Work in Progress: Implementation of Electrostatics Tutorials Utilizing an Electronic Response System in Upper Level Electromagnetics

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WIP: Implementation of Electrostatics Tutorials Utilizing an Electronic Response System

Introduction

Research has shown that an active learning environment implemented in an electromagnetics classroom can yield improved results in student outcomes: increased scores on Fundamentals of Engineering exams, increased conceptual understanding, and reduced failure rates [1], [2]. Research also suggests that an active learning classroom can mitigate the intimidation experienced by junior-level engineers when encountering electromagnetics material. This preliminary study focuses on electrostatics content in a junior level electromagnetism course in an Electrical Engineering (EE) program. Students find electromagnetism to be one of the most difficult courses in the upper-level EE curriculum. Electromagnetics is difficult for students to learn due to the required competency with vector calculus. Topics are especially challenging to teach without tangible applications [3].

The authors created an active learning environment within a junior-level Electromagnetics course by utilizing in-class tutorials with an electronic response system. The intent was to increase student's ability and confidence in performing vector calculus required to solve electromagnetics problems and, in the process, increase conceptual understanding of electromagnetism.

In-class materials for this study were derived from resources available through PhysPort, a resource provided by the American Association of Physics Teachers created to support physics faculty that are implementing research-based teaching methods [4]. While PhysPort is designed for Physics faculty and the content is physics specific, much of the content can be adapted to fit the requirements of engineering courses.

Student learning was assessed utilizing the Colorado Upper-division Electrostatics Coupled Multiple-Response (CUE-CMR) diagnostic test, administered before and after the electrostatics content of the course was presented [5]. The demonstrated 0.12 gain in knowledge, as measured by the Hake score [6], was less than anticipated. A gain of 0.2 is a small effect, whereas a gain of 0.5 or 0.8 is a medium or big effect, respectively [7]. Several factors that were unavoidable at the time of the study may have influenced these results. This study illuminated promising technology and active learning elements for future initiatives to enhance student learning and outcomes.

Tutorial Content

The electrostatics content of the course was delivered in a modified flipped-classroom format. Pre-lecture videos conveyed content and introductory material for the tutorials, and the tutorials provided a framework for deeper in-class thinking and discussion. Five class periods were dedicated to covering five of the course's more conceptually or mathematically difficult topics with tutorials. Table 1 gives the electrostatics topics covered in class, the topics delivered via tutorials, and those presented in pre-lecture learning activities.

Topic	**Pre-lecture**	**Tutorial**
Coulomb's Law	#1	#1
Charge density	#1	
Electric field lines	#1	
Gauss's Law	#2	#2
Electric potential	#3	#3
Properties of conductors	#4	#4
Dielectrics	#4	
Boundary conditions		#5
Method of images	#5	
Maxwell's Equations		#5

Table 1: List of topics covered and corresponding pre-lecture or tutorial in which content was presented. Numbers represent the order in which content was covered.

The tutorials created for this study were adapted with permission from the Upper-Division Electrostatics Transformed Course Materials, University of Colorado (CU), Boulder [8]. The authors of this paper were made aware of the CU materials through PhysPort [4]. The primary reason for re-writing the CU tutorials was to implement a guided-inquiry approach.

Another reason for adaptation of CU tutorials was the use of a different textbook. The CU tutorials were developed for Griffith's *Electrodynamics*; whereas, the text used in the Electromagnetics course under study was Ulaby and Ravaioli, 7th edition, *Fundamentals of Applied Electromagnetics*. One particularly challenging aspect of mastering electromagnetics concepts is that book authors often use different notation. The tutorials were carefully adapted to be consistent with the textbook used in the course.

Classroom and response system

The classroom was a standard lecture classroom featuring a series of narrow rectangular tables for students and a lectern with computer controls at the front. Each table could seat a maximum of 4 students. Unfortunately, the tables were not conducive to group work on the tutorials.

The electronic response system, Kahoot! [9], was used to gauge students' understanding at checkpoints with multiple choice questions. A single instructor directed the 40+ student's attention on specific tutorial questions that address typical misconceptions or mathematics students find difficult. The electronic response system was effective in keeping the class on task and moving forward at a reasonable rate. Kahoot! was selected due to student familiarity and ease of installation on a mobile smart device. In addition, Kahoot! automatically generates data after each session that reveals how each student answered questions and facilitates analysis of student responses.

Pre-lecture activities and in-class work

Prior to attending class, students were required to watch a video and take a short quiz. However, students were sometimes requested to complete an additional pre-class activity. For example, the "*Charges and Fields*" PHeT interactive simulation from the University of Colorado-Boulder [10] enabled students to "discover" Coulomb's Law by measuring the field around a positive point charge. This pre-class activity effectively promoted conceptual understanding and active student engagement.

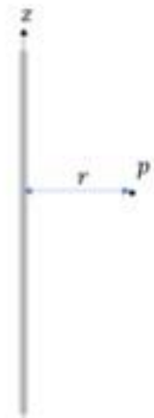
Tutorials were implemented by providing a copy for each student in the class. Students were encouraged to work together through each section of the tutorial. As an example, a section of the Gauss' Law tutorial is shown in Figure 1. The first question required students to use intuition to determine the direction of the electric field for the given line charge density. Next, they were asked to draw a Gaussian surface that would enclose the given charge and to calculate the electric field at a point "p." This step-by-step process continues until the students have fully formed Gauss' Law and assigned information to each of the variables in the law: differential surface element, charge enclosed, limits of integration, etc. These detailed, step-by-step tutorials adapted from the CU Boulder materials were found to be more effective.

Figure 2 is a screenshot of a question presented in class. Most students could not finish sections of the tutorial within the time constraints, so questions were often asked with limited student particpiation as is shown in Figure 3. In the initial delivery of this particular question only 20/47 students demonstrated the ability to answer while only 4/20 provided the correct answer.

In this instance, re-asking the question after an open class discussion was effective. The results of this approach revealed 41 students answered the re-asked question with 24 correct responses, as shown in Figure 3. Re-asking specific questions encouraged discussion for better student understanding. In addition, the ability to discover student reasoning for question answers provided valuable insight for correcting misconceptions. A traditional lecture format rarely provides the insight of an active learning environment with class discussion. Several students stated that they inadvertently selected the incorrect answer on their mobile device. Though not formally polled, some students revealed they enjoyed the class discussion and that it aided their understanding of course material.

The total class time allotted for each tutorial was 50 minutes, which included a few minutes for students to log-in to Kahoot! As previously noted, students were timed on specific sections of some tutorials, so that more of the tutorial material could be covered in class. Following each tutorial, students were assigned homework problems directly related to tutorial content.

i) The figure below shows the uniformly charged "beam line." Based upon your knowledge about the direction of electric fields, what must be the direction of the electric field at all points in space for this line charge?



Uniform line charge ρ_ℓ

ii) Is it possible to draw a Gaussian surface around this line charge that passes through point p, a distance r from the line of charge such that the electric field will be normal to the Gaussian surface? Sketch the Gaussian surface on the figure above.

iii) On the figure from part ii, draw a single vector representing the direction of the electric field at p.

iv) Draw a single vector at p indicating the direction of the *normal* to the surface you drew in ii (draw the normal vector at point p). [recall $d\boldsymbol{s}$ is in the direction of this normal vector].

v) Write down the differential surface area $d\boldsymbol{s}$. *[Hint: see table 3.1 "summary of vector relations"]*

vi) Let us say that the height of the Gaussian surface is h, what is the total charge Q_{enc} enclosed by the cylinder in terms of ρ_ℓ? $\left[Q = \int \rho_\ell d\ell\right]$

vii) Use the information you found in parts i, iv, and vi to write an integral expression for Gauss' law.

viii) Evaluate the integral in part vii and solve for the electric field, $\boldsymbol{D}$. Congratulations, you just found the *electric field outside of an infinitely long line of uniform charge*!

Figure 1: Excerpt of modified Gauss' Law tutorial given to the students in class. Tutorial was adapted from original material sourced from [8].

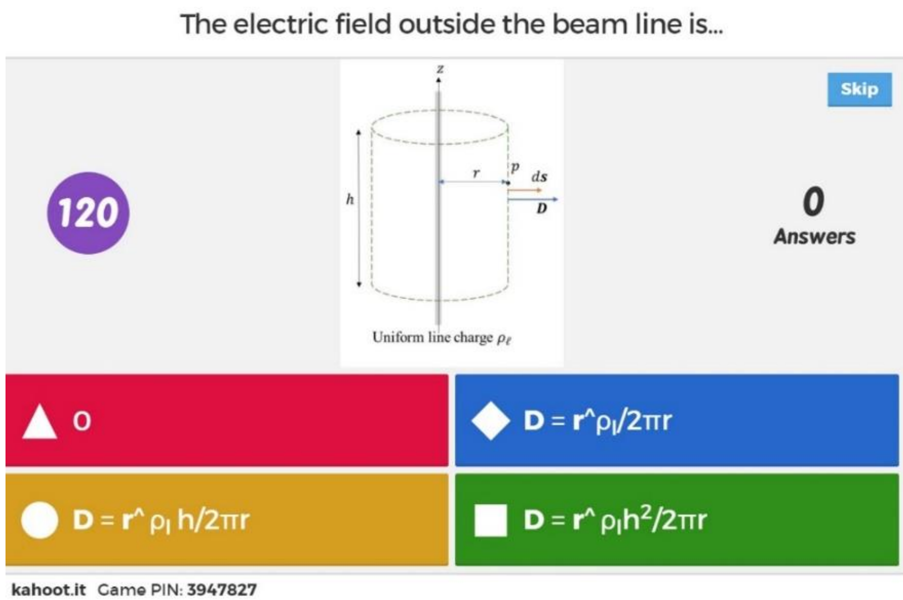


Figure 2: Student's view of Kahoot on the overhead projector.

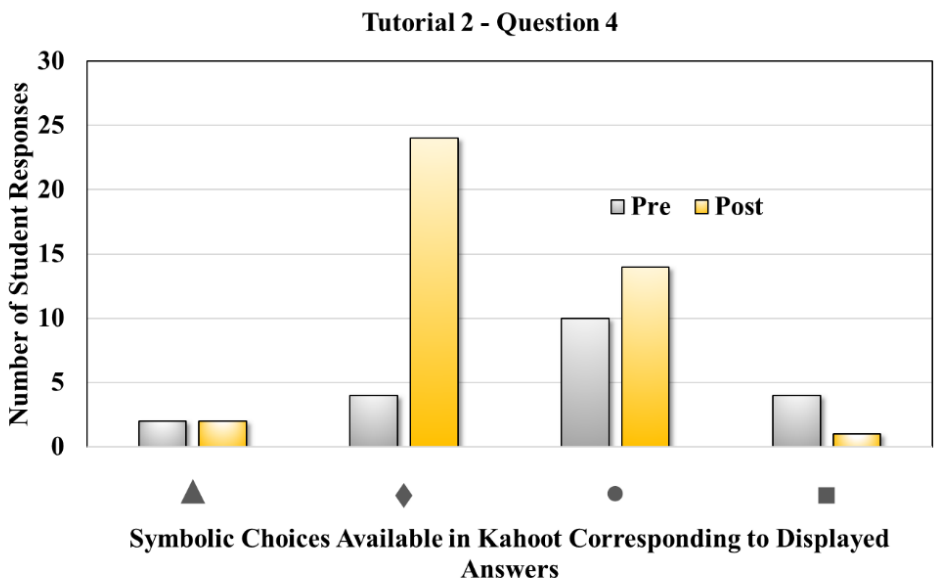


Figure 3: Results of students' response to sample Kahoot! question. "Pre" is the students' responses before entire class discussion, and "Post" is student response after class discussion. The correct answer is the ◊ response.

Preliminary results

This course is offered once each year with one section; therefore, a controlled experiment was not possible. Additionally, this on-going research focuses on a fraction of the material covered in class. At the time of this writing, the course was not yet completed, so a direct comparison of final scores or overall grades from previous semesters was not possible. To perform a qualitative analysis, the Colorado Upper-Division Electrostatics (CUE) coupled multiple-response (CMR) diagnostic test was given. The CUE-CMR is a test designed at the University of Colorado, Boulder, as a conceptual assessment in their upper-division electrostatics course for physics majors [5], [11]. However, most of the content areas of the CUE-CMR match the areas of the electrostatics module of the Electrical Engineering curriculum.

The results for the CMR-CUE are given in Table 2. The pretest was seven questions and the posttest was 16 questions. To assess the gain in knowledge, 7 of the questions on the posttest corresponded to 7 similar questions on the pretest. The results of the pretest and the 7 corresponding posttest questions is given in column a. The average normalized gain was calculated using

$$\overline{gain} = \frac{<pre-post>}{<100-pre>},$$

where *pre* and *post* are the scores (out of 100) on the pretest and post-test. The normalized gain is the “amount students learned divided by the amount students could learn” [6]. Table 2 column b gives the average score for the full post-test. Three topics were covered in the posttest that were not covered in the electrostatics material of this course: separation of variables, method of images, and Ampere’s law. The average posttest score with those three questions removed was 22%. Results for students at University of Colorado (CU) at Boulder, previously published by Wilcox and Pollock [5], [11], is given in columns d and e for the pre and posttest, respectively.

	a	b	c	d	e
	7 Questions	16 Questions Full	16 Questions (3 removed)	CU Results 7	CU Results 16
Pre-test	16.8%	-	-	30.9%	-
Post-test	26.0%	17.8%	22.0%	--	54.3%
Normalized gain	0.12	-	-	-	-

Table 2: Colorado upper-division electrostatics diagnostic results from this study (a-c) and results previously published from the University of Colorado, Boulder (d-e) [5], [11].

When comparing the results of the CUE-CMR of this cohort to those reported for CU students, it is worth noting several substantial differences between the courses and students being assessed. The first difference is the course at CU is a semester-long course dedicated to electrostatics content [8]. Whereas, this course can dedicate only two weeks to electrostatics content. It is also worth noting the relative preparation of students in this course versus the CU students. The differences in the relative preparation of the two groups is illuminated in Table 2, with CU pretest scores of 30.9% compared to this cohort’s 16.8%. Comparison of the CU Physics degree plan with this university’s Electrical Engineering degree plan reveals CU students have greater experience with electrostatics prior to taking Electromagnetism. Additionally, the median composite ACT scores of all CU students admitted is 25-30 [12] while the average ACT scores of students admitted to the electrical engineering program at our university is 25.1

Discussion

The gain in knowledge of 0.12 was far less than anticipated but the authors are confident that the electromagnetism course can be improved using tutorials if implemented differently. First, the Kahoot! response system was not well suited for this application. The timed aspect made it impossible for the questions to be visible for long periods of time. Instead of the response system setting an appropriate uniform pace, some students finished their work while others could offer only guesses for the activities. In the future, a more adaptable electronic response system will be used. Second, the brief 50 minute class period three times per week severely hindered students from completing the in-class tutorial. Additional time for completion would provide students the opportunity to gain both confidence and competence in their work. The next time the class is taught the instructor will request two 80-minute class meetings per week. Finally, 15-20% of students did not attempt to work through the tutorials during class. This low level of participation can be attributed in part to a lack of preparation as evidenced by student's low rate of participation in the pre-lecture assignments and the limitations governed by the classroom arrangement. The classroom used in this study was set up as a traditional lecture classroom. Based on student comments, students attended class expecting to listen to a lecture with no expectations of participating in group exercises. In the future, the course will be offered in a classroom that is more conducive to group exercises. A classroom configured for group exercises (such as a laboratory setting) [2] should inform student expectations regarding class activities.

Conclusions and Future Work

The data from this preliminary study do not yield a firm conclusion about the effectiveness of the guided-inquiry active learning system. The results do indicate a modest gain in learning; however, it is not clear whether students would have demonstrated a higher gain in knowledge within a traditional lecture course. This preliminary study has led to an understanding of what does work well and what requires modification given the study's specific circumstances. Based upon this study, the tutorial presentations will be retained in future courses but with modifications to the pre-lecture activities and quizzes, the electronic response system, the length of the class period, and the classroom layout.

The preliminary study has revealed that the most effective sequence for the pre-lecture material would be a pre-lecture activity (worksheet or other document), followed by a quiz, and then a video lecture to prepare students for the tutorials in class. This proposed sequence differs from most tutorials in this study during which a video preceded a quiz. The pre-lecture activity sequence will be designed to enable students to make their own discoveries of course content. A simulation of an electromagnetic concept could provide an effective means for students to "discover" a basic law or theory. Upon completion of the pre-lecture activity, a quiz could reinforce learning.

The Kahoot! system could work well for some classes, but it does not feature question times beyond 120 seconds. In addition, it is does not allow students to respond when they have completed a section. A new response system will be sought for future implementation. It is not yet known how best to ascertain that all students are completing the tutorial in a timely fashion. One idea is to utilize student pre-lecture performance to create learning groups in class, with a range of performance levels in each group. This approach would potentially have the added advantages of amplifying student engagement and increasing student exposure to different learning styles.

Given the difficulty the students experience with vector calculus, future courses will require a pre-course video review of vector calculus. This video could be produced in collaboration with the Mathematics and Physics departments as those departments provide the pre-requisite courses for the junior-level electromagnetics course in Electrical Engineering. Ideally, students would take the pre-requisites in the semester immediately preceding the one in which they take Electromagnetics. The current curricular structure has most students completing the pre-requisites an entire year prior to taking Electromagnetics, without courses in between requiring the use of such material. This delay is likely a dominant factor in student difficulty with vector calculus.

The relevance of electromagnetic topics and concepts may be enhanced in class through live or video physical demonstrations. Where possible, these activities might increase student engagement and learning. It will be necessary to carry out these activities in a classroom suitable for students to work in groups. Thus, a classroom which facilitates group participation will be used in conjunction with the active learning guided-inquiry lecture.

Longer lecture periods (80 minutes versus 50 minutes) and smaller class sizes will better accommodate the tutorial system. The authors propose that limiting the class size to 25 students would improve student learning and success.

The tutorial system will be expanded to present a range of topics, in addition to electrostatics. An enhancement to the tutorial method could incorporate modeling assignments, where students are required to work individually and in teams to program solutions to standard problems [3].

A summary of proposed class initiatives to be implemented in future semesters is as follows:

- 80-minute course lectures
- Class sizes of no more than 25 students
- Classes that encourage and accommodate student groups
- Development and delivery of pre-course review videos on pre-requisite material
- Deployment of pre-lecture activities prior to each class meeting
- Deployment of a pre-lecture quiz upon each student’s completion of a pre-lecture activity
- Additional guided-inquiry tutorials on more topics
- Utilization of a response system that permits untimed student response to gauge speed of completion

- Integration of hands-on projects and/or demonstrations in accordance with the tutorial learning method

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