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# WIP Adopting the Entrepreneurial Mindset in an Upper Level Engineering Electromagnetics Course

**Dr. Matthew Garett Young, Arkansas Tech University**

Matthew G. Young received his B. Sc. in Electrical Engineering from Arkansas Tech University in 2009. He obtained his M. Sc. in Microelectronics-Photonics at the University of Arkansas in 2012. For his M. Sc. studies, he focused on the growth of silicon nanowires via plasma-enhanced chemical vapor deposition. In August of 2016, he joined the faculty at Arkansas Tech University as an Assistant Professor of Electrical Engineering. His Ph.D. was completed at the University of Arkansas in May 2017. At Arkansas Tech University, Matthew is focused on establishing research experiences in photovoltaics for undergraduate and graduate students and investigating new methods to enhance engineering education in the classroom.

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## Introduction

This work in progress paper provides details about the current status of transforming a junior-level undergraduate engineering electromagnetics course by adding entrepreneurially minded learning (EML) activities to the course. The EML activities are primarily being integrated into the beginning of the course during which electrostatics topics are covered. The course covers more than electrostatics, but a peer-reviewed concept inventory is used to measure student knowledge gain on the electrostatics concepts. A future goal of this work is to explore what effect adding EML activities to the course has on student learning in electromagnetics. The more immediate goal with this paper is to stack EML with a guided inquiry pedagogy and share the results to receive feedback along the way to measuring student learning with EML for future study. Preliminary observational and survey data is presented that reveals some information about the student response and motivation to the new EML based activities.

## A Brief Overview of Engineering Electromagnetics Education Research

Several authors have reported the difficulty students face when studying electromagnetics including the abstraction of concepts and the trouble with vector calculus [1]-[3]. A survey conducted in 2005 of electromagnetics curricula around the world directly identified that students feel that electromagnetics is very challenging and demanding [4]. Due to the difficulty, student motivation is low which does not encourage passion for the course topic [5].

The literature shows that students need help in visualizing the abstract concepts embedded in electromagnetics and have suggested transformations involving computer software packages and numerical simulation [2],[3],[5]. Some authors have even proposed shifts in pedagogy such as a geometrical approach with measured increases in class performance [1]. Another attempt at transforming electromagnetics came from augmenting the course with a team-based project-based learning approach where it was found that student attitudes about relevance improved, but knowledge gain remained like traditional lecture topics. [6]. All these methods from the literature point to an increase in student motivation, but do not show a discernable change in knowledge gain as proven by a rigorously developed exam.

Ideally, one can apply a nationally standardized exam to measure such knowledge gain. There is some evidence of the existence of such exams within engineering disciplines [7], but the author is not aware of a widespread effort or adoption to apply these exams in modern engineering classrooms. However, the physics education community has maintained an effort to provide for best practices in teaching and assessment of learning via Physport [8]. Perhaps one of the most widely cited and used concept inventories is the Force Concept Inventory which measures student understanding of basic Newtonian physics [9].

An electromagnetics concept inventory, the Colorado Upper Division Electrostatics Diagnostic – Coupled Multiple Response (CUE-CMR) [10] was applied to the electrostatics portion of this upper-level engineering electromagnetics course at a public regional university. The CUE-CMR tests student understanding of electrostatics concepts and is not meant to gauge understanding of all the topics covered in an engineering electromagnetics course. The CUE-CMR has been applied at this university since the Spring 2018 semester, where a transformation of the course to an active learning environment was initiated [11].

## Entrepreneurially Minded Learning and Electromagnetics Education

EML is not to be confused with entrepreneurship or even activities that are purely entrepreneurial in nature. EML broadens entrepreneurship education by incorporating a focus on mindset and skillset while attempting to measure the knowledge of students, how students think, skills, and attitudes toward learning [12]. An entrepreneurial activity requires pairing a specific technical skillset with business acumen to create a new venture and put it into practice. The act of creating a new business is the byproduct of many personal attributes possessed by entrepreneurs that any engineering student should have. EML is a teaching method that seeks to reform students' skillsets and mindsets by stacking various pedagogies together to obtain learning outcomes that typify the way entrepreneurs think [13]. A way that EML can be incorporated into a course is by the Kern Entrepreneurial Education Network (KEEN) framework which promotes the "3 Cs" Curiosity, Connections, and Creating Value [14]. This framework provides a set of learning outcomes that can be designed into a single short duration lesson within one class period, or even be extended to a whole sequence of courses and still yet could seek to reform an entire degree. It is not required to have all outcomes in each activity. Further, there is a much broader set of student outcomes ranging from *applying* creative thinking to *contributing* to society as an active citizen that can be incorporated into educational lessons with a longer list found at [15].

There have been several proposals and course transformations aimed at increasing student motivation and understanding of electromagnetic theory, but little to none found that attempt to do so with EML. Searching the literature, it was difficult to find evidence where individuals have directly used EML in an upper-level (senior or junior) undergraduate electromagnetics course. Evidence does exist of a first day course activity that aims to target EML learning outcomes of curiosity and connections [16]. This lack of literature that specifically combines EML with engineering electromagnetics provides the need for the work-in-progress that is pursued with the current study.

## Overview of Previous Semesters and Changes to the Current Semester

The reformation of a junior-level engineering electromagnetics course began in the Spring of 2018. In the Spring 2018 semester, a guided-inquiry approach was used in class in place of traditional lecture. A guided-inquiry format exchanges the traditional whiteboard lecture for a student centered and student led learning experience. Students work in small groups during the class period and are provided a tutorial package on the course topic that would typically be lectured on. The inspiration for this method came from a colleague at the current institution who was aware of the well-established education methods and research of teaching physics electromagnetism at CU Boulder. The tutorials used in the current engineering electromagnetics course are adapted versions of those created by CU Boulder [17].

With the guided-inquiry learning pedagogy, students are ideally required to complete a sequence involving a pre-lecture activity, the course lecture, and then a post-lecture activity. The pre-lecture activities always involve at least a video of the core concepts of the topic being discussed in class. An effort was always put in place to make sure the pre-lecture activity also featured some sort of active-learning component, for instance use of PhET simulations from CU Boulder [18]. Students were required to complete the activity followed by a short multiple-choice quiz that was given online. Once the students earned a 100% on the quiz, then a video would appear. The videos were designed to teach the core mathematical concepts of a topic. Sometimes, tutorials only featured a quiz followed by the release of a video.

When students came to class they were asked to arrange themselves into teams. Students were provided time to log into an open response system and were typically asked a few conceptual questions before the tutorials began. The questions thereafter were asked only as the student teams completed sections of their tutorial. In the Spring 2018 semester, this same process was followed but a think-pair-share style of questioning was used. The students would be asked to answer questions individually, and then team up to discuss and then answer the questions again. In Spring 2019, the method was adapted to just have the students work in teams to solve the tutorial problems and answer conceptual questions individually. If any widespread disagreement is found via the open-responses, a class-wide discussion was held to discuss the concepts. This method was found to allow for more time during the lecture period for the students to complete the tutorials. This method is also used in the current, Spring 2020 semester.

Tutorials were adapted from CU-Boulder [17] and are authored in a style to break down the application of electromagnetic laws as a step by step process, until students reach a solution. They are also asked to practice conceptual understanding and intuition by exploring the meaning of their solutions. While students work on the tutorial, the instructor can use a live open response system to measure how well the class is understanding the content. Where needed, the instructor helps an individual team or else spends time working problems on a white board to help facilitate a starting point, especially when the mathematics maybe a bit tricky to apply.

Following the in-class tutorials, students are asked to complete post-lecture activities. These activities sometimes mirrored what was done in class by extending the thinking to other problems. For example, one of the first tutorials on Coulomb's Law makes students derive an equation for electric field at a point above a ring charged with a linear charge density. The post-lecture activity extends this by requiring the students to apply superposition to use their solution from the tutorial to obtain the electric field due to a charged disc (the disc can be viewed as a superposition of rings).

The number of students enrolled in the course has declined from the original number of 42 in Spring 2018, to 37 in Spring 2019, down to just 28 students for Spring 2020. The reason for the decline was not readily apparent. The number of students in the current semester is close to 25 which was originally proposed as the ideal number of students for the class [11]. A classroom of 25 students would feature anywhere between 6-8 student teams, which is an appropriate number for an instructor to cover with adequate attention paid to each team over an 80-minute lecture period. There was no teaching assistant support for the instructor to help carry out the class materials during the class period.

Between Spring 2018 and Spring 2019 there were no major differences between the grading categories for the class. Class grades were composed of in-class exams, in-class participation (completion of tutorials working as a team), in-class quizzes, and typically either a larger problem or project. The project is introduced later when transmission line theory is covered in the course and does not involve the electrostatics content. This same grading scheme also exists in the current semester, but with the addition of reading quizzes. The quizzes were given online and made available on weekends. This was implemented to encourage students to spend time reading the material in their textbook. Surprisingly, students have responded well to the implementation of the reading quizzes.

In Spring 2018 the course lectures were held on Mondays, Wednesdays, and Fridays for 50 minutes each beginning at 8 AM. The students from that semester rallied on their end of course evaluations that the lecture time was simply not long enough and that 8 AM electromagnetics was torture. In Spring 2019, the course was moved to a Tuesday and Thursday schedule with 80 minutes of lecture time and a 2:30 PM start time. Students are more comfortable with such a schedule. The current semester features a 2:30 PM start time with 80 minute lectures on Tuesdays and Thursdays. Even with an 80 minute lecture, students sometimes still do not finish the tutorials. In this case, students can take the material home to finish.

**Modification of Course in Spring 2020 for Entrepreneurial Mindset**

Because the tutorials already have a well-developed core around applying mathematics and physics to solve the electromagnetics problems, it was decided it would be best to alter the pre-lecture and post-lecture activities by incorporating EML activities. The first two tutorials in Spring 2020 were not modified. The intent of not modifying the tutorials was to give the students a baseline so that they had a comparison between the modified activities and the original tutorial activities. In addition, the tutorials are a different type of learning method that students may not be familiar with and so students must be given time to adjust. Three different EML based activities were added to the course in Spring 2020. The first activity was tied into the post-lecture activity on the topic of Electric Scalar Potential, which is the third topic typically covered in the course. The next lecture covers Conductors and Capacitance, where a modified pre-lecture activity was utilized called Business Card Bash. The post-lecture activity of the Conductors and Capacitance lecture was modified to make students reconsider a familiar electrical system with infinite conductance.

Table 1 shows the EML activities that were used during the electrostatics portion of the electromagnetics course along with the EML outcomes the activities covered. For the “Modifying a favorite game or sport” activity, students were initially asked to form teams at the beginning of the lecture. The student teams then brainstormed lists of their favorite recreational activities. This was followed by a 2-minute period where the student teams were asked to choose one item from their lists. Several students seemed interested in the purpose of generating a list

Table 1. Listing of the various EML activities there were implemented in the electrostatics portion of the course along with their connection to the 3Cs.

| **EML Activity** | **The 3C's** |
|---|---|
| Modifying a favorite game or sport | • Curiosity<br>• Connections |
| Business Card Bash | • Connections |
| A World With Infinite Conductance | • Curiosity<br>• Connections |

but were not instructed as to what it would be used for. The class then proceeded to complete the tutorial, which had no modifications to it. At the end of the lecture, the various teams were asked to consider the recreational activity they chose and to re-think and modify it by applying electrostatic principles. The students were asked to then provide an example solution to the problem they created. This problem-based team activity was a means to get students reconsider an accepted solution as well as to connect something they were familiar with to electromagnetic theory, thus embracing the idea behind the Curiosity and Connections learning outcomes of the KEEN framework. The activity provided them with a set of ambiguous instructions and no other guidance besides applying electrostatic principles to something familiar to them. The outcomes of this were interesting. For instance, one student team applied the concept of electric charge, the electric field, and electric scalar potential to a field goal kick from American football. The football was given a specified charge and the student team imagined that the goal posts were also charged, thus changing the physics of the game. The student team posed this as a typical textbook problem complete with the applied electromagnetics concepts and solution.

“Business Card Bash” required students to create business cards, but instead of just having their personal credentials on the card, they were required to design the card and teach a concept about conductors or capacitance. Before the lecture began, they were required to trade the cards with another student and then provide an elevator pitch on the educational concept and how it was applied. While this was not taking the technical information and placing it in a new context, it was an attempt to get students to think outside the box in terms of how they could learn the material. As such, it coaxed students into considering perspectives beyond their own and had them integrate information from different sources which is a key aspect to the Connections outcome of the KEEN framework.

“A World with Infinite Conductance” was a post lecture problem-based learning activity designed to get the students to apply the concept of conductors to something familiar with them. This activity asked the students to consider any familiar electrical system, and then reconsider the system if it had infinite conductance. Students were required to estimate the cost savings that would be obtained if finite conductance was not an issue. This activity was an attempt to require students to take an electrical system they were familiar with and the reconsider the opportunities that might become available without the constraint of finite conductance. This consideration made students use information from different sources in order to provide a solution to the problem.

**Preliminary Findings**

It is routine in the course that feedback is gathered from the students using the open response system to provide improvements to the course in near real time. A survey of 5 questions was generated to collect information about the student perception of the EML activities in relation to other standard activities in the course. The 5 questions that were asked are shown in Table 2. The students could respond on a 5-point Likert item where the ends point of the ratings were defined. In addition to the survey questions, students were also given the option of providing written or text-based feedback about the EML activities. The data that is presented here is from the survey provided to the students and professor observations from the written feedback coupled with classroom observation.

Table 2 provides the questions that students were asked on the survey. The “Question Number” in column 1, Q1-Q5, refer to the bar plots that are shown in Figure 1 and identify each question. The “Question Text” in column 2 are the questions that appeared on the survey. Students were not required to answer these questions during class time, rather, the survey questions were assigned after class time. As an incentive for survey completion, 1 quiz bonus point was offered as reward for completion of all survey items. A quiz point is equal to 0.07% of the overall final

Table 2. Questions that students were asked during an in-class survey to gather feedback about the EML activities.

| Question Number | Question Text |
|---|---|
| Q1 | On a scale of 1-5 (5 being the most enjoyable, 1 being the least), how well did you enjoy the business card bash pre-lecture activity compared to just watching a video and taking a quiz? |
| Q2 | Do you feel that the business card bash activity helped you to better learn the material? (5 means yes absolutely, 1 means no, not at all.) |
| Q3 | Did the post-lecture activity #3 (where you modified a game) further motivate you to want to study electromagnetics? (5 is yes, it motivated me to want to learn more, 1 is no way, ). |
| Q4 | Do you feel that either the Business Card Bash activity or else the Game Modification activity made you feel as though you learned the material better? In other words, did these activities help you learn the material as compared to working a problem or sets of problems as you did with Tutorials 1 and 2? (5 is yes, they did help me learn, 1 is no the activities did not help me learn). |
| Q5 | I wish that I saw more problems being worked instead of the tutorials or non-problem-based activities. (5 = yes, absolutely. 1 = not at all, ). |

course grade. An additional incentive was that for completing the EML activity, a given student team would be allowed to roll a die and earn an extra number of quiz points equal to the face value of the die roll.

Figure 1 provides several plots that show the responses to the questions given in Table 2. Each bar plot represents the responses to each question, Q1-Q5. The vertical axis and height of bars indicates the number of responses that were given for a rating. For instance, the bar plot in the

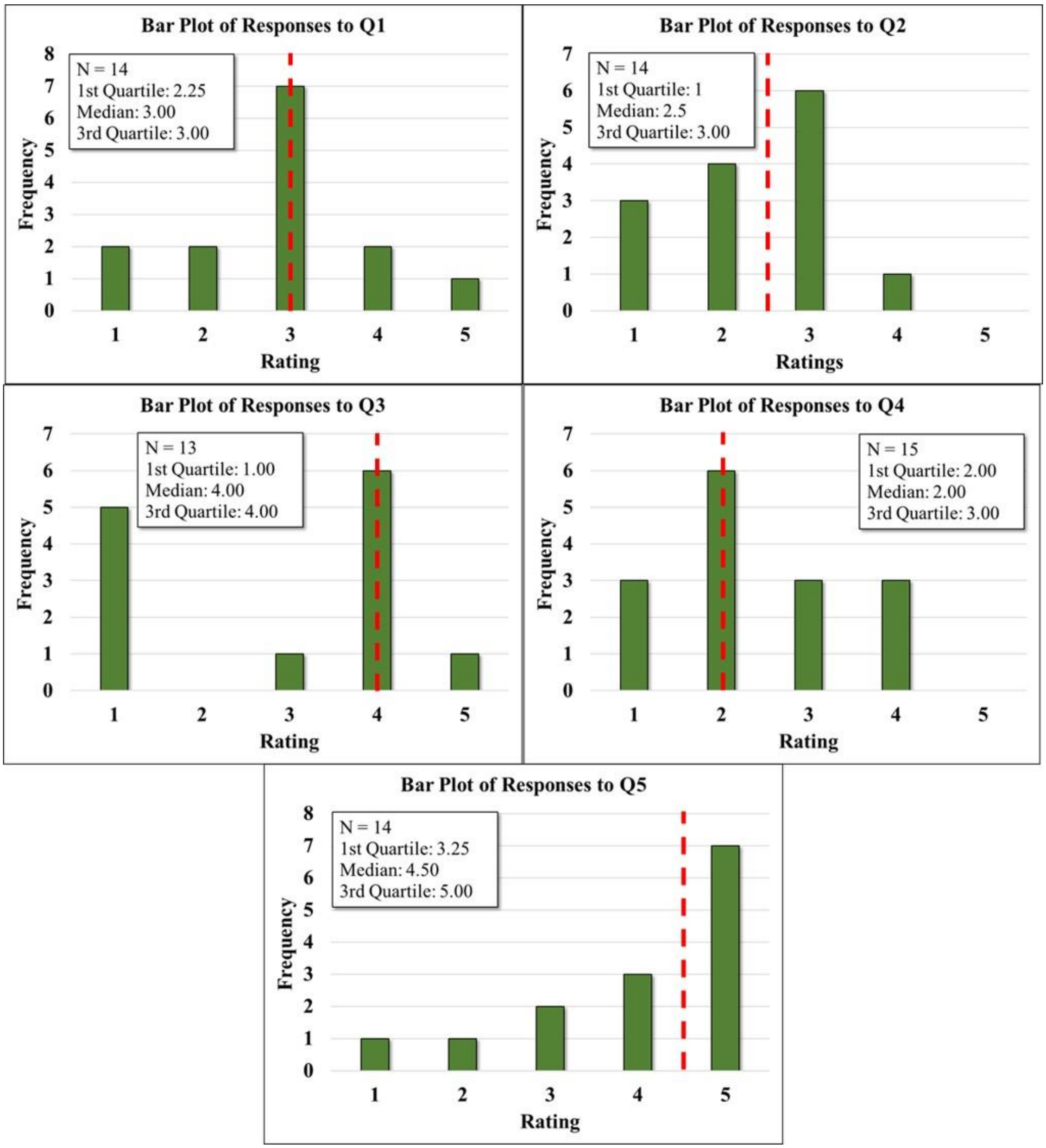


Figure 1. Bar plots showing student responses to survey questions (Table 3). Insets in each plot provide summary statistics for the bar plot. The vertical dashed lines visually indicate the median of each plot.

upper left of Figure 1 provides the responses to Q1. The number of students giving a “1” rating is 2. Within each plot is a small inset window that provides the summary statistics for each plot. The summary statistics provide the number of respondents, N, the first quartile, the median, and the third quartile of each set of responses to each question. The first quartile and third quartile represent the values below which 25% and 75% of the ratings fall and provide a means to interpret the variability of the data. The vertical dashed line in each plot provides a visual marker for the median of each data set.

The ratings are assumed to be ordinal data. The ratings have a distinct ordering; however, it is impossible to know how each respondent assumed the distance would be between the minimum and maximum rating. Because of the ordinal data type, the median for each question is examined instead of the mean. The responses to Q1 shows smaller variation given that the median and third quartile are both 3.00 and that majority of students responded with a rating of 3 or higher. This suggests that most of the responding students felt that the Business Card Bash activity was generally more enjoyable than a standard activity such as watching a video or quiz. Even though the students appeared to enjoy the activity, more of the respondents felt that it did not necessarily help them learn the material better. Q3 was regarding the “Modifying a Favorite Game or Sport Activity” (Table 2) and the data indicates a split in the respondents. Just over 50% of the 13 students that responded indicated that the activity motivated them to want to study the course material more, whereas about 38% responded that the activity did not motivate them to further study the material. The analysis for Q4 shows that the bulk of respondents felt that the activities were not helpful in learning the material. Overwhelmingly students responded that they wanted more solved problems worked in class in Q5, while just a few indicated that they did not necessarily want more solved problems. Obviously, the ability to solve problems improves the chances that the students will earn a higher course grade and thus motivates their desire for seeing more solved problems.

The survey data could be a weak representation of the overall class opinions. Only between 13 and 15 of the 28 students in the course took the time to provide meaningful feedback by responding to the survey. Even more interesting, is that students did not answer the survey questions consistently, with the number of respondents being either 13, 14, or 15 depending on the survey question. Nonetheless, there is still some value in understanding even how a sub-population of the student body in the course answered the questions.

The open response feedback coupled with in-class professor observations was positive with some saying they enjoyed the creativity behind the assignments, but there was an overall theme that not enough solved problem demonstrations were being shown during class time. In place of solved problems, the tutorials feature a structure where students are guided through the application of relevant laws to solve a problem. The tutorials are designed to build problem solving capacity by allowing students to step through the thought process when applying a solution method. Though it was not explicitly measured, the students seemed to lack a confidence in applying the problem solutions. This is even though many student solutions to exercise problems are available on the textbook website that was shown to students at the beginning of the semester. In addition, a live link was posted to the learning management system to the exercise solutions website. Still yet, students desire to see more live problem solutions. This feedback will be used to alter the class by incorporating some traditional lecture time where the instructor solves problems on the board.

The CUE-CMR pre-test was given to the students on the first day of class in the Spring 2020 semester. In Spring 2018 using a guided-inquiry pedagogy coupled with an open-response question system, the class showed a knowledge gain of 0.118. Spring 2019 showed a slightly higher knowledge gain of 0.164. The main differences between Spring 2019 and Spring 2018 were a longer lecture period offered during a different time of day, as well as a change in the open-response system. In addition, the instructor was more experienced with the applied pedagogy.

**Conclusions**

A guided-inquiry learning method is coupled to an in-class open response system with added EML activities to attempt to increase knowledge gain and motivation in a junior-level engineering electromagnetics course. This pedagogy has shown an increase in student knowledge gain since its first application to the course. New to Spring 2020, is the addition of extra EML activities that were applied as pre-lecture and post-lecture assignments. Some preliminary class feedback in Spring 2020 does indicate there might be some increase in student motivation to study the course material due to EML activities.

An ensemble of modifications to the course make it hard to track which individual modifications have the greatest impact in terms of knowledge gain. These include a longer lecture time, lecture during a different time of day, EML activities, mixing traditional lectures into the course, and implementation of reading quizzes, amongst others. The changes between the Spring 2018 and Spring 2019 semesters suggest that a longer lecture time, the time of day the lecture is offered, and the switch to a different open response system might have all contributed to an increase in knowledge gain. In addition, the instructor was more experienced with the implementation of the pedagogy.

EML activities are going to continue to be drafted, improved, and implemented into other sections of the course. This includes topics such as transmission line theory, magneto-statics, time-varying fields, plane-wave propagation, and wave reflection and transmission. The author is not aware of a concept inventory that can be applied to measure knowledge gain in the areas relevant to engineering electromagnetics. The CUE-CMR does facilitate the measuring of knowledge gain in terms of conceptual electrostatics understanding. The plan is to continue to offer the CUE-CMR in subsequent semesters to assess student understanding of electrostatics content.

Future work will involve attempting to have the course split into two sections, one taught with a baseline guided-inquiry pedagogy, and the other taught with the guided-inquiry pedagogy but with EML added in order to measure if any knowledge gain occurs due to EML specifically.

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