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New Partially Flipped Electromagnetics Classroom Approach Using Conceptual Questions*

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We propose using Conceptual Questions to assess class pre-work and improve students' grasp of core concepts of the reading material, as well as facilitate problem-based learning, in electromagnetics classes of the junior year of the electrical engineering program. We also investigate the effectiveness and impact of a teaching method based on the combined use of Conceptual Questions and partially flipped classroom on students' academic performance in an electromagnetics course. Best practices in engineering education require the students to engage very intensely in the assigned pre-work, which must be meaningfully motivated and assessed. A general way to address this need is the use of Conceptual Questions, namely, multiple-choice questions that focus on understanding and mastery of core concepts in electromagnetics, while requiring no or very little calculations, in class pre-work. According to our approach, prior to each classroom meeting, students complete an online, timed quiz with a set of meticulously designed Conceptual Questions concerning the preassigned reading topics, which enables the implementation of a partially flipped classroom instruction of electromagnetics. This study discusses and evaluates such use of conceptual quizzes, with the impact on students' learning, attitude, and success, analyzed and assessed in multiple ways. Student performance on midterm and final exams and overall class scores (in a class with 83 students), including both the D/F/W and the A-level grade rates, as well as their results on the Electromagnetics Concept Inventory assessment instrument, have shown substantial improvements under the proposed method when compared to the traditional pedagogical approach of previous years. Overall, this is one of the most extensive applications of such questions in the electromagnetics area, and likely any electrical-engineering area.

Keywords: conceptual questions; conceptual understanding; pre-work assessment; online assessment system; conceptual quizzes; active learning; partially flipped classroom; engineering electromagnetics teaching/learning

1. Introduction

With 2020 fast approaching, we are still far from achieving "The Engineer of 2020" [1] vision of engineering education [2]. Despite great efforts by engineering educators to devise and implement research supported best practices of teaching and learning for the new century, the current engineering educational system is somewhat failing students as learners by not showing them the relevance of the curriculum and not teaching them more about the role of an engineer or the scope of the field [3]. Many of our students leave the engineering discipline either during their college studies or after graduation and joining the workforce.

Multiple research studies in engineering education and best practices of teaching and learning have indicated that learner-centered pedagogies such as active teaching/learning are effective and may represent a major way of turning around the above outlined state of engineering education. Indeed, active learning and the associated instruction are becoming mainstream in engineering education research and a preferred mode, or a major component, of class delivery for a good number of dedicated engineering educators as they develop, implement, and advance new modalities of instruction that more actively and directly engage students as learners in the classroom and outside it.

For example, Andrews, Leonard, Colgrove, and Kalinowski [4] note that learning difficulties often stem from the passive role played by students during lectures. They are not alone as much research has gone into showing the benefits of active learning resulting in mounting evidence in support of this methodology, for example, improvement of students' attitudes, thinking, and retention of material, per Bonwell and Eisen [5]. Berrett [6], Milman [7], Strayer [8], and Mason et al. [9] all identify the flipped (inverted) classroom as an approach that enables students to engage in active learning. In addition, Prince [10] suggests that problem-based learning is an important instructional modality of active learning.

A large amount of research has been performed on the benefits of both fully and partially flipped classrooms; however, the amount of research done when these techniques are implemented in higher level engineering education is limited. Kerr [11] completed a 2015 survey of the research on the flipped classroom in engineering education, finding 24 studies that met the survey's criteria for fully flipped classrooms. This work found that a mixed methods approach utilizing surveys as well as ana-

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lytical data were common. Within these results, the general conclusion was that students showed positive gains in problem-solving skills, conceptual understanding, and satisfaction with flipped classroom environments. Mason et al. [9] compared an inverted classroom with a traditional classroom and found that the inverted approach enabled coverage of more material while the students also performed equally or better on quizzes, tests, and design problems. Zalewski and Schneider [12] implemented a flipped classroom at the graduate level achieving results slightly better than a mastery learning approach and significantly better than a traditional classroom approach. Vidic and Clark [13] used both a partially flipped and a fully flipped approach showing significantly better results for the fully flipped classroom, but large gains were achieved in both the partial and full implementations. More research into the benefits of partially flipped classrooms would perhaps encourage more faculty to try this approach as a lower-risk transition to the more effective fully flipped classroom.

This paper proposes, discusses, and evaluates utilization of Conceptual Questions in the assessment of class pre-work to motivate preassigned reading, improve students' class participation, and strengthen their understanding and mastery of electromagnetics course concepts in the junior year of the Electrical Engineering (EE) curriculum. To enable knowledge integration with the other two courses within the technical core of the EE program in the junior year, namely, signals/systems and electronics courses (joint sessions of all three courses, discussing commonalities between the courses) [14, 15], the lecture time in the electromagnetics course has been substantially reduced, and hence an even greater need for intense, efficient, and productive engagement of students in the classroom pre-work, which has to be thoroughly designed and facilitated, and, most essentially, adequately assessed. The lead author of this paper has developed a one-of-a-kind set of Conceptual Questions in electromagnetics, to aid students' comprehension of core concepts [16]. This is an unparalleled collection of such questions in electromagnetics, and a similar collection is also not available in other Electrical and Computer Engineering (ECE) areas. This study presents an application of Conceptual Questions to encourage active learning using a partially flipped classroom and problem-based learning.

Student pre-work, prior to each classroom meeting, consists of preassigned reading and a Conceptual Questions quiz, to both evaluate and enhance students' understanding of the core concepts. This enables students' active engagement in the following class that uses problem-based instruction and learning [17], only partially relying on the completed preassigned reading by the students, and with only a partial utilization of the associated interactive discussions (partially flipped classroom). As explained by Healy [18], conceptual understanding and students' ability to work with concepts in undergraduate electromagnetics courses are often more important than deriving them formally. The online, timed quizzes are done for homework credit, to ensure completion of reading assignments, as recommended by Kerr [11].

All the pre-work questions were multiple-choice, core concept questions and an appropriate set was assigned to be completed before each of the 14 classroom meetings delivering electromagnetics learning studio modules (LSMs). This is only about a half of the total number of meetings, the rest pertaining to knowledge integration sessions, exams, and invited lectures, which is another reason why the implemented procedure is considered only partially flipped. Each LSM classroom meeting started with a brief discussion of the Conceptual Questions where the instructor and the students actively engaged in a discussion of the students' misconceptions that were identified by commonly chosen incorrect solutions. They then discussed the reasoning behind the correct answer, allowing students to address and fix their prior misconceptions. Finally, these concepts were reinforced through further questions in the post-work homework. An overview and preliminary results of this approach are presented in [19].

To the best of our knowledge, the work presented here is the first comprehensive use of conceptual-type questions to assess classroom pre-work in junior-year electromagnetics coursework, and perhaps for any ECE coursework, as well as one of the largest utilizations of questions of such kind for any purpose within instruction, learning, and assessment in electromagnetics education or in any other ECE area. Furthermore, the resulting partially flipped classroom instruction of electromagnetics features a rather unique integration of reading pre-work; conceptual thinking, analysis, and synthesis; and problem-based learning. Finally, this study contributes to the limited amount of research into partially flipped classrooms.

2. Using conceptual questions in partially flipped classroom

2.1 Method

Conceptual Questions are multiple-choice questions that focus on and evaluate understanding and mastery of core electromagnetic concepts, while requiring no or very little calculations [16]. In fact, these questions are meant and designed to assess and enforce not only the theoretical concepts but also problem-solving skills based on conceptual analysis, which are later used to perform quantitative analyses and calculations in standard computational problems [17] during class meetings and for post-work homework assignments. Generally, Conceptual Questions are also ideal for various modalities of active teaching and learning [20], for peer instruction [21], and for collaborative teaching/learning [22]. In addition, they are perfectly suited for assessments of students' performance and effectiveness of instruction, as well as the course objectives, student learning outcomes, and program educational objectives, which aligns very well with ABET [23] and similar accreditation criteria.

The partially flipped classroom included preassigned reading from [17], with pre-work assessment in the form of online interactive quizzes containing multiple-choice Conceptual Questions, for credit, administered through the learning management system Canvas, by Instructure. The online assessment system is designed to immediately give a student the total quiz score only, with full feedback on the correctness of each answer being provided later. Hence, the instructor starts each LSM classroom meeting by posing to the class each of the pre-work assessment Conceptual Questions, taking a "vote" on it, and then leading a brief discussion on the different approaches and answers. The discussion includes reflections by the students on their misconceptions and the reasoning behind them, as well as the actual solutions. This is followed by the other components of instruction. In order to strengthen further core conceptual understanding, post-work homework assignments ask the same or similar Conceptual Questions combined with computational problems that are based on the same concepts.

2.2 Implementation

In terms of the logistics and format of how the Conceptual Questions were used to assess class pre-work, a typical pre-class conceptual quiz was set up in the Canvas tool and posted by the instructor 2–3 days prior to the class in which the concepts covered in the quiz were to be discussed. The quiz had to be taken by each student individually, at any time before that class. A typical quiz had 10 Conceptual Questions worth one point each and had to be completed in a single continuous one-hour online session. The quiz could either be submitted by the student immediately after completion or it would be automatically submitted after the one-hour time limit. No repeated attempts were allowed. To take the quiz, the students needed access to any computer or mobile device compatible with the Canvas online tool.

Shown in Figs. 1 and 2 are parts of sample conceptual quizzes as the students see them. In the middle (looking horizontally) of the Canvas page are the Conceptual Questions. Below each question are radio buttons for answers. All the Conceptual Questions can be viewed on a single webpage and can therefore be accessed freely, in any order, while on that webpage. On the right is a navigation panel to quickly access any question. The answers can be changed any number of times before submitting the quiz or before the time limit is over. Once set up, the quiz was graded automatically by the Canvas tool and the total score was displayed. After the due date for the quiz submission, and after the class with the respective LSM discussion, students could also see their individual responses to each question and the correct answers. The students were reportedly comfortable with this method of taking quizzes and we did not receive any complaints or concerns regarding the same.

Both the textbook for the course [17] and the Conceptual Questions [16] were designed by the instructor for the course. This allowed for the best implementation of these questions as the instructor knew the intent and the common misconceptions addressed in each question. This also makes transitioning from the coursework, to the quiz questions, to the book work very fluid.

3. Evaluation and assessment of the new approach

3.1 Results

The partially flipped classroom utilizing Conceptual Questions for assessment of class pre-work and enhancement of engagement of students in electromagnetics LSMs was implemented in the Fall of 2016. We have performed a quantitative analysis of the new approach based on the prior student performance in the Falls of 2012 and 2013, when the same instructor taught this course traditionally (this instructor did not teach this course in 2014 and 2015).

The impact of the new approach was assessed using similar midterm exams and a final exam as in the 2012 and 2013 course offerings. Also, the overall class scores have been compared. Student scores on the midterms is a key factor of their performance in the class overall. If a student scored at least 65% or higher on any exam, this indicated a high likelihood of passing the class. Only 5% of the students who earned a 65% or higher on any exam went on to get a D or F in the class (D essentially is a failing grade for all required courses in our EE curriculum, as a course with a D must be retaken). Conversely, 27% of students who earned less than 65% on any exam went on to get a D or F in the class. Table 1 outlines student performance on midterm exams 1

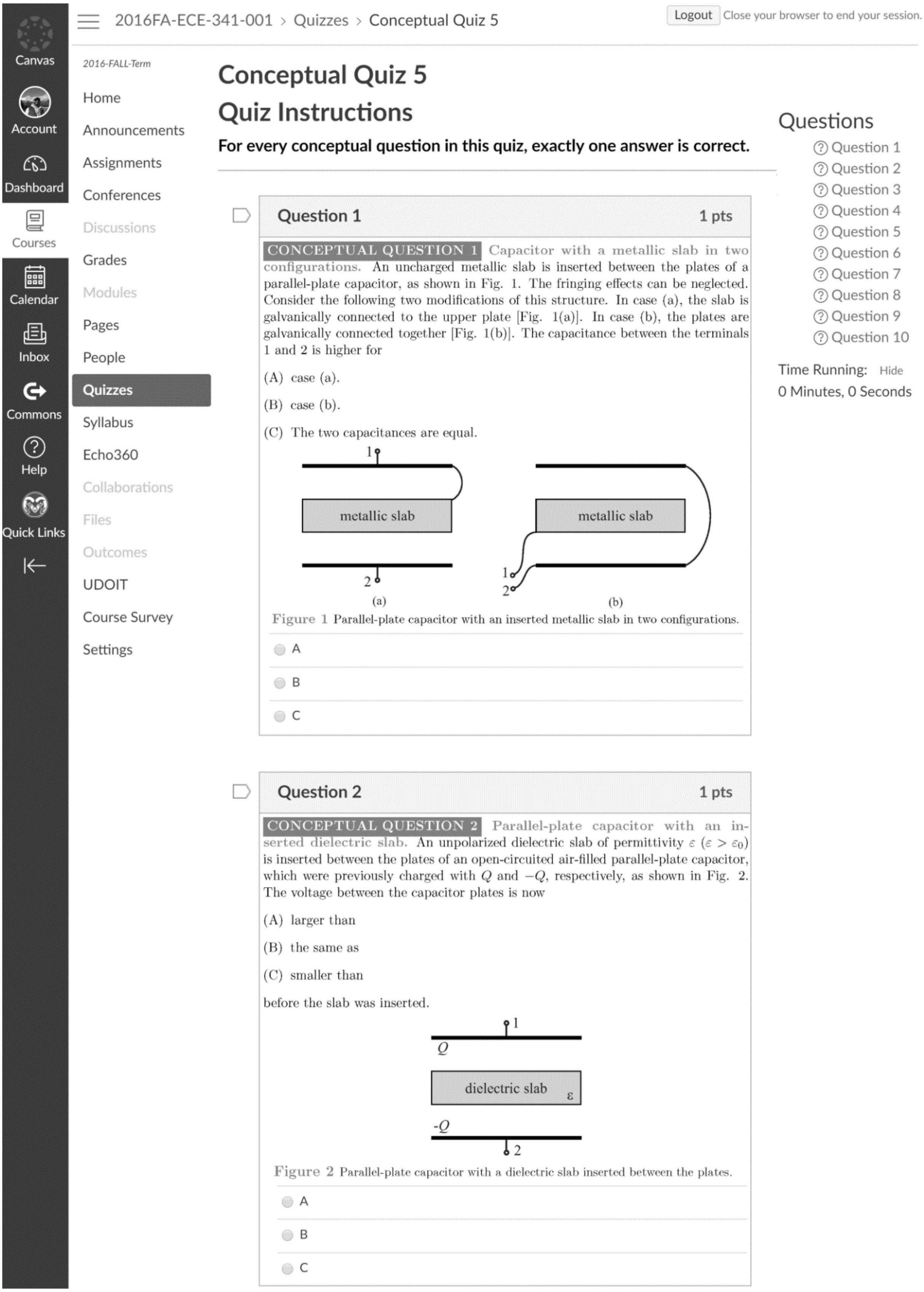

Fig. 1. Illustrative conceptual quiz in Canvas: excerpt of a quiz in electromagnetics learning studio module 2 (Electrostatic Field in Material Media) as students see it during their class pre-work.

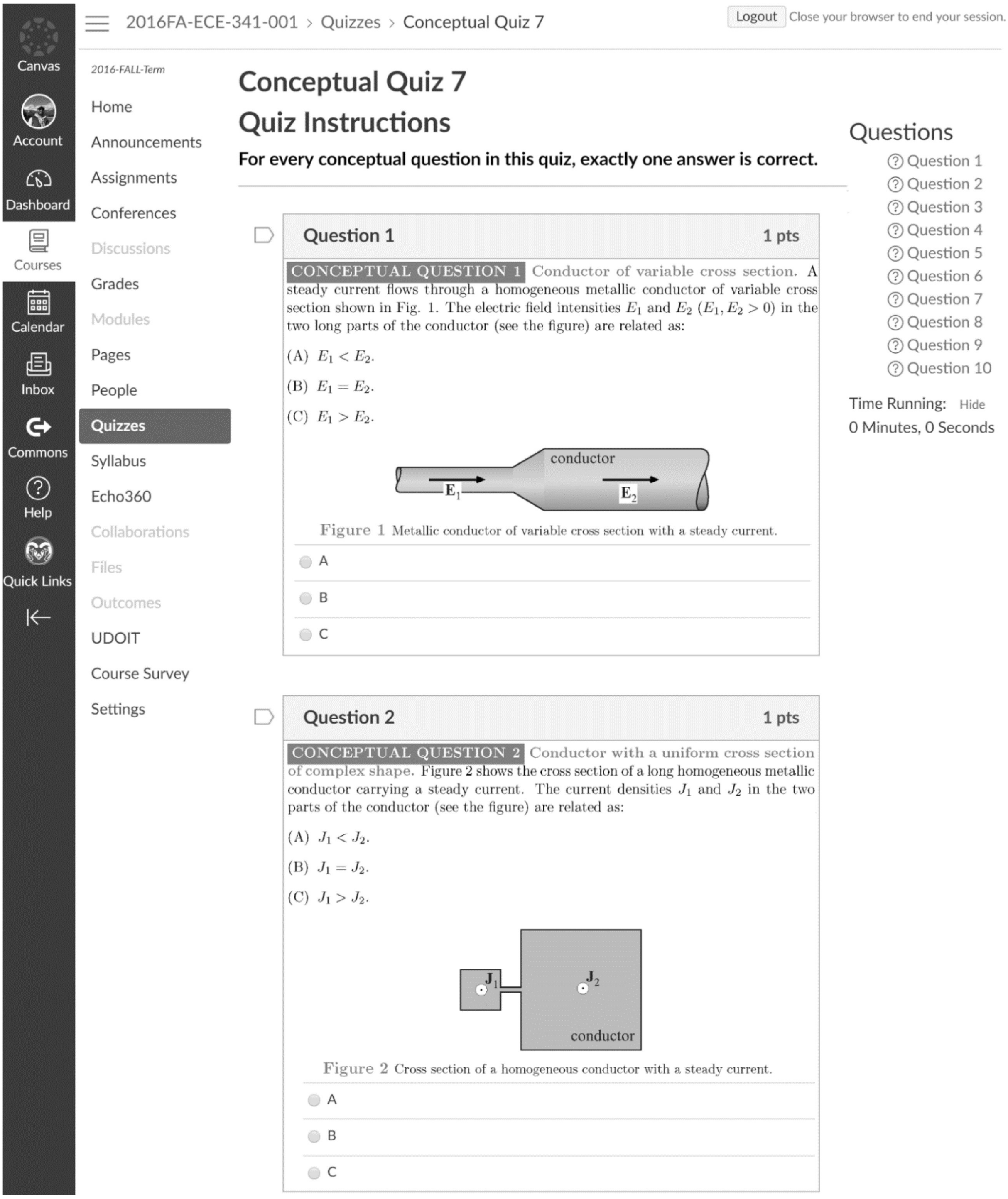

Fig. 2. Portion of another sample class pre-work conceptual quiz in Canvas as seen by students, with Conceptual Questions within electromagnetics LSM 3 (Steady Electric Currents).

and 2 and the final exam, respectively. The overall class scores serve as another assessment — they are given in Table 2.

As one more piece of assessment within the course that supports the success of this effort, Fig. 3 depicts a comparison of how well the students performed on the quizzes versus how well they performed in the class as a whole.

In addition to the overall class score data in Table 2 and Fig. 3, Table 3 shows the letter-grade distribution for the electromagnetics classes taught traditionally in 2012 and 2013 and with the new partially flipped classroom using Conceptual Questions in 2016 (all three times by the same instructor).

Given in Table 4 is additional data on general

Table 1. Summary of student performance on midterm exam 1, midterm exam 2, and final exam under the traditional pedagogy and the new partially flipped classroom using Conceptual Questions

	Student Percentage Scoring ≥ 65 on Exam		
	Traditional Classroom 2012	**Traditional Classroom 2013**	**Partially-Flipped Classroom 2016**
# of Students	41	52	83
Midterm Exam 1	51%	73%	75%
Midterm Exam 2	76%	71%	87%
Final Exam	76%	71%	82%

Table 2. Summary of overall class scores under traditional instruction and partially flipped pedagogy with Conceptual Questions

	Overall Course Scores		
	Traditional Classroom 2012	**Traditional Classroom 2013**	**Partially-Flipped Classroom 2016**
# of Students	41	52	83
Student Percentage Scoring ≥ 65 Overall	80%	83%	94%

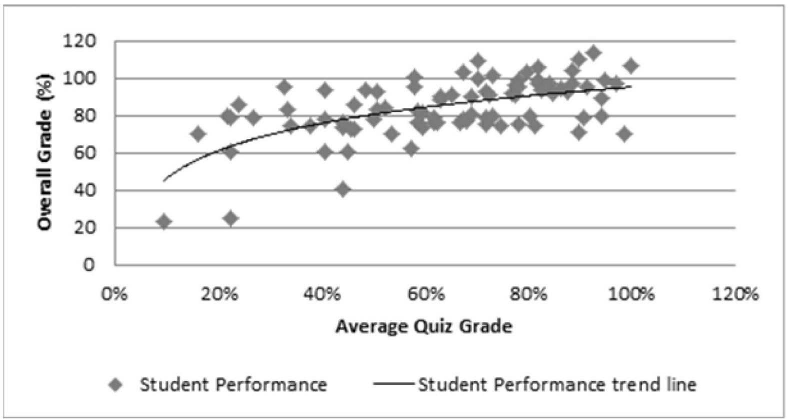

Fig. 3. Overall class percentage grades vs. average conceptual quiz grades for all students in the partially flipped classroom. Note that some students have class grades that are above 100% as a result of completion of extra credit assignments.

Table 3. Distribution of overall course letter grades for electromagnetics classes taught traditionally and with the new partially flipped classroom using Conceptual Questions

	Course Grade Distribution		
Letter Grade	**Traditional Classroom 2012**	**Traditional Classroom 2013**	**Partially-Flipped Classroom 2016**
A+	16.28%	15.22%	16.87%
A	2.33%	15.22%	14.46%
A–	6.98%	2.17%	10.84%
B+	4.65%	2.17%	2.41%
B	13.95%	4.35%	6.02%
B–	13.95%	8.70%	4.82%
C+	0.00%	6.52%	13.25%
C	16.28%	21.74%	21.69%
D	0.00%	17.39%	4.82%
F	13.95%	4.35%	3.61%
W	11.63%	2.17%	1.20%
Total	100.00%	100.00%	100.00%

academic indicators, including the average Colorado State University (CSU) term GPAs, Colorado Department of Higher Education (CCHE) index, ACT Math score, and high-school GPA, for student cohorts taking the electromagnetics course in the Fall of 2012, 2013, and 2016, respectively. This data is presented in order to compare the levels of overall academic performance of the Fall 2016 electromagnetics-class cohort to those of the Fall 2012 and Fall 2013 cohorts.

Table 4. General academic indictors for Fall 2012, Fall 2013, and Fall 2016 electromagnetics-class cohorts (courtesy of Dr. Heather Novak, Assistant Director of Institutional Research, Planning and Effectiveness, Colorado State University)

	Academic Indicators		
	Traditional Classroom 2012	**Traditional Classroom 2013**	**Partially-Flipped Classroom 2016**
CSU Term GPA (Grade Point Average) – Electromagnetics Class Term	2.47	2.67	2.79
CSU Term GPA – Fall Term Prior to Electromagnetics Class Term	3.01	2.76	3.01
CCHE (Colorado Department of Higher Education) Index (Average)	118.40	115.72	116.26
ACT (American College Testing) Math (Average)	27.75	27.62	27.83
High-School (HS) GPA (Average)	3.56	3.46	3.66
Percentage of Students with HS Academic Variables	65%	63%	63%

We also used the Electromagnetics Concept Inventory (EMCI) [24], an assessment tool for measuring students' understanding of fundamental concepts in electromagnetics—developed within the NSF Foundation Coalition project [25]. The EMCI was given to the seniors in the first week of the Fall 2016 and the Fall 2017 semesters, respectively, to measure their understanding and retention of electromagnetics concepts learned in the previous academic year. The EMCI results were used to assess any improvement in the test scores by students who took the 2016 electromagnetics class, with the new partially flipped classroom using Conceptual Questions.

3.2 Discussion

We can observe from Table 1 that the percentage of students making the 65% mark is higher with the implementation of the partially flipped classroom on both midterm exams and on the final. In addition, from Table 2, we observe a very substantial improvement in the overall course scores in the year with the new partially flipped classroom using Conceptual Questions for assessment of class prework and enhancement of student engagement in electromagnetics LSMs.

Many factors play into the relationship shown in Fig. 3, and thus this is not a very rigorous comparison. A correlation here does not necessarily indicate causation. It could simply be the case that the students who do better on quizzes have a higher aptitude in the content or motivation to do well and therefore perform better in the class as a whole. Therefore, no meaningful relationship can be derived solely from this result, but the graph given in Fig. 3 does indicate a correlation between the average concept quiz grades and the overall course grades.

As can be observed from Table 3, there is a dramatic decrease in the D/F/W (non-passing grades) rate between 2012 and 2016 (down to about 10% compared to about 25%) and an increase in the percent of the class that earns an A-level grade (A+, A or A–) (up to 42% in 2016 compared to about 33% in 2013 and 26% in 2012).

The data in Table 4 shows that the average CSU term GPAs, CCHE index, ACT Math score, and high-school GPA of the 2016 cohort are similar to those of the 2012 and 2013 cohorts, i.e., that the 2016 class, with the new partially flipped electromagnetics classroom using Conceptual Questions, was not just a "better" class overall. Specifically, the CSU term GPA calculated right after the electromagnetics class is highest in Fall 2016, which is influenced by the higher electromagnetics course grades. The term GPA for the fall semester prior to the electromagnetics class (e.g., the Fall of 2011 for the Fall 2012 electromagnetics-class students) is similar between Fall 2012 and Fall 2016. With the high-school preparation variables being only available for 63–65% of the electromagnetics-class students, the Fall 2016 cohort does have a slightly higher math ACT score and high-school GPA compared to the Fall 2012 group, but the Fall 2016 CCHE index score is slightly lower. These are all small variations that do not provide evidence for a conclusion that the Fall 2016 electromagnetics-class cohort has higher levels of overall academic performance compared to the Fall 2012 and Fall 2013 classes.

Finally, the results on the EMCI also showed great improvement. The 2017 score, i.e., for students taught electromagnetic fields with the new partially flipped classroom utilizing Conceptual Questions for assessment of class pre-work in Fall 2016, was 2.5 times higher than the score for students taught in the traditional manner.

4. Conclusions

This paper has proposed utilization of Conceptual Questions for assessment of class pre-work and enhancement of engagement of students in junior-level EE electromagnetics learning studio modules, to enable the implementation of a partially flipped classroom instruction, with the impact analyzed and assessed in multiple ways. The available results and analyses conducted show that the new approach can considerably improve students' learning and success. Specifically, student performance on midterm and final exams and overall class scores, including both the D/F/W and the A-level grade rates, as well as their results on the Electromagnetics Concept Inventory assessment instrument, have shown substantial improvements under the new partially flipped classroom approach using Conceptual Questions in comparison to the traditional pedagogical approach of previous years. In addition, although only about a half of class meetings were true learning-studio-module classes, the partially flipped classroom enabled coverage of much more material. The relevance of these observations is supported by the analysis of general academic indicators showing that the Fall 2016 electromagnetics-class cohort has similar levels of overall academic performance compared to the Fall 2012 and Fall 2013 classes.

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