition to DE, and other disciplines are similarly difficult. It is common in engineering schools that the workload is strenuous in the semester when students encounter DE.

DE is required for graduation, yet not required for some of the departmental engineering courses. Additionally, as mentioned above, it is only worth two credit hours. Since it is only two hours, but not required for progression in many cases, a disproportionately high number of students were dropping the course midway through the semester. Anecdotally, many of the students were very capable, they often got behind early on and felt like it wasn't worth the work to catch up for a two-hour course.

The department chair and other instructors decided to tackle this course completion difficulty by modifying the structure of the classroom. This modification was intended to increase student participation and course completion without reducing content or lowering standards. The following sections of this paper describe the actions taken to flip the course, share teachers' experiences of the classroom, and offer advice for other instructors who wish to intervene in a similar way.

Traditional Course Design

In the years prior to 2016, DE had a traditional course design: content was delivered solely by lecture, homework was assigned weekly, and skills were assessed with in-class quizzes and exams. The material was divided into 7 units, and each unit was covered in roughly two weeks. A unit quiz was given one week, and a unit exam the next week, so that there was a quiz or exam every week. Each of the seven units had 8-11 unit objectives and 15-20 homework problems. Homework was collected each week on the day of the quiz or exam.

Classes were held in a large auditorium, and DyKnow was used to deliver the basic course notes to students. DyKnow is an interactive classroom management software. In DyKnow, instructors can share content with students (sharing prepared slides and/or writing on tablets during class), and the notes are projected both to the front of the room as well as onto students' computers. Additionally, instructors can request that students send content/notes/problems/questions live during lecture. The content that the students send to the instructor can be kept private or made public to the class as part of the lecture. Seeing the students' notes privately allows the instructor to see what the students are struggling with and adjust the lecture, and making a students' submitted work public allows students to learn from their peers, whether it is through mistakes or corrections.

In the traditional classroom design, the interactive features of DyKnow were not used. A separate computer and computer program (Microsoft OneNote) was used to project the notes as the instructors solved problems. Students could then take notes in their DyKnow file or use paper if they preferred. This technology enabled the instructors to face students while writing notes. Because of the amount of material to be covered, instructors did not use any specific active learning strategies, although they tried to motivate students with questions, scaffold examples, and streamline the example problems.

Flipped Classroom – Iteration 1

When the course was first redesigned in 2016, the material was redistributed into five units covered roughly every 2.5 weeks. Each of the five units had between 9 and 16 unit objectives, and between 15 and 37 homework problems.

First, videos were created based on the ninth edition of the Nagle, Saff, and Snider textbook: *Fundamentals of Differential Equations* [2]. Videos were created for all content. Each video introduced an objective, put the objective in context with the student's current knowledge, provided an explanation of the relevant theory associated with the objective, and concluded with one or more example problems with explanations. The design goal was to make videos that were 3-7 minutes long. For each unit objective, 1-3 videos were needed. There were 78 videos; 60 were under ten minutes; 11 were 10-12 minutes long, and 7 were 12.5-15 minutes long.

The videos closely replicated a traditional class lecture or demonstration. To make the videos, the department created a small recording studio that included digital cameras, a green screen, recording software, Wacom video screen, and video production software. Four faculty spent between 10 and 30 percent effort for two semesters converting existing course content into video content. This included creating the visuals, writing up the examples in OneNote and recording, editing, and storing the videos. Videos showed faculty working problems and explaining material while facing the camera with visuals in the background. Faculty were always talking to the camera or gesturing to the worked problems or diagrams, and a sample screen shot of a video is shown in Figure 1. Verbal descriptions were carefully edited, and additionally, after faculty reviewed the videos carefully, students were offered ten dollars for every error they found. The videos were therefore more accurate and concise than a live lecture.

In the first implementation of the flipped class design, 3-5 videos were to be viewed before a class (except test or review days). Some notes were provided to students along with the videos; however, the example problem solutions (worked by the instructors in the videos) were not included in these notes. Students were therefore required to follow along and write things down to have a complete set of notes. Class time consisted of a quiz at the beginning of class over video materials (designed to mimic approaches introduced on the videos to insure students came prepared), working through select problems interactively with students, and closed with a slightly more in-depth quiz at the end of class to assess content understanding. The two-quiz structure was intended to encourage students to come prepared and on time, and to engage with the material while there. Instructors used DyKnow for all classroom delivery and interaction. On a typical class day, instructors worked the quiz problems from that class so students had immediate feedback. Instructors also tried to get students to work collaboratively on pre-selected problems that were over objectives covered in the videos. Sometimes, the problems selected were homework problems that were expected to be challenging. The interactive features of DyKnow were used extensively in the flipped classroom design, and students submitted several panels showing their work solving the in-class problems with instructors reviewing and critiquing student work during class. Five unit exams were given in class. Following exam days, Exam Review days were held to go over exam solutions. There were also weekly homework assignments.

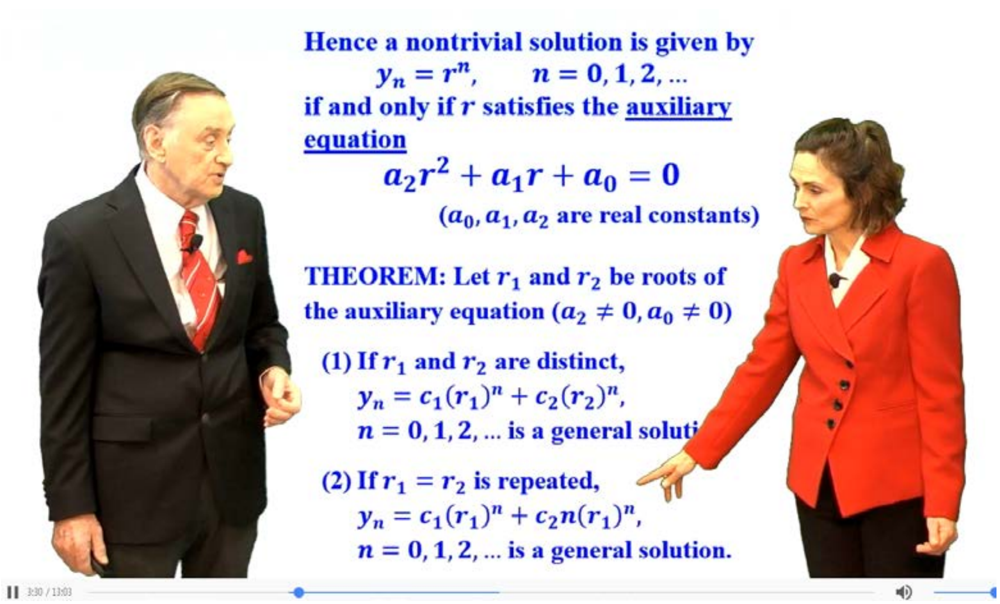

Figure 1: A sample video screenshot.

The professional quality videos took a significant amount of time to prepare during the spring and summer of 2016, and not much time was spent on the development of in-class activities. Therefore, most of the in-class problems were not carefully selected or scaffolded. As a result, many students got frustrated and instead of collaborating or attempting problems in class, merely waited for a correct solution to be shown.

This first iteration of the flipped classroom design was successful in reducing the proportion of students who withdrew from the course mid-semester, as reported in [3]. A survey was given at the end of the semester on various aspects of the course. Students enjoyed the dynamic in-class problem solving with DyKnow. However, students were unhappy being quizzed on new material that was delivered only by video. Survey responses indicated that the quiz at the beginning of class put too much pressure on the students to learn the material from the concise videos. A common complaint was that they were unable to ask questions during the videos. One student called the videos "extremely dense." Because of the speed and density of the videos, students reported having to pause the videos to take notes, which resulted in the videos taking more time than expected. Additionally, despite the videos being the same material that was covered in the traditional lectures, students didn't learn from them immediately. Finally, because the students spent a lot of time taking notes on the videos and there was still homework, a lot of time was required for the course. Instructors realized that they had prepared the first quiz as if students could master the material from the videos without any opportunity for feedback.

In summary, the first iteration of the flipped classroom included the redesign of semester units, and the development of the out-of-class videos. Instructors learned that it was more difficult than expected for students to learn the material from the videos, and that the quiz structure and difficulty needed to be revised. Several adjustments were made to facilitate student learning in the second iteration.

Flipped Classroom – Iteration 2

In the Fall of 2017, a second iteration of the flipped classroom design was implemented. A large change was that complete notes (including all problem solutions) were provided to students to accompany the videos. This removed the need for students to pause the videos to take notes, and it offered students the opportunity to listen, watch, and review and annotate easily. The deadline for homework was moved to Sunday evening to give students time prior to class to watch the videos. Additionally, the quiz at the beginning of class was removed. This change was made for two reasons: to add 10 minutes of class time back to the class, and to give students an opportunity to ask questions on new material prior to a performance measure. Additionally, scaffolded pre-class and in-class activities were developed around the videos to help students master objectives more easily. Finally, a unit review day was planned before the exam over each unit. This day allowed instructors to finish any collaborative work and also the opportunity to "put all the pieces together" before the exam.

The pre-class activities were built in SoftChalk Cloud (https://softchalk.com/higher-education/), a content-authoring software that works seamlessly with Blackboard. It was designed to be a one-stop engagement with each day's lesson, including a description of the objectives, a link to each video, the homework problem set, and short questions over the objectives. The goal was to encourage students to engage with the material as they watched the videos, so that they would come to class better prepared. Students received instant feedback on SoftChalk quizzes and activities. The pre-class problems were short and were often concept-driven questions; they were mostly multiple choice, with some fill in the blank or ordering of solution steps. They were graded (combined with weekly homework for 5% of the overall grade), though students had unlimited attempts on each question. Students were expected to complete one lesson prior to each day of class (excluding exam and review days). It was expected that students would spend 1-1.5 hours on each lesson including the time to watch videos and solve comprehension check problems.

The in-class activities were designed to target specific concepts and procedures by selecting and scaffolding problems. Instead of giving the students a prompt for a problem that might take 10-15 minutes, the students were given a few small segments of a problem to work step-by-step. Instructors also expanded their active and collaborative strategies from simply doing structured problem solving exercises to include concept questions, fill-in the blanks, order-the-steps, very short answers, and more. The problems were broken into more manageable pieces and the students could step through the process of solving them. This allowed the students to see how much of a particular concept that they understood and often that they could at least partially work a problem correctly.

Students were requested to submit DyKnow panels frequently at intermittent points throughout a problem. Instructors then attached student solutions to their notes, and based on student feedback, students were proud when their solution was selected. These problems were prepared ahead of time in DyKnow for the instructors to use throughout the semester. The amount of time students needed for an answer to a prompt was around 30 seconds to 5 minutes. This allowed instructors to be more efficient with class time, and allowed them to cover more and different types of problems than in previous semesters.

A significant amount of time and effort was spent prior to Fall 2017 developing both the pre-class and in-class activities for the second iteration of the course. There were four instructors of record, and two worked on the in-class activities while one developed the pre-class activities and one created the homework and exams.

In reality, many students did not come to class prepared enough to participate in the activities. In a mid-semester survey, students were asked how often they watch the videos, and responses were as follows: Always, 40%; Frequently, 23%; Sometimes, 25%; and Never, 12%. Students were also asked whether they followed along the SoftChalk lessons step-by-step, and answered: Always, 24%; Frequently, 26%; Sometimes, 31%; and Never, 19%. On the pre-class SoftChalk questions, students were given multiple attempts to answer until they got the correct answer. This was intended to help their learning, however, some students (17% reported on the survey) simply "clicked through" these until they got the points for the online assignment, rather than using them to test their preparation for class after watching the video. Then in class, despite the scaffolding, it was difficult for instructors to engage the students.

In addition to these pre-class and in-class design modifications, the instructors were invited to try out a classroom on campus that was designed for active learning: the Teaching Innovation Learning Lab (TILL). The active learning classroom is a technology-rich environment with moveable tables, node chairs and multiple monitors. Instead of desks in rows facing the front of the class, students are seated in groups at tables of up to 10, each with a large monitor that students can use to share work within the group. The classroom design allows instructors and students to interact, teach and learn creatively and collaboratively (https://louisville.edu/till). Two of the instructors took their students to the active learning classroom three times each, and another instructor observed all six active learning classroom sessions. Table 1 details the instructors' in-class strategies. Both instructors reported that their methods adapted over time in the new classroom space.

Table 1: Teaching strategies in an active learning classroom

Instructor 1	**Instructor 2**
Day 1: Students were placed in groups of two. DyKnow was used in the same way as in the auditorium – problems were given, student panels were submitted, a correct panel was selected, and this panel was discussed with the whole class. In this room however, the student who wrote the selected panel was able to present what they did to the rest of the class. Day 2: Students were placed in groups of two to work together. Instead of submitting the panel in DyKnow, students projected the panels onto their group's monitor. The instructor walked around the room to select a good panel, which was then submitted. The panel was then discussed as a group. Day 3: The students were placed in groups of ten with a number (1-10) at each seat. The student in seat 1 displayed their computer screen to the monitor and worked collaborative problem 1. The rest of the group was not supposed to work the problem on their own but help that student work it. The first group with the correct panel was asked to submit it in DyKnow and that was the panel that was discussed as a class	Day 1: The first session was the least structured. Students were free to sit at any table with any group. A set of problems were distributed with DyKnow for groups to work during class. One member from each team projected their work to a large monitor or wrote on a nearby whiteboard. The instructor circulated the room answering questions for the entire class. Days 2 and 3: More structure was provided for group collaboration with the Student Work Groups tool in DyKnow. The students were assigned groups (of 4-6 students) and had a shared workspace (in DyKnow). Students in the same group could all write on the same panel and see each other's work. In this way, they were truly solving the problem together and were encouraged to discuss the problem. It functioned similar to a whiteboard but they all retained an electronic copy of their work. One problem was presented at a time to attempt to keep the class at the same pace. Students were given time to attempt the problem, and the instructor walked around to see their progress and answer questions. The whole class was addressed regarding common mistakes and an overview of the solution.

In summary, the second iteration of the flipped classroom design included development of pre-class and in-class activities, as well as trial classes in a classroom designed for active learning. Students responded well to the scaffolded, in-class activities, however, since there was little incentive to watch the videos or use the new pre-class SoftChalk lessons, many students did not come to class prepared.

Following the completion of the second iteration, the instructors sat together and discussed the main issues with the course. All instructors agreed that the biggest problem with the second iteration was that students were not prepared for class. Three modifications to the design were proposed to fix this issue:

1. Make pre-class questions required, graded, one-try only, and close it before class.
2. Have some homework (more in-depth problems) due before class.
3. Have a conceptual quiz at beginning of class.

Each of these options requires students to watch the videos and put in some effort prior to class while avoiding the problem observed in the first iteration of requiring students to master the materials with the videos alone.

Summary of the Iterations

The sections above are diagrammed in Table 2. The iterations over the different years differed not only in the timing of content delivery and practice, but also in homework requirements, quiz assessments, exams, and in-class activities.

Table 2: Summary of Flipped-Classroom Modifications over Time

Course Activities	2015 – Traditional	2016 – Iteration 1	2017 – Iteration 2
Content delivery	Lecture	Online video lectures; video notes were provided to students but with problem solutions left blank.	Online videos embedded in SoftChalk lessons with content summary, objectives, and short comprehension check problems; complete video notes were provided to students.
Homework	Weekly assigned problem set	No changes to problem set but some were solved in class; due every class (2/week).	No changes to problem set but some were solved in class and some were included as comprehension check problems in SoftChalk lessons; due weekly on Sundays.
Assessment – Quizzes	~20 min quiz every 2 weeks	10-15 min quiz at beginning and end of each class.	10-15 min quiz at end of each class.
Assessment – Exams	7 exams (approximately 1 every 2 weeks)	5 exams (approximately 1 every 2.5 weeks), review day following each exam to go over exam solutions.	5 exams; review day moved to day before each exam.
In-class activities	None (lecture)	Students worked on homework problems and additional book problems.	Problems were scaffolded. Some classes occurred in the active learning classroom.

Teacher Experiences

Instructors were asked for their opinions about the course redesign and their impressions about working in a flipped classroom. Quotations included here are not assigned to specific authors to preserve anonymity. Quotations are included from the whole instruction team, including the two instructors who used the active learning classroom, the observer, and the chair of the department (also a member of the instruction team).

Overall, the teachers of DE found that live DyKnow interactions helped them find common errors and correct thinking in “real-time.” Students appreciated that feedback, and teachers enjoyed supporting students’ learning in this way. One of the instructors who participated in all of the stages of flipping the classroom, from the traditional style to using the videos to developing refined in-class activities, stated:

"In retrospect, the traditional classes were not as enjoyable. I did not know what students were struggling with or misunderstanding until an exam (roughly every two weeks). Students seemed less inclined to ask questions in a large auditorium environment when we as teachers spent most of the time at the front of the room lecturing, or even trying to engage them in question and answering sessions."

That being said, the focus of the first iteration of the flipped classroom had been predominantly on video creation, and not on the in-class activities. Here are several instructor comments about the class time during the first iteration:

"Being in a large auditorium, it was challenging to get students to work in twos or threes, and many refused. Since we did not have a specific assessment associated with collaboration, we did not press this."

"I know there was a lot of frustration on the part of the students as they tried to get accustomed to lecture on video and homework problem solving in class."

"As the semester progressed, collaboration worsened"

"A frustration engagement: there was always a significant number of students waiting either for us to display a correct solution or waiting for their partner to do the problem for them."

"I feel we did not spend enough time designing the class time activities during the first iteration."

During the second iteration of the flipped classroom design, instructors felt that the class time was more valuable. However, there were still some issues with class participation:

"I do think the interactive problem solving was a big success compared to previous semesters."

"In comparison to previous semesters, I felt a much greater connection to my students."

"For me, the interaction made this format much more enjoyable and it felt more successful from a student learning perspective because I was answering questions."

"Breaking problems into steps naturally led to more engagement from the students since the pieces were smaller and seemed to not be so overwhelming to the majority of the students."

"I continue to struggle with the engagement aspect. In walking through the auditorium, there were still some students surfing the web, doing work for another course, or waiting for us to append a correct solution. Also, the quiz at the end does not get at the problem of students needing to come to class prepared."

"Similar to Fall 2016, I found as the semester went on the collaboration with both myself and between students worsened, and the students were very concerned with what content would show up on the quiz at the end of class."

All instructors agreed that many students were not coming prepared to class. The main reason was because the preparation was not mandatory. Not only was there no quiz at the beginning and no homework due prior to class, but also the participation required in the pre-class SoftChalk lessons were multiple choice and permitted multiple attempts. Therefore, students were not putting in any effort. The following comments include identification of the preparation problem as well as potential ways to modify the course moving forward:

"With the quiz at the end, many figured they would just learn what they needed to know in class, banking on us quizzing them over something we were going to work in class."

"Because we allowed an unlimited number of attempts in SoftChalk, I feel many students did not actually benefit from this work, instead 'clicking through' just to get credit."

"The timing of the homework seemed to encourage students to procrastinate as well."

"I think there needs to be a quick quiz at the beginning as well as removing the unlimited option on SoftChalk preparation problems."

"Overall, I felt that Fall 2017 was a more successful teaching method, but I do not think students were coming into class as prepared as needed in either semester. I do not think we have come up with a good solution to guarantee all the students are successful with the quizzes and in class work."

Teacher Experiences in the Active Learning Classroom

Overall, teachers had positive experiences in the active learning classroom. As the instructors became more comfortable with the tools and environment, they felt engagement increase:

> "On Days 1 & 2 in the active learning classroom, I felt like my students collaborated well with me, but not with each other. On Day 3, I finally got the collaboration I was looking for. I still moved slowly but my students collaborated well with each other. Also the groups really wanted to be the first done so they stayed on task." (Instructor 1)

> "On Day 1, many students were still working individually, students were uncomfortable projecting their work to the large monitors, and students were working at very different paces. In many cases, individual students in the same group were working on entirely different problems. If students had questions, they often chose to ask me first without consulting group members (who may have already completed the problem). The later classes went much more smoothly. I was happy with the level of collaboration and I was able to circulate the room to answer questions and keep everyone on track." (Instructor 2)

> "Though I feel simply having students sit at tables facing one another improved collaboration and discussion among groups, it was not ideal and not much of an improvement over our typical class. In fact, it felt more chaotic than our classes in the regular classroom. … [After providing more structure in the activities and how the groups should collaborate,] the classes went much more smoothly."

> "I feel that each session was progressively better as myself and my students became more comfortable in the space and with the change in class activities."

Ultimately, the tools that were available in this classroom did increase collaboration and participation that was significantly different than in an auditorium. Instructor comments on this point are as follows:

> "This environment definitely encouraged collaborative work as the students were in groups of 5-6, with each group sitting around a common workplace and facing one another."

> "I noticed that when the instructor had the groups use the larger shared monitors within each group, collaboration seemed to be enhanced."

> "The monitors made it easier for the students to talk about the displayed work."

Lastly, even doing activities in the active learning classroom did not engage every student.

> "There was somewhat more collaboration between students, but definitely not all! Students typically worked independently and then would discuss their results among their own group members, even in this setting!"

> "There were still a handful of students who did not engage with their teams."

Department Chair Experience

The development of the flipped classroom over 2 years with multiple instructors was additional work for the department chair. The department chair was also one of the course instructors in all 3 iterations.

In Fall 2014, in the traditional design, the instructors had similar teaching styles.

In Fall 2016, during the first stages of the re-design, two junior faculty members were added, and everyone was learning and sharing experiences. All four were in general agreement about all class activities and assessments (that had not been modified), however, were adjusting to the changed format as well as building the class activities only a few days ahead. There was not much time for reflection during the semester.

In Fall 2017, a junior faculty member replaced one of the original instructors on the DE team. In the summer of 2017, the three junior faculty members attended a 2-day institute on active learning. The institute challenged them to explore new learning spaces and to strive for more student-student collaboration. In Fall 2017, instructors had differing teaching ideas and strategies. It was more difficult for the chair to maintain uniformity of student experience across sections. More things were changed, specifically with respect to the in-class activities, and there were differing opinions as to whether all the changes were good. The chair noted:

> "As department chair, and as the course administrator, I often thought it would have been easier if I had just dictated an approach at times, but I resisted that inclination."
>
> "Over time I became convinced that one of the most important things a teacher brings to class is passion – for the subject and for teaching. Each of my junior colleagues was passionate about different approaches. It was important that I find ways for us to deliver the course to meet department expectations while allowing enough flexibility for their individual approaches."

Summary & Conclusions

The DE course was redesigned into a flipped classroom over two years. The work in the first year was directed towards developing the out-of-class videos. The work in the second year was directed towards developing in-class activities. This iterative progression is similar to the general reports that it takes multiple semesters to construct a good flipped classroom design. Through this process, instructors learned several lessons.

1. *In-class activities are a critical part of the flipped classroom design because students need more than lecture videos to learn material.*

For a traditional lecturer, it is easy to ignore the elements of the course structure outside of the lecture content delivery. It is recommended that instructors get everything prepared before doing a full flipped design – including the in-class activities. Others have reported the same issue, stating that videos don't help learning but rather free-up class time for active learning [4]. In *The Practical Guide to Flipping Your Classroom,* Panopto warns that "flipping redefines what's required of the educator twice. First, it requires that lecture materials be made available ahead of class time. Second, it requires teachers to replace passive in-class time with active learning strategies" [5]. If it does in fact take a great deal of preparation time to develop the videos, it may be a better idea to use them to augment traditional lectures for one semester, while developing the in-class activities. Also, when thinking about in-class activities, it is helpful to think about what would work just after a lecture. A comprehensive quiz at the beginning, for example, would not be appropriate, unless it were designed to be conceptual, formative, and low-stakes.

2. *If out-of-class preparation is not graded in some way, it may not be completed.*

To ensure that students are prepared for class, there must be some regular assessment. Whether that is a quick, timed and graded conceptual quiz, or whether it is solving a few problems prior to class, something is needed to get students to put in the work outside of class. As Pienta wrote in an editorial: "the active learning approach requires engaged students" [6].

3. *Student preferences vary. The best course design allows multiple paths for learning.*

Providing the notes to the videos in the second iteration helped many students. However, some students in the second iteration requested that they have the first iteration's version of the notes (without the solutions to the examples), because they wanted to pause the videos and take their own notes of the problem solutions. Overall, however, the first iteration's class was bothered by pausing the videos. Single student complaints should not be the sole reason for making modifications to course redesign.

4. *Teacher pedagogies vary. The best instruction will happen when teachers have flexibility in class.*

Teachers have different preferred teaching strategies as well as amounts of preparation. The chair of the department observed great passion from one instructor in the active learning classroom, and is now aiming to allow more flexibility among teachers. For example, the instructors who wish to continue to use collaborative teaching environments will be able to use a new academic building on campus. Any teaching team will need to standardize expected outcomes based on department expectations while allowing for teaching and testing variability.

In conclusion, flipping the differential equations classroom was done over the course of two years and is ongoing. The experiences shared in this paper are documented to prepare others as they embark on flipping their own classrooms. Future work includes making additional improvements and modifications to the classroom design, as well as a quantitative assessment of performance in each iteration of the flipped classroom development.

Appendix A

Details of the Differential Equations for Engineers course content:

1. Variables separable differential equations, equations of the form $y' = G(ax + by)$, homogeneous (y / x form) equations, equations with linear coefficients, exact differential equations, equations made exact by integrating factors, linear first order differential equations, Bernoulli equations, RL and RC electrical circuits, existence and uniqueness, linear independence, the Wronskian, homogeneous ($= 0$), linear differential equations with real, constant coefficients;

2. Basic theory of linear differential equations, nonhomogeneous equations and the superposition principle, the method of undetermined coefficients, the annihilator, linear difference equations, method of variation of parameters, definition of Laplace transform, linearity, piecewise continuity, exponential order, existence, tables of transforms, translation in "s" property of Laplace transform;

3. Laplace transforms of derivatives, inverse Laplace transforms (including partial fractions), initial value problems with initial conditions at $t = 0$ or $t = c, c > 0$, derivatives of the Laplace transform, solving linear differential equations with coefficients that are polynomials, transforms of discontinuous functions, translation in t, inverse transforms of functions containing e^{-as}, transforms of periodic functions, Impulses and the Dirac delta function, solving differential equations with functions involving jump discontinuities at t=0, convolution;

4. The transfer function H(s), and the impulse response function h(t), the Gamma function, mathematical modeling, mechanical vibrations and simple harmonic motion, undamped and underdamped or oscillatory vibrations, damped, free vibrations, including underdamped or oscillatory, critically damped and overdamped motion, forced vibrations, resonance, beats (amplitude modulation), simple electric (RLC) circuits;

5. Normal form for a system of differential equations, introduction to systems of linear differential equations of first order with constant coefficients, the elimination method, converting an nth order differential equation into a system, solving linear systems with Laplace transforms, compartmental analysis (mixing problems), direction fields, introduction to numerical methods, the approximation method of Euler, using the fourth order Runge-Kutta method and a CAS to solve first and higher order differential equations and systems of differential equations, review of Fourier cosine and sine series, the method of separation of variables for solving partial differential equations.

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