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Calculus II Course Redesign: Supporting Faculty in Pedagogical Change

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ABSTRACT
This article describes a partially flipped course design for Calculus II which has been implemented by a varied instructional team at a medium-sized public engineering university (Colorado School of Mines (Mines)) over a period of three years. We have identified three main factors which have contributed to the success of the implementation: (1) institutional support for teaching, (2) use of evidence-based practices, and (3) creation of faculty community. We demonstrate both student and faculty success through student assessment data and faculty interviews. Success is defined in terms of student performance, the implementation rate of faculty, and the positive experience of the instructional team.

KEYWORDS
Active learning; departmental change; flipped classroom

1. INTRODUCTION

The purpose of this article is to describe a departmental change in Calculus II, by highlighting a partially flipped, multi-section coordinated Calculus II course. In addition to developing the course materials and model, we had the broader goal of creating materials in such a way that would make it easy for other faculty to choose to use them. We view active learning as any instructional method that engages students in the learning process [13]. We view flipped learning to be a type of active learning. A flipped classroom is one in which students’ initial contact with new material occurs outside of class and time in class is spent working on challenging problems [14]. The success of such an active learning model has been previously demonstrated [4, 7, 9]. We define our model as a partially flipped classroom because initial contact with new material occurred both outside and inside the classroom.

In our Calculus II course, evidence of student success was exhibited through exam data and DFW rates (percentage of students earning a D or F in the course or who withdrew from the course). However, we were especially interested in the experience of other faculty who adopted our course model. In the Scholarship of Teaching and Learning (SoTL) taxonomy, this is an example of a “What is?” question which seeks to describe, but not evaluate the effectiveness of, different learning approaches [6]. Specifically, we are seeking detailed information about the
student and faculty experience with a model that we have been implementing for multiple semesters. Therefore, interviews were conducted with faculty instructors who have used the model to gain insight on their perceptions. Faculty success was demonstrated by a high rate of faculty adoption of the course model, their positive experience using the model, and the performance of their respective students. We are claiming a successful departmental change due to both student and faculty success with the course model. We believe the three main factors contributing to this successful departmental change are (1) institutional support for teaching, (2) use of evidence-based practices, and (3) creation of faculty community.

The article begins by focusing on the local context, including the prior Calculus II course design. This is followed by an explanation of the expertise of the leadership team, as well as detailed information around the course redesign, supports in place, and the implementation plan. Revisions to the plan as well as student and faculty indicators of success will be highlighted. The article concludes with challenges and reflections.

2. LOCAL CONTEXT

Carney and Swanson teach in an applied mathematics and statistics department at a western public engineering school, and Sanders, Spiegel, and Vasquez are employed in the university’s teaching and learning center (Trefny Innovative Instruction Center). At the Mines, all students are engineering, science, or mathematics majors; therefore, each student is required to take Calculus I, II, and III. The calculus courses are taught in approximately 40-person sections that meet for 4 contact hours each week. For Calculus II, roughly 20 sections are taught each academic year, with 7 taught each fall semester and 13 taught each spring semester. The mathematics department has 10 teaching professors and 13 tenure/tenure track professors. For further context, the duties of a teaching professor consist of a mix of teaching and service with scholarship optional, but valued, in the promotion process. Whereas a tenure/tenure-track faculty’s duties include a combination of teaching, research, and service. Individual sections of each calculus course are generally taught by teaching professors, adjunct faculty, post-doctoral fellows, and graduate teaching fellows.

The Calculus I, II, and III courses have historically been coordinated in the following sense: students in different sections took common exams, instructors had the option to use common homework, and each section used common course-level learning outcomes. However, how individual instructors decided to teach had been the choice of that instructor. The coordinator could not (and cannot) require instructors to apply a specific instructional method and classes were typically taught in a lecture format. There were also no explicit common day-level learning outcomes, and before Carney and Swanson joined the department, a habit of regular group meetings for instructors of a common course was not well established. These factors helped inform the choice to create course materials centered on active learning which would be easy for other instructors to choose to implement.
We would also like to note that the fall cohort of Calculus II students consists mostly of new first-year students with AP or transfer credit. The spring cohort of Calculus II students consists mostly of students who have completed Calculus I at our institution. Additionally, Calculus I is primarily taught in a lecture format with approximately 15 activity days during the semester. We do not feel that the type of instruction that students were receiving in Calculus I had an effect on the student’s acceptance of the Calculus II model.

3. EXPERTISE OF LEADERSHIP TEAM, COURSE DESIGN, SUPPORTS IN PLACE, AND IMPLEMENTATION PLAN

3.1. Expertise of Leadership Team

Carney and Swanson were hired by Mines in 2012 and have since served as the primary coordinators for Calculus II. Both authors have an interest in pedagogical improvements and regularly participate in teaching professional development, which includes attending workshops and leading professional development and learning communities. Additionally, they had prior experience in redesigning math courses as they collaborated on a 2014 partially flipped project in Linear Algebra and have published the results of that study [4]. The authors were able to build on the lessons learned from their Linear Algebra redesign as they worked on their Calculus II redesign. First, the authors experienced student success with an active learning model and knew they wanted to extend that success to Calculus II. Also, other instructors had used their linear algebra materials and Carney and Swanson had learned the necessity of having better supports for the implementation of the materials, resulting in the creation of daily lesson plans for Calculus II and the scheduling of weekly instructor meetings.

In addition, Carney and Swanson already had a multi-year habit of collecting data for the purpose of course improvement. Also, there was a departmental expectation for course coordinators to create an end-of-semester assessment report. This, together with the authors’ prior experience of data collection for the flipped Linear Algebra project, and support of a university center for teaching and learning, all led to a culture of data collection. All these supports aided the authors’ in developing an assessment plan for the Calculus II course redesign.

In 2015 Mines created the Trefny Center for Innovative Instruction. Spiegel was hired as the founding director of the center and began early work with Carney and Swanson in considering course redesigns. One of the center’s first initiatives was to develop an opportunity to support faculty to make significant changes to their teaching with the goal of institutional change. The center developed a framework to guide the faculty members in research-based course design approaches. The framework was designed based on an engineering design model to make the process more accessible to STEM faculty. We refer to the framework as Engineering Learning\textsuperscript{SM}. Engineering Learning\textsuperscript{SM} guides faculty through a backwards design (reverse engineering) process [2, 10, 12, 15]. Engineering Learning
has faculty first “Articulate” the main goal, purpose, and sequence of the course. Then, like reverse engineering, they first clearly define specific and measurable learning outcomes. The learning outcomes then guide the rest of the design and enactment. The framework becomes part of a faculty member’s routine as they embrace the practice, including a continuous improvement model that is built into the framework (reflect and collaborate stages). The framework also moves faculty towards more active learning as they align the learning opportunities and assessments with the learning outcomes. Very few of our courses have primarily low cognitive demand outcomes (the types of outcomes where lecture is a reasonable approach). See https://trefnycenter.mines.edu/engineered-learning/ and https://trefnycenter.mines.edu/effective_teaching/.

To this end, funding was secured by the Board of Trustees to support cohorts of 20+ faculty for three summers with one-month of summer salary and to provide an intensive month-long workshop to help faculty make course changes. Carney and Swanson applied and were accepted to be part of the first cohort in summer 2016 with the goal of creating a partially flipped Calculus II course, including materials that would encourage the implementation by other Calculus II instructors, as described below.

### 3.2. Course Design

Carney and Swanson developed their Calculus II course model in 2016 with the support of the Trefny Center. At that time they developed day-level learning outcomes that mapped to course-level outcomes to inform their course planning and to better communicate expectations to other faculty teaching the course. Detailed materials were created for each class day, described in detail below.

On a typical day, before attending class students watch a short, 8–10 min, introductory video and respond to pre-class questions. The pre-class questions are graded for completion only and are used as a formative assessment to determine how well students seem to understand the video. Class time is a mix of discussion and collaborative student work on challenging problems, referred to as daily activities. The mini-lecture and discussion is informed by the student responses to the pre-class questions. Typically when working on the daily activities, students are applying what they have learned to new situations or they are guided in discovering new ideas. Students work in assigned groups and abide by common peer interaction norms. Instructors can use observations about student thinking during the activity to guide their wrap-up portion of the discussion. After class, students complete homework. In addition to developing all course materials, Carney and Swanson created a daily lesson plan with the intent to assist other instructors in using these materials. The lesson plan includes the day’s learning outcomes, a list of the pre-class questions, a problem to engage student interest, recommended discussion topics and examples, daily activities, and suggested discussion points. See the online appendix for examples.
Most recently, all Calculus II sections have been taught in rooms with tables and movable chairs, which help to facilitate group work. Previously, the model has been implemented in rooms with traditional desks that can be arranged into groups. We have observed no difference in the experience in these two settings other than it can be more difficult for the instructor to move about the room in the more traditional classroom while students are in groups.

### 3.3. Supports in Place

The authors have identified the following supports which have contributed to the success of the course redesign and the option of that design by other faculty as evidenced in Section 5.

#### 3.3.1. Institutional Support for Teaching

Carney and Swanson were beneficiaries of a variety of departmental and institutional supports for teaching. First, they took part in the intensive summer course redesign program in 2016 sponsored by the Trefny Center, as mentioned above. This month-long program provided essential instruction on designing learning outcomes, class activities, and assessment measures. The summer course placed significant emphasis on using evidence-based practices in designing the course. The university provided participants one month of salary, highlighting their commitment to investing in teaching. Carney and Swanson spent a significant portion of that month developing day-level learning outcomes for Calculus II that supported course-level outcomes. From there, course materials were created, as described above. Because there was a strong desire to maintain faculty autonomy, the lesson plans were intentionally developed to be easy to use by other faculty, therefore clear facilitation notes and a solid course design with pre-built resources (videos, tests, and daily assignments) were embedded. The lesson plans are thought of as suggested lesson plans, in the hope that faculty could easily adapt them individually. This is consistent with research on supporting faculty in the change process by providing easily modifiable materials [11].

In addition to supporting faculty in redesign efforts and providing an excellent center for teaching and learning, there is a general cultural support of teaching. In 2011, Mines developed a Teaching Assistant Professor, Teaching Associate Professor, and Teaching Professor track. Across campus, teaching faculty are valued and voting members of departments and are involved in both departmental and institutional governance. Finally, Mines has a long history of providing campus wide pedagogy seminars and significant travel support to teaching faculty for teaching-oriented professional development purposes.

#### 3.3.2. Use of Evidence-Based Practices

Through the support of the center, Carney and Swanson implemented evidence-based practices when creating the Calculus II course design and materials. These
practices included the design of learning outcomes at the topic level and the development of assessments that were aligned to the outcomes. Additionally, the course design utilized a cycle of student practice and feedback. Motivations included the desire to create materials that were easy for faculty to use, to respect instructor autonomy, and to focus on creating materials that lead to student learning successes. They benefited from cultural supports and traditions that were already in place at the course level. This included common exam and homework as well as a tradition of collecting and sharing local assessment data. Because of this, it was easy to encourage other members of the instructional team to continue to collect and use local data for the purpose of course improvement.

3.3.3. Creation of Faculty Community
Finally, the adoption of the course model benefited from the creation of a sense of community at a variety of levels. Carney and Swanson had already had a history of holding weekly instructor meetings when coordinating calculus and continued the tradition. Again, this is consistent with research on supporting faculty in the change process by emphasizing personal connections [11]. Meetings serve as a forum for discussing the next week’s lessons and for instructors to discuss the implementation of the previous week’s material. The meetings provide an opportunity for the instructional team to ask questions, share advice, and give feedback. These weekly meetings help to create a sense of community amongst the instructional team.

Additionally, having a critical mass of faculty interested in pedagogy served as an impetus for the creation of a departmental Professional Learning Community (PLC). Beginning in fall of 2016 and continuing today, members of the mathematics department meet on a monthly basis to discuss issues related to student learning. Regular attendees include teaching faculty, adjunct faculty, graduate teaching fellows, and postdoctoral fellows. At these meetings, Insights and Recommendations from the MAA National Study of College Calculus [3], the MAA Instructional Practices Guide [1], other papers, and even our own course assessment reports are discussed. Both the weekly instructor meetings and the department PLC led to a supportive instructional community. These were the only forms of professional development that were consistently provided to all members of the instructional team.

3.4. Implementation Plan
See below for an implementation timeline. Eleven unique instructors have used the course materials and the model has been implemented in 51 out of 62 sections of Calculus II since fall 2016. Note that when we refer to an instructor opting into the model, that means they are implementing the provided lesson plans which includes the pre-class work and in-class activities. More specifically, the 11 instructors were using all the materials. The variations in implementation were only in content of the daily class discussions, and the mode of feedback provided on daily activities.
Initial Test Run – Fall 2016: Carney and Swanson implemented the course model in a smaller Honors Calculus II cohort. Adjustments to the lessons were made in real time.

First Roll-out – Spring 2017: The was the first large roll-out of the course model. The instructional team consisted of Carney and Swanson, one other teaching professor, one graduate teaching fellow, and two adjunct faculty members. Carney and Swanson, the graduate teaching fellow and one of the adjunct faculty members implemented the entire course model. Data on student success was gathered and can be seen in Section 5.2.

A Pause – Fall 2017: Due to external factors, neither Carney nor Swanson taught Calculus II and the faculty coordinator did not utilize our learning outcomes.

Full Adoption – Spring 2018 and Fall 2018: Carney coordinated the course both semesters. Based upon the data collected during spring 2017, every one of the instructional team members opted to use the course materials.

Mostly Full Adoption – Spring 2019: Swanson coordinated the course. The instructional team consisted of Swanson, five adjunct faculty members, and one graduate teaching fellow. Only one adjunct faculty opted not to use the materials, but the rest of the team fully implemented the course model.

Experiences of faculty using our course model are summarized in Section 5.1, but, generally the instructional team has a very positive opinion of the course model. Overall, faculty were invested in implementing the redesigned course, found the materials well designed and highly organized, thought the course coordinators were approachable and responsive to questions, and felt successful using all course materials.

4. REVISIONS TO THE INITIAL PLAN AND REASONS WHY

The necessary revisions to the initial implementation have been minor. Based upon our own experiences and discussions with other faculty members using the materials we have developed, some lessons have been modified or are currently being modified. For instance, in our first semester, we had a mix of pre-class reading and video assignments. Students seemed to find the video assignments more useful, so we developed video assignments for most sections of the course but also provided a reading assignment option. As another example, there were times when parts of a particular lesson did not work as well as it could when implemented by us or other faculty, and collaborative discussions around student work and the course design allowed us to adjust lessons to be richer experiences for all of the students. Finally, for each pre-class assignment, we added a question soliciting questions about the video or reading. In the end, we unknowingly created a repository of common student questions that we can now anticipate and are therefore more prepared to adjust our lessons with these questions in mind. Some of these revisions are in place, and some are still in progress.
We will continue to modify and adjust lesson plans with the overall goal that the plans are easy for other faculty members to use and that the lessons are well designed to support mastery of the intended learning outcomes.

5. FACULTY AND STUDENT SUCCESS

5.1. Faculty Success

A large indicator of success is that the course model has been widely adopted by the instructional team for Calculus II over the last few years, as highlighted in Section 3.4. To gauge instructor perception of the course design interviews were conducted by Vasquez. Structured interviews were conducted with eight instructors. Three of the instructors were adjunct faculty, two were graduate teaching fellows, two were teaching postdoctoral fellows, and one was a visiting professor. All had taught the redesigned course one or more times. The interviews followed a structured protocol, and each took approximately 15–25 min. Interviews asked for instructor opinions around the weekly meetings, the ease and difficulty encountered with the course design, which components of the course design best facilitate active learning, and perception of student experience in the course. Interviews were coded and analyzed using a deductive thematic approach.

One key takeaway that emerged from the interviews was the sense of community instructors felt in teaching the course, due in part to the weekly meetings. Overall seven instructors explicitly mentioned the weekly meetings being beneficial. One instructor said in response to a question about which supports were in place to help them utilize the materials, “I would say, just the team, having someone there to talk through and the support. To ask questions about the material, that was the best thing.” This sentiment about group support and community was echoed by many of the other instructors as well. Research shows that a sense of community among faculty instructors can strengthen faculty learning and help foster pedagogical improvements that promote student success [5]; and collegial relationships among faculty can lead to increased job satisfaction [8]. In addition to the weekly meetings building a sense of community, they also promoted consistency across the course sections. One instructor highlighted it by saying,

Because we have 14 sections and 600 students, just making sure seven different instructors are presenting at the same depth and the same scope of material, same pace, it is really important, for fairness for the students. Because it shouldn’t depend which instructor they have what education they get.

Having this sense of community and consistency has positive implications for faculty success in teaching the course model and in increasing student achievement.

The interviews also indicated that all eight instructors felt it was extremely easy to implement the course design due to the setup of the course on Canvas and all the materials being accessible in a shared, secured cloud-based folder. In addition, many instructors found the course coordinators extremely responsive to questions, allowing them to feel successful and supported, as one instructor said, “I have never
really felt like I am not able to ask Deb [Carney] and Becky [Swanson] if I have questions. I have definitely used their support throughout the semester.” Several of the instructors indicated they did not face any difficulties when using the new course model. Those who did express any difficulty indicated that it had to do with initial student resistance, explaining, “I have had a little bit of negative feedback from students. If they are used to a more lecture-based course. They want to just show up to class and have you tell them what to do.” But even this student push-back eventually changed as they grew used to the course model.

All eight instructors felt the course model helped facilitate active learning in the classroom. The instructors felt that the component of the course model that was most helpful in facilitating active learning were the daily activities. As a reminder, the daily activities are challenging problems that the students worked on collaboratively in groups during class time. Instructors highlighted that students were “actually taking what they heard briefly and trying it. They have to make these connections, make decisions about what applies, and work together so they are discussing and doing it and asking for help sometimes.” This targeted in-class work time allowed students to spend a significant amount of the semester actively working on problems and getting deep into content knowledge for Calculus II.

Instructors were asked about how student engagement and their connection with students had changed since implementing the course model. Seven of the instructors overwhelming indicated they felt more connected to students and students appeared more engaged. This was mainly due to the daily activities and the ability of the instructors to touch base with so many students during these daily activities. One instructor emphasized,

This is such the beauty of this flipped classroom, they were way more engaging. I was able to talk to everyone, at a least a couple of minutes each class. So by the end of the week, they all knew who I was, they all felt comfortable, so not only did they talk more in class, but they were really quick to come to my office hours, so I was actually having way more people in my office hours than I ever had before, which was really cool.

Due to the course model instructors were better able to connect with students, have small group conversations, and check on the progress of students who were struggling with the material.

The interviews indicated that the perception of the instructional team around the course design was overwhelmingly positive. They felt a sense of community among the faculty, felt supported by the course coordinators, and effective at implementing the materials. The daily activities allowed the course to be an active learning environment, resulting in increased student engagement and connectedness between faculty and students.

**5.2. Student Success**

While the focus of this article is more about the departmental change process, there is also evidence of student success as seen by learning outcome attainment and DFW rates.
### Table 1. Percentage of students scoring at or above 70%.

<table>
<thead>
<tr>
<th>Number of students</th>
<th>Not flipped</th>
<th>Flipped authors</th>
<th>Flipped other</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO1: Computation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1</td>
<td>68.6</td>
<td>81.7</td>
<td>74.3</td>
<td>0.06 (*)</td>
</tr>
<tr>
<td>Q2</td>
<td>57.8</td>
<td>77.7</td>
<td>63</td>
<td>0.003 (**)</td>
</tr>
<tr>
<td>Q12</td>
<td>49.4</td>
<td>67.5</td>
<td>59.3</td>
<td>0.009 (**)</td>
</tr>
<tr>
<td>LO2: Application</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3</td>
<td>87.3</td>
<td>95.6</td>
<td>97.2</td>
<td>0.001 (**)</td>
</tr>
<tr>
<td>Q11</td>
<td>53.6</td>
<td>67.3</td>
<td>59.8</td>
<td>0.086 (*)</td>
</tr>
<tr>
<td>Q14</td>
<td>79.5</td>
<td>86.9</td>
<td>82.8</td>
<td>0.261</td>
</tr>
<tr>
<td>LO3: Reasoning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q6</td>
<td>74.7</td>
<td>77.5</td>
<td>71.9</td>
<td>0.617</td>
</tr>
<tr>
<td>Q7</td>
<td>56.5</td>
<td>60.4</td>
<td>64.3</td>
<td>0.065 (*)</td>
</tr>
<tr>
<td>Q8</td>
<td>64.8</td>
<td>82.7</td>
<td>77.4</td>
<td>0.00002 (**)</td>
</tr>
</tbody>
</table>

#### 5.2.1. Learning Outcome Data

In Calculus II, there are learning outcomes related to the ideas of Computation, Application, and Reasoning, with final exam questions focused on these learning outcomes. Student final exam scores from spring 2017 were examined because the spring 2017 semester is the only semester in which there was an even split between flipped and lecture-based sections of Calculus II. The number of students who scored at or above a 70% on individual problems was calculated, as scoring a 70% or better can be viewed as a benchmark of success. The data is organized into the learning outcomes, and the “Q” refers to the question number on the exam. The data compares the performance of the non-flipped sections, those that were flipped by Carney and Swanson (Flipped Authors), and those that were flipped by other faculty (Flipped Other). The column at the end gives information about the statistical significance of the differences when using a Chi-Square test (see Table 1). The values denoted with (*) were significant at the 0.1 level and values denoted (**) were significant at the .01 level. The data demonstrated that the flipped classes were performing at least as well as the non-flipped ones. Additionally, in comparing the two flipped versions, there was only one statistically significant difference (Q2), providing some evidence that the other faculty were successfully able to use our course model.

#### 5.2.2. DFW Rates

Another piece of evidence is historical DFW rates (see Table 2). The bold values in the table refer to the semesters where the partially flipped course design for Calculus II was implemented. We include these to indicate the overall students are not doing any worse than they were before implementation. We have only included the spring DFW rates for three reasons. First, the fall and spring Calculus II students are different populations. Second, the implementation of the model has primarily taken place in the spring. Third, the fall semester typically only has two distinct instructors which could skew results.
6. LOCAL DEPARTMENTAL CHALLENGES AND MITIGATION STRATEGIES

One of our largest challenges has been related to the idea of instructor and even coordinator autonomy. So far, this has been mitigated by the flexibility of our lesson plans as being suggestions, rather than requirements. In particular, most of the faculty teaching Calculus II in the past few years have chosen to use course materials we have developed. One point to highlight, during structured interviews faculty were asked if they felt they had ownership over how they taught the Calculus II course and if their voice was implemented in the classroom while they were teaching. Overwhelmingly faculty indicated that they still had a voice and they felt they could “put their own spin” on teaching the course even with the provided materials. So while instructors feeling they have autonomy is a challenge, the materials are presented in such a way that faculty still feel ownership over how they deliver each lesson.

An additional challenge lies in coordination across the calculus sequence. In recent years, Calculus I, II, and III were each run quite differently with various expectations and structures. While the math department is beginning to address this problem by examining cross-sequence course-level learning outcomes, there are still challenges related to the extent to which we must agree on learning outcomes at the daily or topic level. For instance, different faculty tend to prefer to present different applications of integration in Calculus II. We must grapple with the question “To what extent do we have to agree on daily or topic-level learning outcomes?” It is a question we have not fully addressed, but we are beginning that process within our departmental undergraduate committee. The issues it caused were most apparent in fall of 2017 when another faculty member stepped in to coordinate but chose not to use our materials or, more particularly, our topic-level outcomes. The other faculty member teaching that semester did choose to use our materials, but these materials were not designed for the (implied) outcomes assumed by the other faculty member. This meant that the other faculty member was not preparing students for the exams. We anticipate similar issues would arise if neither Carney and Swanson were assigned coordination duty for Calculus II. We do not have a particular mitigation strategy in mind, but it is our hope that as a result of these departmental-level efforts, that we can come to some agreement regarding at least a partial list of required daily and topic-level learning outcomes that would be consistent across semesters.

Change is challenging, especially when trying to move a group of diverse faculty towards common teaching approaches, so that students across a large number

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**Table 2.** DFW rates for Calculus II for the spring semesters 2010–2019.

<table>
<thead>
<tr>
<th>Spring semester 20xx</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td># Sections adopted / Total # Sections</td>
<td>8/13</td>
<td>13/13</td>
<td>11/14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DFW rate percentage (%)</td>
<td>25</td>
<td>30</td>
<td>21</td>
<td>21</td>
<td>22</td>
<td>14</td>
<td>16</td>
<td>13.1</td>
<td>8.6</td>
<td>10.7</td>
</tr>
</tbody>
</table>
of sections have similar experiences (learning opportunities and supports) regardless of which instructor they are scheduled with for their section. The Engineering LearningSM framework provides the guidance to routinize research-based design approaches to courses, reflection, and collaboration to facilitate and support the desired changes.

See https://trefnycenter.mines.edu/engineered-learning/.

7. CONCLUSION, REFLECTION, AND FUTURE WORK

To summarize, we have described a partially flipped course design for Calculus II which is successfully implemented by a varied instructional team. The main factors which have contributed to the success of the implementation are (1) institutional support for teaching, (2) use of evidence-based practices, and (3) creation of faculty community. We have demonstrated indicators of both student and faculty success, through student assessment data and faculty interviews. Learning outcome data and DFW rates indicate that students are completing the course at least as successfully as they were before the implementation of the model. Faculty successes include a high adoption rate and ease of use of the course materials, increased use of evidence-based teaching practices, and increased consistency across sections. Additionally, faculty report feeling like they are a part of an instructional community and have better connections to students.

As Carney and Swanson reflect on their experience, the main takeaway is that creating and supporting pedagogical change is so much more than creating and sharing materials. We knew that we would have to provide support to the instructional team, but did not appreciate the scope of that support. The creation of a supportive and safe faculty community was integral to implementing and sustaining change. Through weekly meetings, faculty were able to ask questions, give advice, and connect with the team. Just as importantly, we were able to gain feedback from the team about the model. We would respond and make changes based on faculty suggestions, which contributed to the sense of community and improved the course design.

For future work, we expect to continue to make modifications to the Calculus II model based on feedback from students and faculty. One issue that we have been facing is related to communication among the instructional team and how different instructors interpret different learning expectations. In a coordinating setting, with common assessments, it is important for faculty to have similar expectations. This has proved challenging with a rotating instructional team, which almost always includes someone who is new to the course structure each semester. While there certainly have been improvements like the implementation of learning outcomes, and we are mindful of these challenges as coordinators, there still is work to be done. Finally, as mentioned previously, the mathematics department still needs to work together to make the calculus sequence more cohesive in terms of course goals, learning outcomes, and student expectations.
Acknowledgments

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APPENDIX: SAMPLE LESSON PLANS

We have included sample lessons plan for the sections on cylindrical shells (day 1) and trigonometric substitution (day 2). The authors are happy to share additional materials upon request. These are typical examples of the lesson plans that are shared with the instructional team. For each day of class, the following materials are shared with instructors:

- A lesson plan document.
- A link to the pre-class video or pre-class reading (when applicable).
- A daily activity for student distribution.
- Solutions to the daily activity.

Additionally, a typical lesson plan (as shared in this appendix) includes the following components:

- Daily learning outcomes.
- A description of the pre-class assignment (reading or video or none).
- A list of pre-class questions to be assigned through the learning management system.
- An interactive hook question to draw student interest.
- Suggested topics for a mini-lecture at the start of class and before the student activity period.
- The list of problems included on the student activity.
- Suggested ideas and topics for briefly wrapping up the lesson at the end of class.

Finally, when coordinating the course, the authors also manage a course shell for the instructional team in the learning management system for ease of distribution of materials and assignments to the students.

REFERENCES


**BIOGRAPHICAL SKETCHES**

Deb Carney is a Teaching Professor at the Colorado School of Mines and the Assistant Department Head for the Department of Applied Mathematics and Statistics. Deb received her Ph.D. in mathematical logic from the University of Maryland, College Park in 1998. She arrived at CSM in 2012, after spending 9 years on the faculty at the University of Denver. She is interested in innovative teaching techniques that improve student learning and she was awarded the Mines Teaching Award for teaching faculty in 2019. Additionally, she has developed a passion for mentoring women in mathematics through the Society of Women in Mathematics at Mines which she cofounded with Rebecca Swanson. She enjoys hiking and traveling, especially to Cape Cod every summer with her family.

Megan Sanders is the Senior Assessment Associate at the Trefny Innovative Instruction Center at the Colorado School of Mines. Before joining Mines, Megan worked at the Eberly Center for Teaching Excellence and Instructional Innovation at Carnegie Mellon University, where her role focused on supporting instructors in conducting research about student outcomes in their courses. Megan’s disciplinary background is in educational psychology. She earned her PhD from the Ohio State University, and her research focused on the idea of relevance in higher education—how we define it, how students perceive it, and how to measure it—an interest that continues to inform her work.

Sam Spiegel is the Director of the Trefny Innovative Instruction Center at the Colorado School of Mines. He previously served as Chair of the Disciplinary Literacy in Science Team at the Institute for Learning (IFL) and Associate Director of Outreach and Development for the Swanson School of Engineering’s Engineering Education Research Center at the University of Pittsburgh. Prior to joining the University of Pittsburgh, he was a science educator at Biological Sciences Curriculum Study (BSCS). Sam also served as Director of Research & Development for a multimedia development company and as founding Director of the Center for Integrating Research &
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Rebecca Swanson is a Teaching Professor at the Colorado School of Mines. She received her Ph.D. in mathematics from Indiana University in 2010. Prior to arriving at the Colorado School of Mines in 2012, she was an Assistant Professor at Nebraska Wesleyan University. She enjoys the beauty and elegance of discrete mathematics and the challenge of pedagogical innovation. Rebecca has been recognized for her efforts with the Rocky Mountain MAA Early Career Teaching Award (2016) and the university’s Board of Trustees Award for Outstanding Faculty (2017). Rebecca also enjoys mentoring women in mathematics through the university AWM student chapter she cofounded with Deb Carney, as well as co-advising the department Putnam team with her husband and colleague, Stephen Pankavich. She likes to spend her free time with her husband, two young daughters, and her dog, and enjoys traveling, baking, running, and reading.

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