ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #20874

A competency-based flipped classroom for a first year hands-on engineering design course

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A Competency-based Flipped Classroom for a First Year Hands-on Engineering Design Course

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***Abstract* - This paper presents the implementation and results from combining a specific flipped classroom technique with a competency-based learning approach. Results from the analysis of student performance on selected course objectives indicate improved student motivation to attempt the course objectives. Significant difference was also observed in the percentage of students that were able to successfully complete the selected course objectives. Strengths of this teaching method include greater overall student satisfaction with in-class assistance and competency-based assessment. Results also suggest an impact on mid-level and low achieving students leading to a higher overall class performance. Criticisms suggest simplification or emphasis on the workings of the system from time to time. The effect of this course delivery on different assessment formats is discussed, with recommendations on the type of assessments that are best suited for this method. Based on the analysis of the data collected, modifications for future offerings of the course are discussed. Overall, results suggest that a combination of competency-based assessment and flipped classroom approach is more effective in a first-year hands-on engineering design course than each of these individual styles of course delivery.**

Index Terms – active, competency, design, flipped, hands-on, interactive

INTRODUCTION

Flipped classroom techniques have increased in the past decade and have been increasingly employed in combination with other active learning techniques giving rise to more varieties in the so called blended techniques [1] [2]. The flipped classroom technique, primarily, is still a framework where content is disseminated outside the classroom and the concepts are applied inside the classroom in the presence of the instructor. Many studies have been conducted in all areas of education by partially [3] or fully flipping a classroom [4] and results have been presented. The overwhelming majority of these studies present a positive response by students towards some form of "flipping" [5]-[7]. One of the many different theoretical frameworks used in flipping a classroom that have been developed over the past two decades [8] is the ICAP framework [9] – [13]. The framework describes a movement of the student engagement in the course materials from the Passive to Active to Constructive to Interactive, which stand for each of the letters in the abbreviation ICAP. While the flipped classroom is a technique that is expected to increase student engagement and accommodate students to watch self-paced video content, a learning-centered evaluation method is needed to accommodate students with different learning paces as well as students in the medium to low-achieving categories [14] – [15]. This is evidenced by "learning at my own pace" being an important factor of student satisfaction with courses that have an online or e-learning component [16]-[21]. One such learning approach is the mastery-based approach which has been demonstrated to have increased student confidence and examination scores [22] – [27]. In this approach, students with various learning speeds are given an equal chance to demonstrate aptitude for the course objectives. The course objectives are assessed through competencies that students can attempt (theoretically as many times as they need). If the competency is not demonstrated, specific feedback is provided to the student in a bid to correct the gaps in the learning objective.

This paper reports on the results of an 18 month study in a lower-division engineering course where a comparison was made between different blended approaches by combining traditional or flipped course delivery with the competency-based learning approach. The blended approaches were applied in the spring 2016, fall 2016 and spring 2017 semesters of a freshman year course (Foundations of Engineering Design Project II) at Arizona State University. The course objectives and instructor for the three versions of the class were the same for all three semesters. However, the method of delivery and learning approach in each semester were different. The spring 2016 semester combined traditional classroom lectures with a competency-based learning approach. The fall 2016 semester used a flipped classroom delivery with traditional evaluation. The spring 2017 semester used a flipped classroom delivery with the competency-based learning approach. In each of these semesters, 44 ±3 students were enrolled in the classes where these techniques were applied. Standardized course objectives were compared between the three offerings to analyze the efficacy of each method. To analyze student attitudes, student evaluations conducted by the university at the end of the semester were accessed.

The goals of the study were the following:

1) To evaluate how the flipped classroom when combined with a competency-based learning approach, affects student motivation to attempt

assignments demonstrating aptitude towards course objectives, in comparison to earlier approaches adopted in spring and fall 2016.

2) To evaluate if the blended approach in spring 2017 affected student performance in comparison to the earlier formats applied. Specifically, the comparison was made between objectives that demonstrate technical skill objectives of the course.
3) To assess student perceptions of the Flipped classroom, competency-based approach in comparison to the approaches used in 2016.

METHOD

The competency-based traditional classroom approach was based on an earlier work that was done by Bekki et al [28]. The ICAP framework was adopted from a Solid Mechanics course designed by Zhu [12]. The implementation of the competency-based approach and flipped classroom delivery are described in the following sections.

I. Competencies and grading

The course objectives were directly mapped on to “competencies” that students were supposed to demonstrate before the end of the semester. The relevant competencies that were compared in this study are given in Table I.

TABLE I
COURSE COMPETENCIES EVALUATED IN THE STUDY

Competency	Description	Assignments
Coding	Write accurate, executable code to make the Arduino perform a simple, defined function.	PA: Coding Basics I PA: Coding Basics II PA: Sensors I PA :Sensors II **CT: Coding**
Multimeter Skill	Use a multi-meter to correctly measure the voltage, resistance, and current of a specified device or circuit.	PA: Breadboard + Multimeters I PA: Breadboard + Multimeters II **CT: Multimeter Skill Assessment**
Process Representation	Accurately represent a specified process using a flow-chart that includes at least one loop and appropriate conditional logic (IF-THEN-ELSE).	PA: Process Representation PA: Sensors II **CT: Process Representation**

In Table I, PA represents Practice Assignments and CT represents Competency Test. The meaning of these terms are explained in the following sections.

II. Teaming

Students in the class were divided into teams of four that would work on two hands-on projects based on the class objectives through the semester. Teaming was done based on student preferences, past performance and self-declared teaming strengths and weaknesses. The teams were deliberately made diverse in each of these categories so that collaboration could take place. The projects themselves were not directly graded. Class Objectives were measured through assignments and quizzes that depended on project deliverables.

III. Video Lectures (fall 2016 and spring 2017 versions)

Each course lecture that directly related to a course objective was delivered as a video posted online. All lecture videos were accessible anytime from the starting date of the course till the last day of the course. It was ensured that each of the videos lasted no more than 7 minutes of content to match student attention spans [29] – [32]. Each video link was accompanied by additional optional video resources or reading materials that interested students may like to watch or read. Slides for the class where the topic will be reviewed are posted as well. Students were instructed to watch the videos pertaining to a specific day’s topic before coming to class. In class, before starting the in-class activity, questions that were raised by students through online discussion boards, email or in-person are addressed using the review slides.

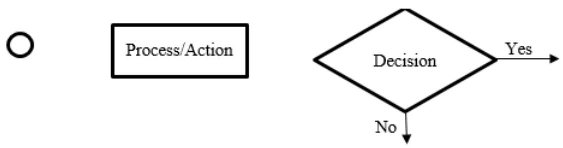
IV. Practice Assignments

The in-class activities were termed as practice assignments (PA) that could be a hands-on activity or an assignment that needed to be finished by students before the end of class. Students could ask for help from the instructor, undergraduate teaching assistants or their team mates. However, the work was needed to be turned in individually. The PAs are in effect used to reinforce the content covered in the video lectures. Evaluation of these, therefore, was done based on student effort rather than on the correctness of the answers. Feedback on these assignments was essential in bridging gaps in the student understanding of the course objective that the assignment dealt with.

To engage students from all levels of aptitude towards the associated course objective, the PA usually consisted of three levels of questions. The first level consisted of two – three questions directly related to the content that was watched before in the video. The second level consists of questions that would require some amount of inference from the video lecture and probably discussion within the team or with the instructional faculty in the class. The last level of questions requires, sometimes, working in groups of two or three to arrive at the result.

An example table of questions from the PA Process Representation is shown in Table II. The specific example shown in Table II is an in-class PA that needs to be completed within the class hour. Other examples of PAs can include hands-on activities, such as, building a circuit and using a multimeter to measure specific values or using a sensor and creating an excel graph to describe its behavior. In both types of PAs, three levels of questions were provided.

TABLE II
PA: PROCESS REPRESENTATION

Level	Question
1	For each of the following operations from a-e, identify and provide the correct shape you would use in a flowchart from the shapes below:  a. Checking if 'x' is less than 'y' b. Assign a value of 30 to variable p c. Begin a flowchart d. Print the value of x e. Ask the user for their age
2	Draw a flowchart to add any two numbers provided by a user. The steps for this are described below: i. Initialize sum = 0 (PROCESS) ii. Enter the numbers (I/O) iii. Add them and store the result in sum (PROCESS) iv. Print sum (I/O)
3	Draw a flowchart to find the sum of numbers from 1 to n using a loop structure. The number n will be provided by the user. You will need two variables – 'sum' and 'count' and set both of them to zero. The sum variable will store the result while the count variable will keep track of how many numbers we have read.

V. Competency Tests

After completion of a PA related to a specific course objective and receiving feedback, students had the opportunity to demonstrate aptitude towards the course objective by completing an individual take home assignment called a competency test (CT). The CT was a completely individual submission and the students were instructed not to take the help of fellow students. The test clearly indicated the course objective or competency that the student was demonstrating. The grading for the course competency was done based on a grading rubric that was also supplied to the student. Grading outcome was demonstrated or not demonstrated (for example pass/fail) rather than on a scale of 0 -100 %. In case a student was unable to demonstrate the competency in their first attempt, a second attempt was provided after feedback on the first attempt was delivered to the student. The feedback from the first attempt ensured that any gaps in demonstrating the competency were addressed with the student. The second attempt, although required the student to demonstrate the same course objective as before, was a completely different assignment and not in essence a corrected resubmission of the first attempt. A rubric was provided to the student for the second attempt as well. An example of the competency test towards the Process Representation competency is shown in Figure 1. The rubric used to grade the CT is given in Figure 2. Student submissions that satisfied all requirements of the rubric were considered to have demonstrated the competency. Students that missed the requirements of the rubric were deemed to have not demonstrated the competency. Detailed feedback about what was missing in the submission was given to the student to fill the gaps in the student understanding. A second attempt was provided to students that were unable to demonstrate this competency in the first attempt. Although the rubric was the same in the second attempt, the question asked in the CT was different from the one in the first attempt.

While CTs in general followed the same format, some competencies were evaluated as in-class quizzes. From Table I, Electrical Concept Application and Multimeter Skill were evaluated as in-class quizzes. Quizzes were not provided with either a rubric or a reference sheet. Like all other CTs, graded quizzes were provided with feedback and a second attempt to demonstrate competency.

Process Representation: *Accurately represent a specified process using a flow-chart that includes at least one loop and appropriate conditional logic (IF-THEN-ELSE).*

For this competency assignment, you will submit a flow-chart representation that prints the leap years from the years 2004 to 2020. Use a loop structure to increment through the years.

Your submission must contain the following:
A complete flowchart for the process you are describing. Your flowchart should include circles representing the beginning and end of the process, actions (square boxes), and at least two decisions (diamond shaped boxes); at least one decision should be part of a loop structure

FIGURE 1
CT: PROCESS REPRESENTATION

Assignments need 3 of the 4 attributes listed below in order to have successfully demonstrated the Process Representation competency (check if the requirement has been meet in the submission):

- The flowchart has "begin" and "end" circles______
- Boxes are used to represent actions______
- Diamonds are used to represent decisions______
- Parallelograms are used to represent input and output______

Assignments also need 3 of the following 3 attributes to successfully demonstrate the process representation competency.

- The flowchart correctly represents the process and displays the correct leap years ______
- The flowchart includes a correctly applied loop structure______

FIGURE 2
GRADING RUBRIC FOR CT: PROCESS REPRESENTATION

V. *Assessment Method*

The course consisted of a total of 15 competencies that were graded according to Table III. Grading also depended on student participation in the in-class PAs and attendance according to Table IV and Table V. A total of 16 PAs were done in all three semesters. However, in the spring 2016 traditional classroom competency-based model, 4 PAs were in-class while the rest were homework assignments. In the flipped versions of the class in fall 2016 and spring 2017, all 16 PAs were in-class assignments. Projects were not separately graded. However, team participation was evaluated through a specific competency. Final grades assigned to the students were the lowest of the three categories: CTs, PAs and Absences.

In the fall 2016 flipped-class version, since a competency-based approach was not followed, the grading scheme was based on a 0 - 100 % scale shown in Table VI. Since all PAs were in-class, absences were not separately recorded. To compare the competency-based results with the traditional results for specific course objectives, students who scored in the A & B level in the traditional evaluation were considered equivalent to students who passed a competency test in the competency-based evaluation.

In all three versions of the class, students who scored a grade A were categorized as high-achieving students, B & C as mid-level achieving students and D & E as low achieving students. In addition to the course competencies evaluated in Table I, data regarding attempts made by students to demonstrate a competency was recorded. Specifically, the number of students that made an attempt to submit all competencies was recorded. A distinction was not made to keep a record of whether a student had passed a CT in the first or in the second attempt.

TABLE III
COMPETENCY-BASED GRADING SCALE (SPRING 2016 AND SPRING 2017)

Competencies Demonstrated	Grade
15 - 14	A
13 – 12	B
11 - 10	C
9 - 8	D
7 or below	E

TABLE IV
PAS GRADING SCALE

PAs attempted	Grade
13 or more	A
12 – 11	B
10 - 9	C
8 -7	D
6 or below	E

TABLE V
ABSENCES GRADING SCALE

Absences	Grade
4 or less	A
5 - 6	B
7 - 8	C
9 - 10	D
11 or more	E

TABLE VI
FALL 2016 GRADING SCALE

Score (%)	Grade
80 - 100	A
65 - 79	B
55 - 64	C
50 - 54	D
0 - 49	E

Student perceptions about the course were gathered through end of semester evaluations administered by the university. Only qualitative questions were selected in order to get raw student perceptions about the course rather than quantified data. The selected questions were the ones which almost all students had answered in the end of semester surveys conducted in all three semesters. The terms 'flipped classroom' or 'competency-based' were not mentioned in the survey in order to get particularly strong positive or negative reactions that students may have towards these techniques rather than getting pointed feedback focused on these techniques.

The questions selected for evaluation were as follows:

1. What did you like most about this course?
2. What did you like least about this course?
3. What would you like to see changed in this course?

RESULTS

Results from evaluating the course objectives shown in Table I from spring 2016, fall 2016 and spring 2017 are shown in Figure 3, Figure 4 and Figure 5 respectively. Each competency was evaluated for the percentage of students that passed the competency, did not pass the competency and percentage of students that attempted the competency.
In addition, the percentage of students that attempted all competency tests (irrespective of passing it or not) is shown in Figure 6. The final grade distribution in each of these semesters is shown in Figure 7.

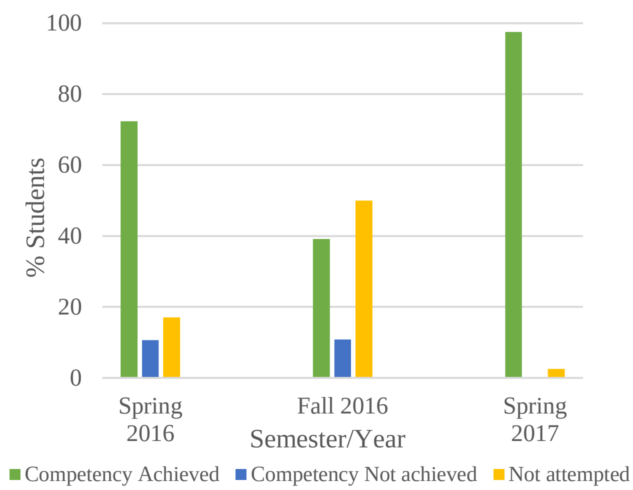


FIGURE 3
COMPETENCY TEST RESULTS: CODING

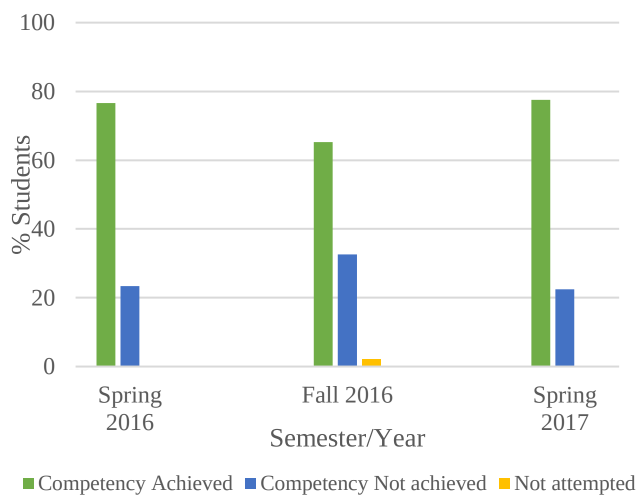


FIGURE 4
COMPETENCY TEST RESULTS: MULTIMETER SKILL ASSESSMENT

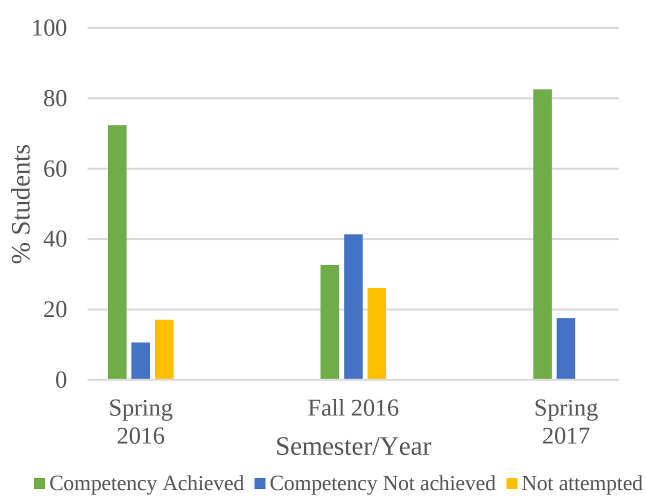


FIGURE 5
COMPETENCY TEST RESULTS: PROCESS REPRESENTATION

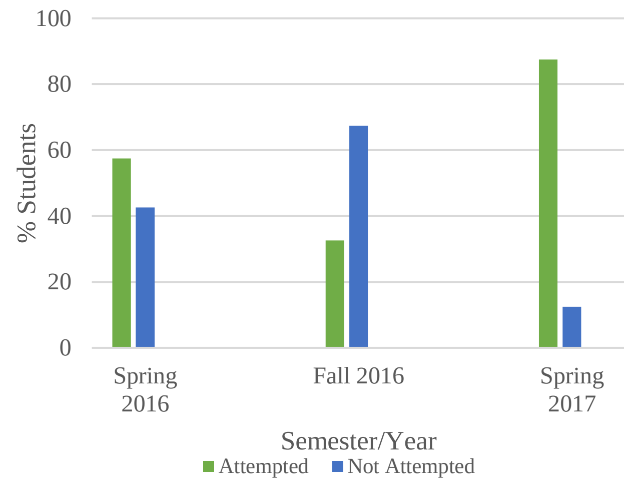


FIGURE 6
% STUDENTS THAT ATTEMPTED ALL COMPETENCY TESTS

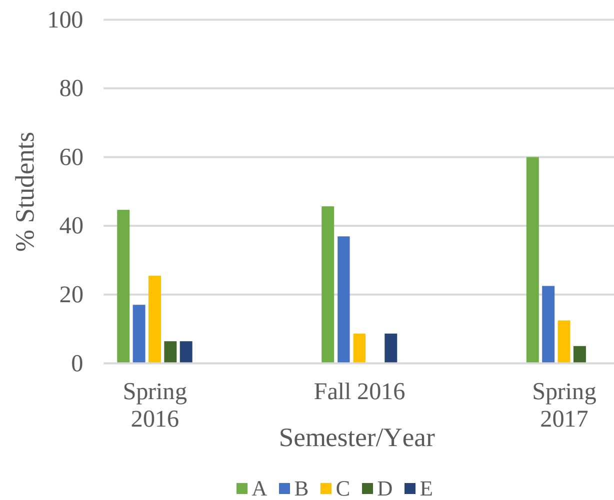


FIGURE 7
GRADE DISTRIBUTION IN SPRING 2016, FALL 2016 AND SPRING 2017

Representative student comments from the survey questions are presented in Table VII.

TABLE VII
REPRESENTATIVE STUDENT PERCEPTIONS

Question	Spring 2016	Fall 2016	Spring 2017
1	The variety of learning topics covered and applicability of the projects	It was structured to be more hands-on	The practice assignments in class increased our competency to face projects
2	There should be partial credit instead of the pass or fail grading method.	Quantity of assignments	Although lecture videos were helpful, coding could have been instructed in class
3	Rework the complicated grading policy	This is a horrible system for people who learn by reading	No specific comments on class delivery

DISCUSSION

The grade distribution from all three semesters shown in Figure 8 indicates that there is a definite increase in numbers in the high achieving students in the spring 2017 semester and <10% low-achieving students. The flipped and competency-based blended approach seems to have positively affected about 30% of the class in terms of final grades.

Comparing the grade distribution between spring 2016 and fall 2016 semesters indicates that there is no appreciable effect on the percentages of high and mid-level achieving students. However, there is a slight reduction in the amount of low achieving students in the competency-based setup of spring 2016 compared to that of fall 2016. This indicates that the competency-based learning technique is specifically helpful for the low-achieving students.

In the case of the specific CT that is a hands-on in-class quiz shown in Figure 4, no major difference was observed between the competency-based approaches adopted in spring 2016 and spring 2017. The fall 2016 traditional approach saw lower successful attempts. Since the quiz is a hands-on quiz on using a multimeter to measure circuit parameters, the flipped technique did not play a significant role in this specific course objective. However, the competency-based assessment played a major role by helping mid and low achieving students to fail in the first attempt and learn. This indicates that in course objectives that are tested by hands-on methods, the competency-based learning technique is useful to adopt.

In the case of CT Coding, which is a take-home hands-on assignment, shown in Figure 3, all students that attempted the CT demonstrated the competency successfully. In case of assignments like these, the combination of in-class PA and a competency-based approach that gives students to fail and learn improves results, specifically for mid-level achieving students.

The results from CT Process Representation, a take-home written assignment, shown in Figure 5, indicate a significant increase in the percentage of high-achieving students with a corresponding decrease in the number of mid-level achieving students. The in-class PA helped students who attempted the CT the first time. However, if there were gaps in understanding the concept, the feedback from the first attempt helped a mid-level achieving student to successfully complete the assignment in their second attempt.

An interesting observation made during the semesters that had the flipped classroom delivery was that the final grades depended solely on the number of competencies achieved. Almost 90% of the class had a grade A in both PAs and class attendance. This indicates that the flipped approach helped improve attendance and participation in class.

The motivation for students to attempt the CTs increased significantly in spring 2017 as seen in Figure 6. While the flipped traditional evaluation in fall 2016 saw a significant number of at least one non-attempted CT, the spring 2016 competency-based traditional classroom saw around 40% of at least one non-attempted CT. It is seen that the competency-based grading system motivates students to attempt assignments more than the fall 2016 assessment based on percentages. The flipped competency-based model had more success in motivation compared to the spring 2016 traditional, competency-based class. Adding the flipped component seems to have made a positive impact on the confidence of students to try the CT rather than not attempting it at all.

From Table VII, one of the significant criticisms of the competency-based model is the absence of partial credit. Some student feedback indicates preference for partial credit rather than a pass/fail model with two attempts to pass. One recommendation towards this is to reinforce the fact that a PA and two attempts with feedback are provided towards each competency. It has also been observed, at least in the initial half of the semester that explaining a CT in-class, when it is announced, along with the rubric, helps students understand the requirements of a successful competency. Another criticism of the system has been "trouble in understanding the grading system". While the system was explained in detail at the beginning of the semester and in the syllabus, it is recommended that a reminder about the system may be provided mid-semester, specifically before the start of second attempts for competency tests. This would remind students that if they have not achieved competency in one or more of the course objectives, they have a last and final attempt that can be used to demonstrate the competency. As for the flipped classroom technique, some of the students who prefer reading seemed to have a negative reaction to using a computer to watch and rewind lectures. This could be attributed to the demographics of the class in terms of age. The spring 2017 system of combining competency-based learning with the flipped approach seems to have reduced this criticism. Some topics such as coding might need in-class instruction according to a few responses, however, in general students liked the flipped delivery. Specifically the in-class practice assignments were appreciated by students.

CONCLUSION

This paper presented the implementation and results from combining a flipped classroom with a competency-based learning approach. The results indicate improved student motivation to attempt the course objectives. The method worked better for assignment-based course objectives compared to a hands-on in-class quiz. Significant impact was observed on mid-level and low achieving students leading to a higher overall class performance. Criticisms suggest that periodic reminders must be provided to students about competency-based grading. Students must be encouraged to read feedback from Practice Assignments and the first attempt of Competency Tests. Overall, the results suggest that a combination of competency-based assessment and flipped classroom is more effective in a first-year hands-on engineering design course than each of these individual styles of course delivery. It is expected that implementing the approach over several semesters would provide additional results to support the effectiveness of this approach.

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