

EFFECTS OF THE FLIPPED CLASSROOM MODEL ON STUDENT ACHIEVEMENT IN
ADVANCED PLACEMENT PHYSICS C

by

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A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

August 2026

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DEDICATION

This work is dedicated to my parents, Mike Schiller and Kathy Schiller, and my family who constantly encouraged me throughout this master's program.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my advisors and readers, Robyn Gotz, and Tsunefumi Tanaka, for guidance, encouragement, and support throughout this research process. I am also thankful to the faculty of the Master of Science in Science Education program at Montana State University for their instruction and feedback throughout my graduate studies.

I would also like to thank my colleagues and administrators at James B. Conant High School for their support during this project. I am especially grateful to my students, whose participation and honesty made this study possible.

Finally, I would like to thank my family for their patience, encouragement, and unwavering support throughout this journey.

TABLE OF CONTENTS

1. INTRODUCTION AND BACKGROUND.....	1
Context of the Study	1
Focus Question.....	3
2. CONCEPTUAL FRAMEWORK	4
Basics of a Flipped Classroom.....	4
The Importance of Allowing Space for Failure	5
The Problem with Traditional Homework and Lectures.....	6
Flipped Classrooms' Impact on Student Achievement and Confidence	8
3. METHODOLOGY	9
Demographics	9
Treatment	9
Data Collection and Analysis Strategies	11
4. DATA ANALYSIS: CLAIMS AND EVIDENCE.....	14
Results.....	14
Pretest to Posttest Growth	14
Treatment vs. Nontreatment Normalized Gains	15
Student Perceptions on the Flipped Classroom Model	17
5. VALUE: REASONING AND REFLECTION	20
Claims from the Study	20
Value of the Study and Consideration for Future Research	22
Impact of Action Research on the Author	24
REFERENCES CITED.....	26
APPENDICES	28
APPENDIX A: IRB PROTOCOL EXEMPTION	29
APPENDIX B: GAUSS' LAW PRETEST	31
APPENDIX C: GAUSS' LAW PRETEST SCORING GUIDE	33
APPENDIX D: GAUSS' LAW POSTTEST.....	37
APPENDIX E: GAUSS' LAW POSTTEST SCORING GUIDE	40
APPENDIX F: ELECTRIC POTENTIAL PRETEST.....	43
APPENDIX G: ELECTRIC POTENTIAL PRETEST SCORING GUIDE	46
APPENDIX H: ELECTRIC POTENTIAL POSTTEST	50

TABLE OF CONTENTS CONTINUED

APPENDIX I: ELECTRIC POTENTIAL POSTTEST SCORING GUIDE	53
APPENDIX J: FLIPPED CLASSROOM FEEDBACK.....	58
APPENDIX K: STUDENT INTERVIEW QUESTIONS.....	60

LIST OF TABLES

Table	Page
1. Table 1. Data Triangulation Matrix.....	4

LIST OF FIGURES

Figure	Page
1. Figure 1. Average pretest and posttest scores for the nontreatment and treatment units, ($N=26$).	15
2. Figure 2. Normalized gain by group: treatment versus nontreatment ($N=26$).	16
3. Figure 3. Likert survey responses from strongly disagree to strongly agree reported with number of students who selected that response per question, ($N=27$). Some students chose not to respond to certain questions, so n varies from 23-27.	18
4. Figure A1. Institutional Review Board (IRB) approval for Jeffery Schiller effective from 11/19/2025 to 11/19/2030.....	30
5. Figure A2. Guass' Law Pretest asking students to derive the magnitude of the electric field from a thin rod lying along the x-axis.....	32
6. Figure A3. Scoring guide containing the criteria to score the pretest question with seven total possible points for part a.....	34
7. Figure A4. Scoring guide containing the criteria for the Guass' Law pretest with three possible points for part b as well as the requirements to receive each point.	35
8. Figure A5. Scoring guide containing the criteria for the Guass' Law pretest with three possible points for part b as well as the requirements to receive each point.	36
9. Figure A6. Part a and b of the Gauss' Law posttest asking students to derive the electric field at different points within two spherical conducting shells.....	38
10. Figure A7. Part c and d of the Gauss' Law posttest asking students to graph the electric field magnitude as a function of r	39
11. Figure A8. Gauss' Law posttest scoring guide for parts a and b listing the criteria to receive points with 15 points total possible for the question.....	41
12. Figure A9. Gauss' Law posttest scoring guide for parts b and c listing the criteria to receive points with 15 points total possible for the question.....	42

LIST OF FIGURES CONTINUED

13. Figure A10. Electric Potential pretest asking students to derive an expression for the electric potential of an insulating sphere as a function of r from the center.	44
14. Figure A11. Electric Potential pretest part b asking students to draw equipotential lines in the sphere and derive an expression for the speed of a charged particle released from the center as it approaches the edge of the sphere.	45
15. Figure A12. Electric Potential pretest scoring guide for part a showing the requirements to earn each point with four points earned on this page.	47
16. Figure A13. Electric Potential pretest scoring guide for part a and b showing the requirements to earn each point with two points earned on this page.	48
17. Figure A14. Electric Potential pretest scoring guide for part b showing the requirements to earn each point with two points earned on this page.	49
18. Figure A15. Electric Potential posttest asking students to indicate the directions of the electric field and derive an expression for the work done by an external force to move a positive charge into a configuration of four other charges.	51
19. Figure A16. Electric Potential posttest asking students to graph the potential energy as a function of the distance x from the center of the charge arrangement and to analyze its relationship to the function created in part b.	52
20. Figure A17. Electric Potential posttest scoring guide showing how the three points are earned for the directions of the electric field due to the configuration of charges.	54
21. Figure A18. Electric Potential posttest scoring guide showing how points are distributed for the derivation of work done with four points possible.	55
22. Figure A19. Electric Potential posttest scoring guide showing how points are distributed for part c with three total points possible.	56
23. Figure A20. Electric Potential posttest scoring guide showing how points are distributed for part d with two total points possible.	57

ABSTRACT

In this action research study, a flipped classroom model was implemented in an AP Physics C: Electricity and Magnetism course to examine its effect on student achievement and perceptions of learning. The study compared two sequential units during Spring 2026: a nontreatment Gauss' Law unit taught through traditional direct instruction and a flipped Electric Potential unit in which students viewed AP Classroom videos before class and used class time for guided problem solving and discussion. Student learning was measured using pre and post assessment free-response questions, with performance analyzed through score comparisons and normalized gains. Survey and interview data were also collected to examine student perceptions, and thematic analysis was used to identify recurring patterns in student responses. Results showed strong pretest-to-posttest growth and high normalized gains in both units, with the flipped treatment group showing greater variability in outcomes. Students reported benefits in preparation, use of class time, retention, and independence, while evidence related specifically to deeper understanding and transfer to unfamiliar College Board-style problems remained mixed. Overall, the findings suggest that the flipped classroom may be most effective as a structure for supporting active in-class learning rather than as a direct guarantee of improved transfer to novel problems.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

Context of the Study

James B. Conant High School is a large school in the northwest suburbs of Chicago. The school has a population of about 2,503 students according to the principal (J. Novak, personal communication, 2025). The school boasts an extensive listing of extracurriculars, elective classes, and advanced placement (AP) courses. About 50% of students at Conant will take at least one AP course before moving on to life outside of high school (U.S. News & World Report, 2024). The driving reason for students to take these courses, besides a GPA boost, is to get a chance at earning college credit while still in high school. This is achieved by getting a satisfactory score on the AP exam in May, usually a score of 3-5, which translates to a C or above on a regular grading scale.

Without a satisfactory score, students will still receive credit for the course but lose the chance to get the college credit. This failure results in students retaking the same course again in college if it is one they need for their program. AP Physics C is a very important course for many students planning on majoring in a science, technology, engineering, or mathematics (STEM) program in college. It covers all the basics from mechanics to electricity and magnetism which are often required courses for these students. As a result, this course is one that most students will have to take in college if not completed in high school. As such, it becomes important for the students to perform well, get the most out of the course, and pass the exam while in high school.

According to the College Board, the group that creates and scores the AP exams, nationwide about 30% of students will score a 5 on the exam and receive college credit. At James B. Conant High School, on average 15% of students taking the exam have scored a 5 in the past 2 years. One major reason for this is that the course curriculum has not been fully updated to match the changes that the college board has made to the course. Conant runs two sections of AP Physics C, one run by me and one by my colleague. For the past twenty years or so, these two sections have been run solely by my colleague. As such, he has had a difficult time keeping up with the changes alone and the course material is out of date. Students at Conant have been exposed to older versions of questions and have not been as prepared for the varied types of questions that come with the newer versions of the exam.

Beyond this, most of class time is spent completing direct instruction of the content through notes. Students receive old example problems, but do not have enough time in class to uncover all the possible sticking points. They learn how to complete one type of question in class, and struggle when they must apply the concept to a new scenario. This lack of time compounded with out-of-date practice questions has been a disservice to students who are trying to get college credit. To remedy this, students need updated course material as well as quality time in class to try, fail, discuss, and correct these difficult questions together.

One method that makes it possible to have this practice time is a flipped classroom. The idea is that students will watch brief content videos at home and then come to class and apply their knowledge to practice problems there. Rather than struggling through complex questions at home by themselves, students get to productively struggle in school with peers and their teacher. These videos replace students' homework as all the critical learning occurs through classroom

practice. Ideally, students prime themselves with a video before class. In class, students get to see various applications with the guidance of their instructor. This is an improvement upon the previous surface level understanding gained from in class notes and direct instruction. Students have historically fallen short when applying their knowledge to new scenarios. The solution lies in creating more opportunities to apply their knowledge to new contexts, with the goal of increasing student success on the AP test.

A flipped classroom method lends itself well to AP Physics C in particular. All students in this course are required to have taken a physics course. This requirement means that most of the content is review, just with more complex math applied to it. Additionally, the students are all seniors who have had four years to improve their time management skills. Time management is crucial for success in a model that has students watch content at home. Additionally, the College Board creates daily content videos to treat every topic on the exam. These videos come with AP style questions directly related to the test. Students will be able to watch these high-quality videos before class and answer the complex application questions in class the next day. This method of instruction gives students the updated, interactive learning experience that they have been missing. Students will be continuously exposed to different ways of thinking about difficult physics questions, preparing them well for the style of questions on the exam itself.

Focus Question

My focus question was, Will a flipped classroom lead to a deeper understanding of how to apply physics concepts and methods to novel problems presented by the College Board?

CHAPTER TWO

CONCEPTUAL FRAMEWORK

Basics of a Flipped Classroom

Flipping classrooms has become more and more popular in recent years. A flipped classroom inverts the traditional lecture and homework framework such that homework time is done in-person and direct instruction or lecture is done at home. Oftentimes a flipped classroom will deliver instruction through pre-recorded video notes or lectures and assign these in place of homework. The goal is to remove the teacher from the role of all-knowing content master to someone who guides students along in the process of learning new information. This model takes class time and uses it for students to actively engage in content previously covered in the videos in a collaborative problem-solving environment (Song & Kapur, 2017).

The intention of a flipped classroom is to give students a more active role in learning. A flipped classroom allows students to construct their own understanding of concepts through solving problems, rather than passive participation. An example of this would be when the students are told how their teacher would solve a problem rather than encouraged to create a path to the solution themselves. This design aligns well with classes that require students to develop higher order and critical thinking skills. Active learning can be particularly powerful in science and mathematics classes when learning abstract topics that are more easily understood with hands-on application and discussion amongst peers (Song & Kapur, 2017).

The Importance of Allowing Space for Failure

Flipped classrooms are popular because they allow more time for productive failure. Productive failure is a classroom design where students attempt new problems before learning much about them, which tends to result in initial failure. It has been shown that this struggle and failure often results in deeper understanding and allows students to retain information for longer periods of time. In failing, students frequently realize their own misconceptions as they rely on prior knowledge that is not accurate in this context. Surfacing these misconceptions primes students to absorb the correct information later. While confronting their misconceptions may hinder short-term performance and confidence at the start, it results in enhanced long-term learning (Kapur, 2016).

Beyond the benefit of enhancing long-term learning, productive failure has been shown to increase conceptual understanding in students. Though productive failure does not emphasize specific procedures to solve problems, as is traditional in a direct instruction style classroom, studies indicate that students leave class with an understanding of key concepts. Students are then able to apply these concepts to new situations and contexts (Kapur, 2016). Productive failure is most useful in STEM classrooms where students are required to apply underlying concepts to new situations. Further, it is beneficial in these classes since they often require students to collaborate in lab environments whose purpose is discovery without prior knowledge. When constantly exposed to mini-failures, and when those mini-failures are promoted as opportunities for growth in the classroom, students are less afraid of making mistakes and more willing to share ideas as they learn the normalcy of being incorrect (Song & Kapur, 2017).

It is important to note that productive failure must be carefully carried out in a classroom. It requires creating an environment where failures are celebrated rather than looked down upon. This happens by cheering students on when they get an answer wrong and thanking them for helping the class learn something new. An encouraging classroom also comes from designing questions that are low stakes so that students are not scared to attempt an answer. A question that is too difficult will result in students giving up before attempting to solve it. The key to productive failure is in the follow-up time. Students' attempts and thoughts must be leveraged to arrive at the right answer. When every answer and prediction is shared students see that their peers think similarly to them. Through the discussion of each wrong and right thought, the class creates an agreed upon conclusion. This judgement free discussion shows students that their failures can lead to the correct answer and helps highlight misconceptions that are integral to long-term conceptual understanding (Song & Kapur, 2017).

The Problem with Traditional Homework and Lectures

Traditional homework and lectures do not allow space for productive failure. Traditional lectures have been a popular model in education for the past century. This method is scrutinized for the way it fails to promote deep, conceptual understanding of content. Traditional direct-instruction style lectures often place students in the role of passive listeners. As a result, rote memorization is emphasized over deeper thinking; students are encouraged to memorize a set of steps rather than learn to use problem solving tools. There is little room for critical thinking and application in these environments (Ge et al., 2020).

The traditional model fails to make time for dialogue, inquiry, or addressing misconceptions. These tools are crucial in building a robust understanding of abstract ideas in a

science context. The restrictive nature of traditional lectures is best seen when compared to newer models like flipped classrooms. Students in flipped classrooms, where class time is devoted to active learning, consistently outperform their peers that are in direct instruction style classrooms. These findings demonstrate how traditional classrooms lack the dynamic and collaborative learning environment that prepares learners for success (Ge et al., 2020).

Part of this dated model is traditional homework: practice problems that take place at home without instructor guidance. Previously it was thought that more homework would result in better performance and understanding of content. However, cross-cultural analyses have found that increased homework time does not reliably predict higher academic achievement. A study on student backgrounds and homework load showed that when accounting for specific student backgrounds and context, increased homework can negatively impact student performance (Dettmers et al., 2009). In addition, a separate study has found that students who spend more time on homework are not necessarily learning more. (Trautwein et al., 2003).

Furthermore, most homework assignments emphasize repetition of procedures learned in class. Repetition fails to foster problem-solving skills and does not require students to apply their knowledge to new contexts. Without space for productive struggle, homework can become a passive exercise rather than a chance for growth. These findings call into question the efficacy of traditional homework in improving student achievement. There remains room for improvement in the realm of at-home content practice for students (Trautwein et al., 2003).

Flipped Classrooms' Impact on Student Achievement and Confidence

Flipped classrooms have been proven to successfully prepare students for success. Recent research highlights the positive impacts of flipped classrooms on student achievement and motivation. In a synthesis of 95 studies with over 15,000 participants completed by Zheng et al., (2020) it was found that flipped classrooms had a moderate positive impact on learning achievement. The results were seen across all disciplines but were most evident in natural sciences and engineering. When students interacted with high quality videos outside of class throughout the semester, there was a noticeable increase in learning achievement (Zheng et al., 2020). Additionally, 75% of students reported positive feelings towards the flipped classroom model. The students perceived their learning to be more effective and felt better supported in their learning endeavors (Nouri, 2016).

Flipped classrooms have also been shown to increase students' confidence and motivation (Zheng et al., 2020). One study found a strong correlation between the flipped classroom model and increased motivation, perceived effectiveness of learning, and active engagement in the classroom (Nouri, 2016). Students appreciated the ability to pause and rewatch lectures in conjunction with the support provided by the teacher in class. This allowed classes to dig deeper into concepts that may have been difficult to understand in the video alone. Notably, lower achieving students reported greater increases in motivation, confidence, and academic gains than their higher achieving peers. Results like this suggest that the flipped model may help mitigate learning achievement gaps (Nouri, 2016). Overall, these findings underscore the ability of the flipped model to enhance learner achievement, confidence, and motivation.

CHAPTER THREE

METHODOLOGY

Demographics

James B. Conant High School is a large school in the northwest suburbs of Chicago. The school has a population of about 2,503 students according to the principal (J. Novak, personal communication, 2025). Of these students, 43.6% are White, 3.8% Black, 19.4% Hispanic, and 29.3% Asian (Illinois Report Card, 2024). Approximately 29.4% of students are considered low income which means they qualify for free or reduced lunch. The culture at this school is overall positive. Most students are involved in extracurriculars, and most teachers sponsor extracurriculars. There is a high standard for all our students to achieve academic success.

The school boasts an extensive listing of extracurriculars, elective classes, and advanced placement (AP) courses. About 50% of students at Conant will take at least one AP course before moving on to life outside of high school (U.S. News & World Report, 2024). My AP Physics C course consisted of 26 students, 14 of whom were Asian/South Asian (54%), and 12 of whom were White (46%). Seven of the 26 were girls (27%), and 19 were boys (73%). All students in the course were seniors.

Treatment

The treatment I used was implementing a flipped classroom model for my AP Physics C class. Before the treatment, our class time was split between lecturing on notes and completing practice problems on worksheets. Oftentimes these practice problems ended up being homework that had to be completed on their own. Lecture time was also used to field questions from

students until everyone had an apparent understanding of the day's material. When implementing the flipped classroom, the class time shifted. Lecture materials and notes were assigned as homework to watch out of class. As a result, class time was used exclusively to answer questions and try practice problems based on content learned in the videos.

The videos used were assigned on, and viewed on, the AP classroom website. This is a website where all students have accounts and access to videos, practice questions, and other materials distributed by the College Board. Each night one to three videos of about 6 to 7 minutes each in length was assigned. The class set of notes was distributed alongside these videos so that students could fill in or add to the notes based on the information they watched in the videos for their own reference later. The expectation was that students watched the videos assigned that day after class on the AP classroom website. The following day this content would be applied to questions and labs all completed in class.

The research and data collection began during second semester when we began learning content about electricity and magnetism. For the first unit (Electric Fields and Gauss' Law) of this new content, class was conducted as normal. This was about three weeks. The flipped classroom treatment was implemented during the next unit (Electric Potential) of content, again for about three weeks. Another pre and posttest on that content was given at the end of that unit to measure their achievement with the treatment. The data collection concluded after this one cycle for analysis.

The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for work with human subjects was maintained (Appendix A).

Data Collection and Analysis Strategies

To measure the impact of the treatment, I implemented a mixed methods approach. Students took a pretest and posttest for each unit, one prior the treatment and one after the treatment. The Gauss' Law Pretest and was used to measure the students' content understanding prior to instruction without the treatment (Appendix B). The Gauss' Law Posttest was used to measure the students' content understanding after instruction without the treatment (Appendix C). These tests consisted of one free response question with multiple parts worth a total of 15 points.

Students were scored according to the two College Board scoring guides (Appendices C and D) and given a score out of 15 each time. I used normalized gains to compare pre and posttest scores and measure students' growth in content knowledge after instruction. The normalized gain was calculated to determine differences in student knowledge. Normalized gains of less than .3 were considered low, gains .3 to .7 were considered a medium gain and normalized gains greater than .7 were considered high (Hake, 1998). Then I calculated the median score. This was used to create a box and whisker chart for the final scores of the nontreatment unit to see how tightly packed student scores were, or if there was a wide spread of grades.

The same methods of analysis were used for the treatment unit. The Electric Potential Pretest (Appendix F) was given as the start of the unit and graded with the Electric Potential Pretest Scoring Guide (Appendix G) as dictated by the College Board. This was compared with the Electric Potential Posttest (Appendix H) which was graded using the Electric Potential Posttest Scoring Guide (Appendix I). These grades were used to analyze normalized gains for the

treatment unit. The posttest grades were used to calculate a median and a box and whisker chart was created to visualize the spread of final student scores upon completion of the treatment unit.

After the treatment unit and posttest, students completed a Likert scale survey called, Flipped Classroom Feedback as a Google form to assess my students' confidence in applying physics concepts to novel problems, their perception of learning in the flipped classroom model, their engagement with the format, homework completion, and self-perceived achievement (Appendix J). Their answers ranged from strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5). Averages were taken, as well as frequency analysis of students who chose each option. These were organized into bar charts to visualize the spread of responses for questions of interest.

Finally, all students were interviewed within their lab groups, which consisted of three to four students. Students were asked the Student Interview Questions (Appendix K) to gauge their feelings, experiences, and perceptions of the flipped classroom model. The interviews were recorded for later analysis. Thematic analysis was used on these recordings by noting trends and patterns in the responses of students. Certain student quotes that are representative of these trends and patterns were pulled to be used in further analysis later in this study. Pre and posttest data was used as quantitative data. Survey responses were compiled to make quantitative data. Finally interview data was used to create qualitative data. All these instruments are used to answer the focus question of the study as follows in Table 1.

Table 1: Data Triangulation Matrix

Research Question	Data Source 1	Data Source 2	Data Source 3
Will a flipped classroom lead to a deeper understanding of how to apply physics concepts and methods to previously unseen problems presented by the College Board?	Gauss' Law Pretest and Posttest and their Scoring Guides Electric Potential Pretest and Posttest and their Scoring Guides	Likert Scale Survey	Student Interview Questions

CHAPTER FOUR

DATA ANALYSIS: CLAIMS AND EVIDENCE

Results

This research was focused on whether a flipped classroom supported a deeper understanding of the application of physics concepts to novel College Board-style problems. The study collected data to compare a nontreatment Gauss' Law unit to a flipped Electric Potential unit. Results were presented through pre and post free response question (FRQ) performance, normalized gains from these FRQs, student survey responses, and interview data. The findings indicate that the flipped classroom model did not clearly improve or impair students' abilities to apply novel concepts to College Board style questions. Taken together, the data showed strong pretest-to-posttest growth across both groups. Both the treatment and nontreatment units had high gains according to the quantitative data. Student perceptions were positive when it came to in-class learning experience and independence. Student perceptions were more mixed when it came to the impact on deeper understanding and application to unfamiliar FRQs. These findings are organized and presented by major trends in the data.

Pretest to Posttest Growth

The first major trend in the data was that student performance increased substantially from pretest to posttest in both the nontreatment and treatment units. Both units began with very low pretest averages and ended with much higher posttest averages. Pretest and posttest averages were comparable between the treatment and nontreatment units (Figure 1). During the

nontreatment unit, the pretest score was an average of 9.73% and the posttest score was an average of 79.03%. Student average scores jumped 69.3% during the nontreatment unit. During the treatment unit the pretest average score was a 9.08% and the posttest score average was 76.35%. Student average scores jumped 67.3% during the treatment unit.

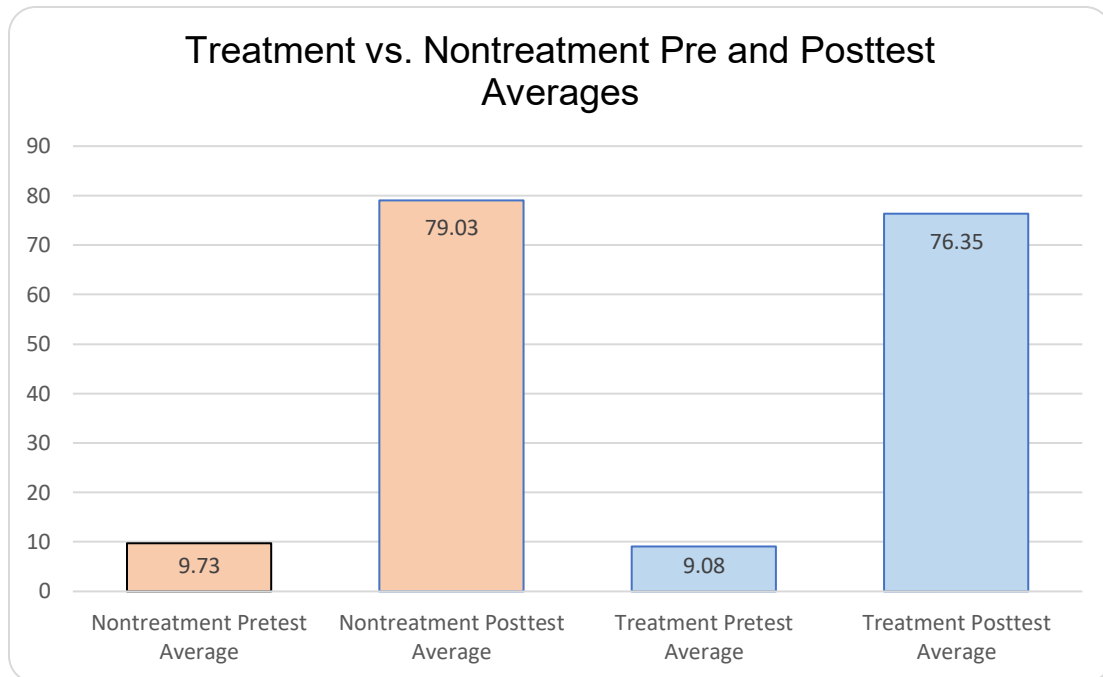


Figure 1. Average pretest and posttest scores for the nontreatment and treatment units, ($N=26$).

Treatment vs. Nontreatment Normalized Gains

A second major trend in the data was that both groups showed generally high normalized gains, while the treatment group displayed a wider spread of outcomes. Both groups showed high normalized gains as they were greater than .7 (Hake, 1998). The nontreatment group showed an average gain of .79 and the treatment group showed a gain of .72. There is a wider spread of student gains for the treatment unit while gains were more uniform during the nontreatment unit (Figure 2). During the nontreatment unit students were more uniform in their low pretest scores and on average had high gains. Several treatment students posted very high gains from .8 to .97.

The nontreatment group appears to have fewer very low-gain cases. Both groups had many students clustered in the high-gain range identified as being greater than .7. The nontreatment group data appears more tightly clustered with many gains concentrated around the .82 to .97 range. The treatment group data indicated many high gains as well, but the spread was wider, extending from .43 to .97. The mean marker for the nontreatment group is roughly .80 and the mean marker for the treatment group is around .72. Both groups appeared to achieve many high-gain outcomes. The treatment group's results were less uniform, as the flipped unit included both strong gains and limited gains. The nontreatment group appears to be more consistent in its gain pattern.

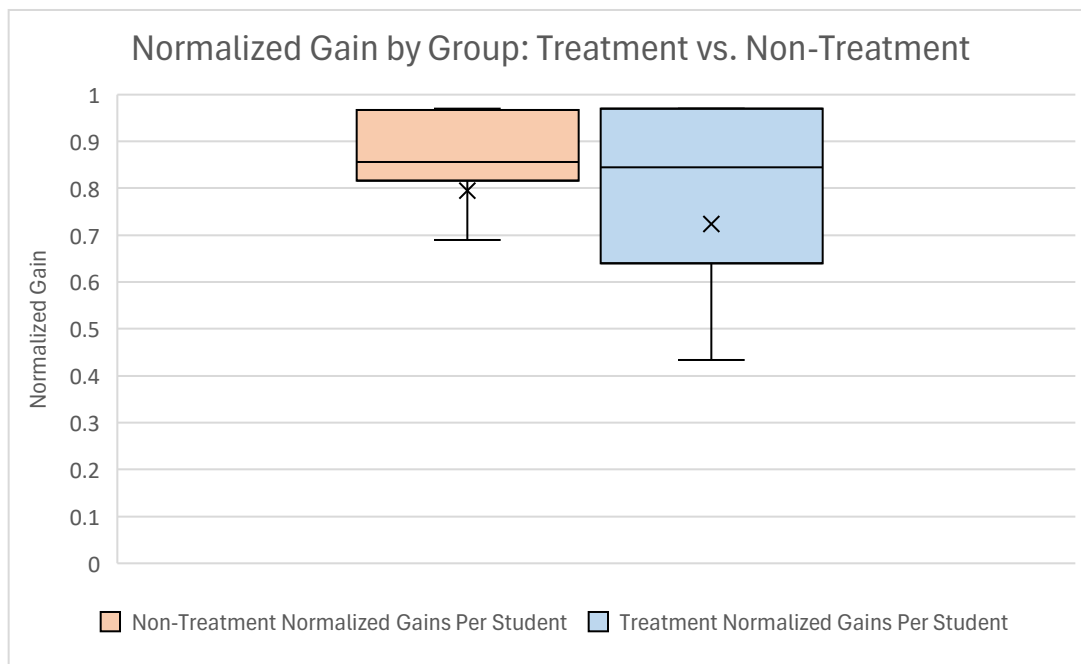


Figure 2. Normalized gain by group: treatment versus nontreatment ($N=26$).

Student Perceptions on the Flipped Classroom Model

Student perception data showed support for the flipped classroom as a structure for engagement, retention, and in-class learning support. Results related to deeper understanding and transfer to unfamiliar FRQs were overall positive but more mixed (Figure 3). One of the biggest positive points as reported by students was the increase in in-class problem solving time as well as retention. About 62% of total respondents to the question answered positively when asked if in-class time was more helpful after watching a video lesson beforehand. One student stated, “in class we could actually ask questions and work through problems,” and another reported, “the videos helped me come in with a baseline understanding”. There were 15 positive responses (56%) to the question about information retention after solving problems in class rather than only practicing at home. When it came to questions about engagement and homework support 76% of students said they were more engaged in traditional lectures. There was also a strong preference among students for the traditional lecture-based instruction over the flipped classroom. One student stated, “I found it difficult to follow along with some of the videos because some of the speakers moved too slowly and were boring to watch.” Out of the entire class, 65% of students responded negatively when were asked if they preferred the flipped classroom over the traditional lecture-based instruction. However, one of the most positively reported answers from students was that they felt the flipped classroom helped them become more independent learners. The survey showed that there was a strong positive response to the usage of class time, retention, and independence during the flipped classroom model. The responses were mixed when it came to engagement, homework clarity, and preference of instructional method.

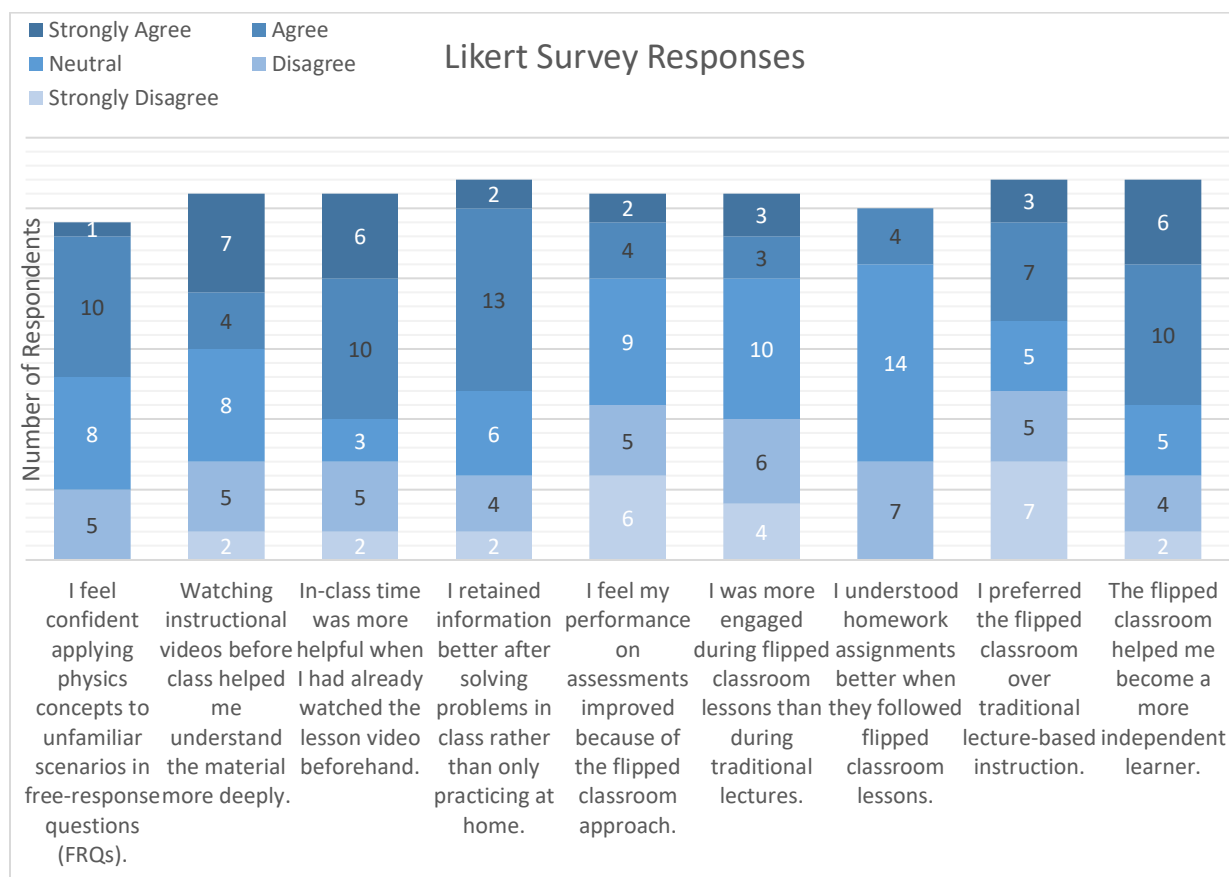


Figure 3. Likert survey responses from strongly disagree to strongly agree reported with number of students who selected that response per question, ($N=27$). Some students chose not to respond to certain questions, so n varies from 23-27.

Student perceptions of their understanding of physics concepts and their applications were mixed. Of the nonneutral answers, 69% of students responded positively when asked about perceived confidence in applying physics concepts to unfamiliar FRQs. In the post interview, one student stated, “more of it [the flipped classroom videos] helped with reinforcing concepts,” and another said that “the videos did not provide any challenging information that really required thinking”. Likewise, when asked how the flipped classroom helped their understanding and performance responses were notably mixed with no clear positive or negative skew. One student reported that, “I think it [the videos] lulled me into a false sense of security,” and another said

that “when it was time to apply it to a more specific or unfamiliar FRQ, it was challenging at times”. This perception aligns with the quantitative data in that the treatment unit produced the strongest posttest performance but did not clearly exceed the nontreatment average and showed greater variability. Some of the responses point towards increased confidence while certain quotes show hesitation or neutrality. There was not a uniform positive self-reported response from students when it came to transferring knowledge to unfamiliar FRQs.

CHAPTER FIVE

VALUE: REASONING AND REFLECTION

Claims from the Study

Through the previous synthesis of data, the question of whether a flipped classroom led to a deeper understanding of how to apply physics concepts and methods to novel College Board-style problems can be answered. In this chapter I will make claims about this question that are supported by evidence from pretest and posttest scores, normalized gains, Likert survey responses, and a qualitative thematic analysis of interview responses. These conclusions are cautious rather than absolute. The findings from this data suggest promise, but not a universal effect. Taken together, the data supported three broad claims.

The first claim supported by this data is that the flipped classroom appeared to support the learning process by improving student preparation for class, use of in-class time, and independence. While this does not necessarily prove deeper understanding itself, it supports the conditions under which deeper understanding may develop. All self-reported survey questions related to the helpfulness of in-class time, information retention during the flipped classroom, and independence in learning showed more positive responses than neutral or negative. In total there were anywhere between 15-16 positive responses out of the total 26 students for these three questions (57.7-61.5%). Using a flipped structure shifted first exposure of content to home, which reserved class time for more interactive practice. Students consistently identified this shift as beneficial with statements such as, “the videos helped me come in with a baseline understanding,” and “it made me more independent”. This agrees with the research by Nouri

(2016) as students reported feeling more supported in their learning endeavors. While this evidence is strong, it points only to process benefits rather than achievement benefits. When looking at the achievement data, a more complicated view arises, and a second claim can be made.

The flipped classroom did not produce clear evidence of stronger overall performance than the nontreatment unit, but it did show substantial student growth and many high gain outcomes. This contradicts what has been seen by Zheng et. al (2020) as there was no noticeable growth in student achievement between units. Both treatment and nontreatment units showed large gains with an average gain of .79 for the nontreatment and .72 for the treatment, both of which are above the 0.7 threshold for high gains. The box and whisker chart shows a tight cluster for the nontreatment gains, suggesting a more uniform growth and performance from pretest to posttest (figure 2). The treatment group had a wider spread overall, suggesting less uniformity. This data shows that the flipped classroom was associated with meaningful improvement from pretest to posttest, but not in a way that was drastically different from the nontreatment unit. The wide variation may suggest that the flipped model may not have benefitted all students in the same way. However, it is also possible that this is due to the treatment unit coming after the nontreatment unit. Pretest scores may have been more uniformly close to zero in the nontreatment unit because it was the very first unit in electricity and magnetism. By the treatment unit, students had already had some background knowledge and were able to perform better on their pretest score which affected the gains. This distinction between meaningful growth and uneven outcomes becomes even more important when the findings are considered in direct relation to the study's core focus.

The final claim is that the evidence suggests that the flipped classroom may have supported deeper understanding indirectly, but that the results were mixed when the focus narrowed to application on unfamiliar College Board-style FRQs. In the survey, the question directly asking students about their confidence when applying concepts to unfamiliar scenarios resulted in 45.8% positive, 33.3% neutral, and 20.8% negative responses out of all respondents to the question. This mixed response leaves no clear answer. Furthermore, students said, “when it was time to apply it to a more specific or unfamiliar FRQ, it was challenging at times”. While it resulted in near equivalent achievement and gains, there was no clear benefit in terms of confidence in applying physics concepts to new problems. This qualitative pattern suggests that videos alone did not produce a deeper understanding. Students seemed to identify that guided problem solving in class was where a deeper understanding was more likely to develop. Therefore, the best supported conclusion is that the flipped classroom may contribute to a deeper understanding when paired with strong in-class application, but the evidence does not show a simple direct effect. These three claims point to the practical values of the flipped model and inform us of considerations should one wish to use it in the future.

Value of the Study and Consideration for Future Research

Although the findings were mixed in some respects, the study still offers important value as these findings inform practice. This data goes beyond looking to see if a flipped classroom, works, but rather shows in what scenarios and in what ways it works best. One piece of evidence that now informs my instruction is how it has the potential to make class time more effective. Students reported that in-class learning was more effective when they had a baseline understanding of the content. It appears that there is value in restructuring when and where

learning happens. Active class time and teacher support were the most positive outcomes. After the study, I often had students in class tell me how they would have liked the flipped classroom more if it was my recorded lectures rather than the College Board's. Zheng et. al (2020) discussed the importance of high-quality videos to the flipped classroom model in their research. If I were to implement this model again, I would spend more time creating videos that better align with my content and teaching style instead of the College Board's videos. Besides this, the study revealed several limitations and questions that future research should address.

One of the clearest limitations was that this comparison was done across two different instructional units rather than identical content taught in two ways. One result of this was that during the treatment unit, students began with some content under their belts which increased their pretest score when compared to the nontreatment unit. Another limitation was that this research was only conducted across one class, as it is the only AP Physics C course I teach. Additional classes could help create more well-rounded data. Furthermore, deeper understanding is difficult to measure. Using student self-reporting and achievement scores alone, it is hard to get the full picture. All of this may have been influenced by the quality of the videos, whether students watched the videos at home, and the design of in-class activities.

Future iterations of this research should take those previous factors into consideration. As it was my most received comment, it would be worth recording my current lectures and using those as the pre-class videos in a future iteration. Most of the negative comments on the flipped classroom were that it, "lulled me into a false sense of security," and that "the videos did not provide any challenging information that really required thinking". This point could be improved which would help retain the positive impact of in-class work time. Beyond this, implementing

some form of checks to ensure that students watched the videos could avoid potential pitfalls of low accountability. This consideration may make the flipped learning itself better, which may lead to higher reported confidence and understanding. Beyond classroom implications and research considerations, this study has also impacted me as a reflective practitioner.

Impact of Action Research on the Author

Conducting this research had a meaningful impact on my development as a teacher and reflective practitioner. This study deepened my understanding of how students experience flipped instruction. It showed me that giving videos before class alone was not enough. These videos needed to be thoughtfully created or selected and paired with more scaffolding to support transfer to unfamiliar problems. Rather than focusing on whether students completed pre class work, I see it is more important to look at how each part of the flipped model may contribute to conceptual understanding and transfer. Pairing relevant scaffolded activities alongside these videos could improve this understanding and transfer. Rather than only discussing examples as a class, activities should allow for the gradual release of responsibility. This could be an I do, we do, you do format where the result is students trying questions on their own in class rather than watching me model problem solving. This may support confidence in applying learned concepts to new situations.

Beyond the classroom impact this process also strengthened my ability to use evidence to evaluate instructional decisions. Both quantitative and qualitative data guided decisions about what changes could be made to improve this method. I became more confident in collecting and triangulating multiple forms of data to inform these decisions. I also saw the value of listening to student perception data alongside the quantitative data. In the past, I have informed instructional

decisions based on scores and my own perceptions alone. After conducting this research, I am reminded of the importance of student perceptions as those drive their confidence and ultimately their performance in class. Mertler (2025) describes how the action research process should be iterative, constantly refining results to improve instruction. I feel an increased confidence in implementing new strategies, collecting data, analyzing it, and planning from there. This process has led me towards a more inquiry-driven approach to teaching.

Finally, this project reinforced a more reflective and responsive teaching stance. The research encouraged humility about innovation as even strategies with plenty of promise still require careful study. Classroom change is iterative, and any one single change will not immediately result in a perfect outcome. This study reinforced the importance of remaining open to complexity in the classroom, especially when evaluating strategies that are often discussed in broad or simplified terms. Overall, this study produced cautious but meaningful conclusions. The flipped classroom showed promise as a structure that supports preparation and independence, but evidence for deeper transfer to unfamiliar FRQs was more mixed. Ultimately, this study suggests that the flipped classroom may offer meaningful benefits to AP Physics C when it is used to support active in-class problem solving, but it also underscored the need for continued attention to how deeper understanding and transfer are cultivated and measured.

REFERENCES CITED

- Dettmers, S., Trautwein, U., & Lüdtke, O. (2009). The relationship between homework time and achievement is not universal: Evidence from multilevel analyses in 40 countries. *School Effectiveness and School Improvement*, 20(4), 375–405.
<https://doi.org/10.1080/09243450902904601>
- Ge, L., Chen, Y., Yan, C., Chen, Z., & Liu, J. (2020). Effectiveness of flipped classroom vs traditional lectures in radiology education: A meta-analysis. *Medicine (Baltimore)*, 99(40), e22430–e22430. <https://doi.org/10.1097/MD.00000000000022430>
- Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64–74.
- Illinois Report Card. (2024). School Profile: J B Conant High School. Illinois State Board of Education. Retrieved from
<https://www.illinoisreportcard.com/School.aspx?source=profile&Schoolid=050162110170001>
- Kapur, M. (2016). Examining Productive Failure, Productive Success, Unproductive Failure, and Unproductive Success in Learning. *Educational Psychologist*, 51(2), 289–299.
<https://doi.org/10.1080/00461520.2016.1155457>
- Mertler, C. A. (2025). *Action research: Improving schools and empowering educators*. Sage Publications, Inc.
- Nouri, J. (2016). The flipped classroom: for active, effective and increased learning – especially for low achievers. *International Journal of Educational Technology in Higher Education*, 13(1). <https://doi.org/10.1186/s41239-016-0032-z>
- Song, Y., & Kapur, M. (2017). How to Flip the Classroom - " Productive Failure or Traditional Flipped Classroom " Pedagogical Design? *Educational Technology & Society*, 20(1), 292–305.
- Trautwein, U., & Köller, O. (2003). The relationship between homework and achievement - still much of a mystery. *Educational Psychology Review*, 15(2), 115–145.
<https://doi.org/10.1023/A:1023460414243>
- U.S. News & World Report. (2024). *James B. Conant High School*. U.S. News & World Report.
<https://www.usnews.com/education/best-high-schools/illinois/districts/township-high-school-district-211/james-b-conant-high-school-6918>
- Zheng, L., Bhagat, K. K., Zhen, Y., & Zhang, X. (2020). The Effectiveness of the Flipped Classroom on Students' Learning Achievement and Learning Motivation: A Meta-Analysis. *Educational Technology & Society*, 23(1), 1–15.
[https://doi.org/10.30191/ETS.202001_23\(1\).0001](https://doi.org/10.30191/ETS.202001_23(1).0001)

APPENDICES

APPENDIX A: IRB PROTOCOL EXEMPTION

Protocol Detail Report

Printed By: Schiller, Jeffery
4/16/2026 10:25:08 AM

Report Comments

Protocol Information

Version # 1

Reference Number 2355

Protocol Number 2025-2355-EXEMPT

Protocol Title EFFECTS OF THE FLIPPED CLASSROOM MODEL ON STUDENT ACHIEVEMENT IN ADVANCED PLACEMENT PHYSICS C

Protocol Type: Original

Principal Investigator: Schiller, Jeffery

Approval Date: 11/19/2025

Submittal Date: 11/17/2025

Effective Date: 11/19/2025

Author: Schiller, Jeffery

Renewal Date: 11/19/2030

Status: Approved

Next Review Date: 11/19/2030

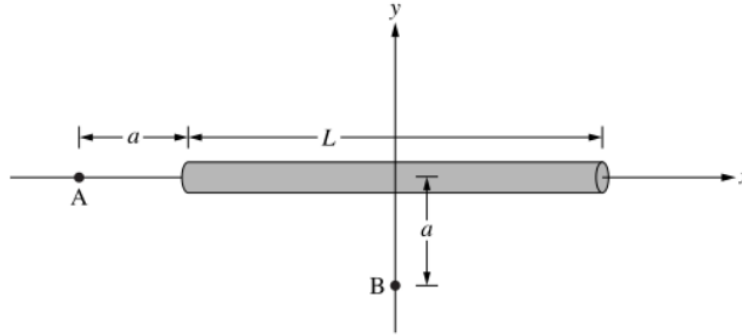
Inactive Date:

Expiration Date: 11/19/2030

Figure A1. Institutional Review Board (IRB) approval for Jeffery Schiller effective from 11/19/2025 to 11/19/2030.

APPENDIX B: GAUSS' LAW PRETEST

1. Show all your work for each part of the question. The parts within the question may not have equal weight.



Note: Figure not drawn to scale.

A thin rod lies along the x -axis of an xy -coordinate plane with its center at the origin, as shown in the figure. The rod has length L , a diameter that is negligible compared to L , and a uniform linear charge density λ_0 . Point A is located on the x -axis and is a distance a to the left of the left end of the rod. Point B is located on the y -axis and is the same distance a directly below the center of the rod.

(a)

- i. **Derive** an expression for the magnitude E_A of the electric field at Point A in terms of L , a , λ_0 , and physical constants, as appropriate.
- ii. **Write**, but do not solve, an integral expression with correct limits that could be solved to determine the magnitude E_B of the electric field at Point B. Express your answer in terms of L , a , λ_0 , x , and physical constants, as appropriate.

The original rod is replaced with a new rod of the same length, same diameter, and same total charge as the original rod. However, the new rod has a nonuniform linear charge density modeled by $\lambda(x) = \beta\left(\frac{L}{2} + x\right)$, where β is a positive constant.

- iii. How does the magnitude E_{new} of the electric field at Point A due to the new rod compare to the magnitude of the electric field E_A derived in part (a)(i)? **Justify** your response.

The new finite rod is then replaced by an infinitely long line of uniform linear charge density λ_0 along the x -axis.

- (b) **Derive** an expression for the electric field magnitude at Point B due to the infinitely long line of charge. Express your answer in terms of a , λ_0 , and physical constants, as appropriate.

Figure A2. Gauss' Law Pretest asking students to derive the magnitude of the electric field from a thin rod lying along the x -axis.

APPENDIX C: GAUSS' LAW PRETEST SCORING GUIDE

0	1	2	3	4	5	6	7
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The response accurately includes **all** of the following criteria.

- ☐ 1 point is earned for a multistep derivation that uses the integral of the electric field produced by infinitesimal sections of the rod for the electric field at Point A.
- ☐ 1 point is earned for correctly substituting an expression for the differential charge element dq .
- ☐ 1 point is earned for performing a correct integration with appropriate limits (or integration constant) to find an expression for the magnitude of the electric field at Point A.

Example Response

$$E_A = \int \frac{1}{4\pi\epsilon_0} \frac{dq}{r^2}$$

$$dq = \lambda_0 dx$$

$$E_A = \int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{1}{4\pi\epsilon_0} \frac{\lambda_0 dx}{\left(a + \frac{L}{2} + x\right)^2}$$

$$E_A = \frac{\lambda_0}{4\pi\epsilon_0} \left[-\frac{1}{a + \frac{L}{2} + x} \right]_{-\frac{L}{2}}^{\frac{L}{2}}$$

$$E_A = \frac{\lambda_0}{4\pi\epsilon_0} \left[-\frac{1}{a+L} + \frac{1}{a} \right]$$

$$E_A = \frac{\lambda_0 L}{4\pi\epsilon_0 a(a+L)}$$

- ☐ 1 point is earned for a correct expression for the distance from Point B to an infinitesimal section of the rod.
- ☐ 1 point is earned for
 - recognizing that only the vertical components of the electric field are relevant at Point B,
 - using the appropriate trigonometric function expressed correctly in terms of x and a ,

AND

- having correct limits on the integral for the electric field at Point B.

Example Response

$$E_B = \int \frac{1}{4\pi\epsilon_0} \frac{dq}{r^2}$$

$$dq = \lambda_0 dx$$

Figure A3. Scoring guide containing the criteria to score the pretest question with seven total possible points for part a.

$$\text{so } E_B = \int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{1}{4\pi\epsilon_0} \frac{\lambda_0 dx}{a^2+x^2} \cos \theta$$

$$\text{so } E_B = \int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{1}{4\pi\epsilon_0} \frac{\lambda_0 dx}{a^2+x^2} \frac{a}{\sqrt{a^2+x^2}}$$

$$E_B = \int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{1}{4\pi\epsilon_0} \frac{\lambda_0 a dx}{(a^2+x^2)^{\frac{3}{2}}}$$

- ☐ 1 point is earned for correctly indicating that E_{new} is less than E_A , with an attempt at a relevant justification.
- ☐ 1 point is earned for relating a smaller electric field to the charge being distributed farther from Point A.

Example Response

E_{new} is less than E_A . The total charge is the same as for the original rod, but some charge has been moved to the right, farther from point A. Since some charge has moved farther away, the integral

$$E = \frac{1}{4\pi\epsilon_0} \int_{-L/2}^{+L/2} \frac{\lambda dx}{r^2} \text{ will be less for } E_{\text{new}} \text{ than for } E_A.$$

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1	2	3
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The response accurately includes **all** the following criteria.

- ☐ 1 point is earned for a multistep derivation that uses Gauss's law.
- ☐ 1 point is earned for using a cylindrical Gaussian surface centered on the x -axis and having Point B on its outer surface.
- ☐ 1 point is earned for
- an equation that correctly expresses Gauss's law,
 - substituting a correct expression for the charge enclosed by the Gaussian surface,

AND

Figure A4. Scoring guide containing the criteria for the Gauss' Law pretest with three possible points for part b as well as the requirements to receive each point.

- correctly solving the Gauss's law equation for the electric field at Point B in terms of the indicated quantities and physical constants, as appropriate.

Scoring Note: The correct answer is $\frac{\lambda_0}{2\pi\epsilon_0 a}$.

Scoring Note: Full score can also be earned from correctly performing the integral derived in part (b) and taking the limit $L \rightarrow \infty$.

Example Response

For a cylindrical Gaussian surface of radius a , length Δx , and its central axis along the x -axis, Gauss's law gives

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\epsilon_0}$$

$q_{\text{enc}} = \lambda_0 \Delta x$, so

$$\oint \vec{E} \cdot d\vec{A} = E 2\pi r \Delta x = \frac{\lambda_0 \Delta x}{\epsilon_0}$$

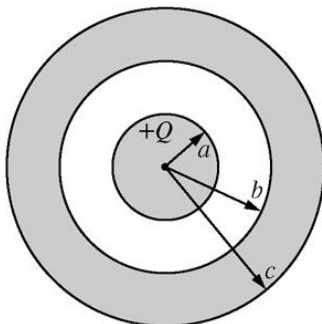
$$E = \frac{\lambda_0 \Delta x}{\epsilon_0 2\pi r \Delta x} = \frac{\lambda_0}{2\pi\epsilon_0 a}$$

Figure A5. Scoring guide containing the criteria for the Gauss' Law pretest with three possible points for part b as well as the requirements to receive each point.

APPENDIX D: GAUSS' LAW POSTTEST

Unit 8 Free Response
AP Physics C

Name _____
1 2 3 4 5 6 7 8



A metal sphere of radius a contains a charge $+Q$ and is surrounded by an uncharged, concentric, metallic shell of inner radius b and outer radius c , as shown above. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Determine the induced charge on each of the following and explain your reasoning in each case.

i. The inner surface of the metallic shell

ii. The outer surface of the metallic shell

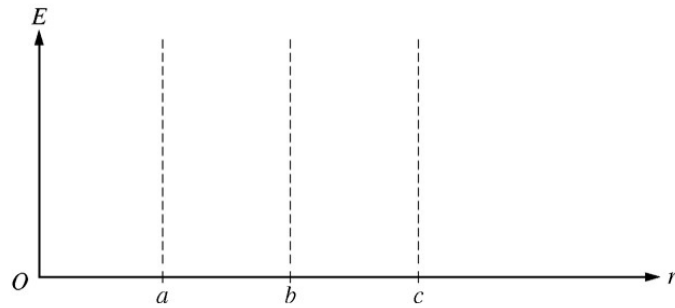
(b) Determine expressions for the magnitude of the electric field E as a function of r , the distance from the center of the inner sphere, in each of the following regions.

i. $r < a$ ii. $a < r < b$

iii. $b < r < c$ iv. $r > c$

Figure A6. Part a and b of the Gauss' Law posttest asking students to derive the electric field at different points within two spherical conducting shells.

- (c) On the axes below, sketch a graph of E as a function of r .



- (d) In a different experiment, the inner metal sphere is replaced by a plastic sphere with a uniform charge distribution. The net charge on the plastic sphere is $+2Q$. On the axes below, sketch a graph of E as a function of r .

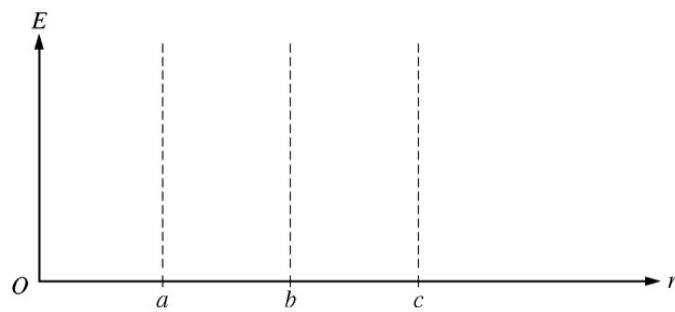


Figure A7. Part c and d of the Gauss' Law posttest asking students to graph the electric field magnitude as a function of r .

APPENDIX E: GAUSS' LAW POSTTEST SCORING GUIDE

15 points total

Question 1

Distribution
of points

(a)

(i) 2 points

For indicating that the charge on the inner surface of the shell is $-Q$

1 point

For a correct explanation with no incorrect statements

1 point

Examples:

- Applying Gauss's law to a Gaussian surface within the shell gives $Q_{\text{enclosed}} = 0$, since the field within a conductor is zero. Therefore the charge on the inner surface of the shell is $-Q$.
- The $+Q$ on the sphere attracts an equal and opposite charge onto the inner surface of the shell. (Equal magnitude could be implied by a statement that earned the first point.)

(ii) 2 points

For indicating that the charge on the outer surface of the shell is $+Q$

1 point

For a correct explanation with no incorrect statements

1 point

Examples:

- Applying Gauss's law to a Gaussian surface outside the shell gives $Q_{\text{enclosed}} = +Q$, therefore the sum of the charges on the inner and outer surfaces of the shell must be 0.
- The net charge on the shell is zero. Therefore the charge on the outer surface must be the opposite of the charge on the inner surface because of conservation of charge.

Note: If the correct sign of the charge is given in part i or ii without the magnitude (Q), a correct explanation could receive 1 point.

(b)

(i) 1 point

Since the sphere is a conductor all the charge lies on the outside surface. Applying Gauss's law to any Gaussian surface inside the sphere gives $Q_{\text{enclosed}} = 0$.

For a correct answer

1 point

 $E = 0$

(ii) 1 point

For any surface between the sphere and the shell the net enclosed charge is $+Q$.

Applying Gauss's law

$$E4\pi r^2 = Q/\epsilon_0$$

For a correct answer

1 point

$$E = Q/4\pi\epsilon_0 r^2 \text{ or } E = kQ/r^2$$

Figure A8. Gauss' Law posttest scoring guide for parts a and b listing the criteria to receive points with 15 points total possible for the question.

of points

(b) (continued)

(iii) 1 point

For any surface inside the shell the net enclosed charge is zero.

For a correct answer

$$E = 0$$

1 point

(iv) 1 point

For any surface outside the shell the net enclosed charge is $+Q$.

Applying Gauss's law

$$E4\pi r^2 = Q/\epsilon_0$$

For a correct answer

$$E = Q/4\pi\epsilon_0 r^2 \text{ or } E = kQ/r^2$$

1 point

(c) 4 points

For drawing $E = 0$ for $0 \leq r \leq a$ (must have a line drawn on the axis)

1 point

For drawing a positive, decreasing, concave up function with $E(b) \neq 0$ for $a \leq r \leq b$

1 point

For drawing $E = 0$ for $b \leq r \leq c$ (must have a line drawn on the axis)

1 point

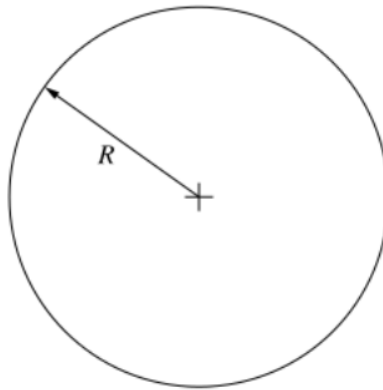
For drawing a positive, decreasing, concave up function with $E(c) < E(b)$ for $r \geq c$

1 point

Figure A9. Gauss' Law posttest scoring guide for parts b and c listing the criteria to receive points with 15 points total possible for the question.

APPENDIX F: ELECTRIC POTENTIAL PRETEST

1. Show all your work for each part of the the question. The parts within the question may not have equal weight.



Cross Section of
Charged Insulating Sphere

Figure 1

A solid insulating sphere has a radius R , as shown in the cross-sectional view in Figure 1, and is electrically charged with a net charge $+Q$. The sphere's charge density is nonuniform and given by the equation $\rho = Cr$, where C is a positive constant and r is the distance from the center of the sphere.

(a)

- i. Taking the electric potential to be zero at the center of the sphere, **derive** an expression for the electric potential at a point inside the sphere that is a distance r from the center. Express your answer in terms of C , r , and physical constants, as appropriate.

Figure A10. Electric Potential pretest asking students to derive an expression for the electric potential of an insulating sphere as a function of r from the center.

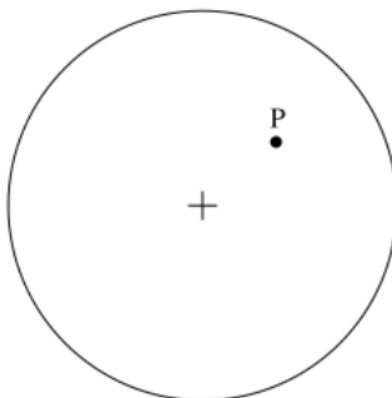


Figure 2

Figure 2 shows the same cross-sectional view of the sphere as well as a point labeled P in the interior of the sphere.

- ii. On Figure 2, **sketch** a line or curve representing an equipotential surface that includes Point P.
- iii. On Figure 2, **indicate** the direction of the electric field, if any, at Point P. If the field is zero at Point P, write " $E = 0$ " next to Point P. Otherwise, represent the field direction with an arrow that starts on Point P and points in the direction of the field.

A narrow hole is drilled in the sphere from the surface radially inward to the sphere's center. The hole does not significantly change the electric field or the electric potential within the sphere. A positively charged particle of charge q and mass m is then placed at the sphere's center and given an initial velocity v_0 toward the sphere's surface and along the direction of the hole.

- (b) **Derive** an expression for the speed of the charged particle when it reaches the surface of the sphere. Express your answer in terms of C , R , q , m , v_0 , and physical constants, as appropriate.

Figure A11. Electric Potential pretest part b asking students to draw equipotential lines in the sphere and derive an expression for the speed of a charged particle released from the center as it approaches the edge of the sphere.

APPENDIX G: ELECTRIC POTENTIAL PRETEST SCORING
GUIDE

Unit 9 Progress Check: FRQ 1

- Applying Gauss's law,
- Deriving the charge enclosed within a sphere of radius r ,

OR

- Deriving the integral $\int \vec{E} \cdot d\vec{A}$.

Scoring Note: The application or derivation need not be done correctly in order to earn this point.

- ☐ 1 point is earned for correctly deriving the total charge enclosed in a sphere of radius r .
- ☐ 1 point is earned for either:

- correctly applying Gauss's law,

OR

- indicating that the enclosed charge can be treated as a point charge located at the sphere's center to derive the electric field.

- ☐ 1 point is earned for correctly integrating an electric field expression $\int \vec{E} \cdot d\vec{A}$.

Scoring Note: it is not necessary to have the correct sign, integration limits, or integration constant to earn this point.

- ☐ 1 point is earned for:

- correctly integrating an electric potential expression using $\Delta V = V_b - V_a = - \int_a^b \vec{E} \cdot d\vec{r}$,
including the correct sign and correct integration limits or constant,

AND

- a final expression for the potential difference that is in terms of the indicated quantities and physical constants, as appropriate.

Scoring Notes:

The expression must equal zero for $r = 0$ in order to earn this point (correct use of integration limits or integration constant).

Correct expressions are

$$-\frac{Cr^3}{12\epsilon_0} \quad \text{or} \quad -\frac{\pi kCr^3}{3}.$$

Example Response

$$\int \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\epsilon_0}$$

$$q_{\text{enc}} = \int \rho \, dV$$

Figure A12. Electric Potential pretest scoring guide for part a showing the requirements to earn each point with four points earned on this page.

$$q_{\text{enc}} = \int_0^r Cr(4\pi r^2)dr = C\pi r^4$$

$$\int \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\epsilon_0} \Rightarrow E(4\pi r^2) = \frac{C\pi r^4}{\epsilon_0} \Rightarrow E = \frac{Cr^2}{4\epsilon_0}$$

$$V_b - V_a = - \int_a^b \vec{E} \cdot d\vec{r} = - \int_0^r \frac{Cr^2}{4\epsilon_0} dr$$

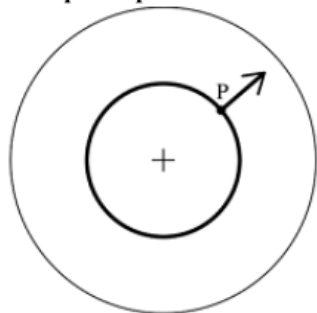
$$\Delta V = -\frac{Cr^3}{12\epsilon_0} \text{ or } -\frac{\pi kCr^3}{3}$$

- ☐ 1 point is earned for representing an isoline of potential by drawing a circle that is concentric with the sphere **AND** contains Point P at its edge, with no extraneous lines or curves.
- ☐ 1 point is earned for representing the field by drawing a single arrow starting at Point P that is either:
- directed radially outward,

OR

- perpendicular to the equipotential drawn at Point P and having a radial component that is directed away from the sphere's center.

Example Response



Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1	2	3
---	---	---	---

The response accurately includes **all** the following criteria.

- ☐ 1 point is earned for a multistep derivation that uses conservation of energy.

Figure A13. Electric Potential pretest scoring guide for part a and b showing the requirements to earn each point with two points earned on this page.

- ☐ 1 point is earned for substituting a potential energy expression consistent with the answer from part (a)(i) for $r = R$.
- ☐ 1 point is earned for correctly solving a conservation-of-energy equation for the final speed **AND** writing the expression in terms of the indicated quantities and physical constants, as appropriate.

Scoring Note: Correct expressions are

$$\sqrt{v_0^2 + \frac{qCR^3}{6\epsilon_0 m}} \quad \text{or} \quad \sqrt{v_0^2 + \frac{2\pi kqCR^3}{3m}}$$

Example Response

$$K_f + U_f = K_i + U_i$$

$$\frac{1}{2}mv^2 - q\frac{CR^3}{12\epsilon_0} = \frac{1}{2}mv_0^2$$

$$\frac{1}{2}mv^2 = \frac{1}{2}mv_0^2 + \frac{qCR^3}{12\epsilon_0}$$

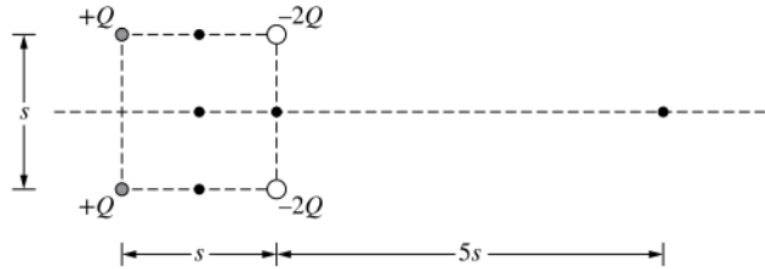
$$v^2 = v_0^2 + \frac{qCR^3}{6\epsilon_0 m}$$

$$v = \sqrt{v_0^2 + \frac{qCR^3}{6\epsilon_0 m}} \quad \text{or} \quad \sqrt{v_0^2 + \frac{2\pi kqCR^3}{3m}}$$

Figure A14. Electric Potential pretest scoring guide for part b showing the requirements to earn each point with two points earned on this page.

APPENDIX H: ELECTRIC POTENTIAL POSTTEST

1. Show all your work for each part of the the question. The parts within the the question may not have equal weight.



Note: Figure not drawn to scale.

Figure 1

Four small charged spheres are fixed in place at the vertices of a square of side length s , as shown in Figure 1. The charged spheres at the upper-left and lower-left corners of the square each have a positive charge $+Q$ while the two charged spheres at the upper-right and lower-right corners of the square each have a negative charge $-2Q$. Also shown are five dots, with one located at the center of the square, three located at the midpoints of three sides of the square, and one located a distance $5s$ to the right of the square.

- (a) At each of the five dots in Figure 1, **indicate** the direction of the electric field, if any, at the dot's location. If the field is zero at any of the dots, write " $E = 0$ " next to those dots. Otherwise, represent each field direction with an arrow that starts on a dot and points in the direction of the field.

Note: It is not necessary to indicate the relative magnitudes of the electric fields at the different locations.

Small Sphere A with charge $+2Q$, is moved from very far away by an external force to the center of the square, where it is held in place.

- (b) **Derive** an expression for the work done by the external force to move Sphere A from very far away to the center of the square. Express your answer in terms of Q , s , and physical constants, as appropriate.

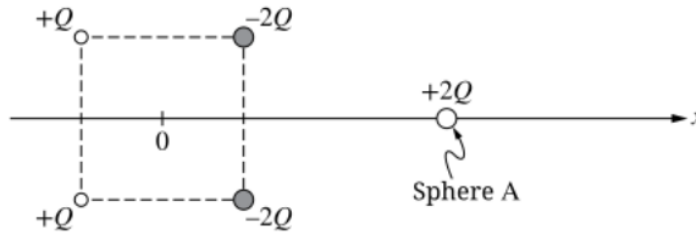


Figure 2

Figure A15. Electric Potential posttest asking students to indicate the directions of the electric field and derive an expression for the work done by an external force to move a positive charge into a configuration of four other charges.

(c) Figure 2 shows the original four spheres in the same square arrangement. Sphere A is shown at an arbitrary location along the x -axis, where $x = 0$ corresponds to the center of the square. On the axes in Figure 3, **sketch** a graph of the electric potential energy U of the five-sphere system as a function of x for $x \geq 0$. Take the electric potential energy of the five-sphere system to be zero when Sphere A is infinitely far away and the other four spheres are arranged as shown in figures 1 and 2.



Figure 3

Consider the electric field, if any, that you indicated in part (a) for the following two locations:

the center of the square

a distance of $5s$ to the right of the square

(d) Is the graph you drew in part (c) consistent or inconsistent with the electric field at these two locations? **Justify** your response.

Figure A16. Electric Potential posttest asking students to graph the potential energy as a function of the distance x from the center of the charge arrangement and to analyze its relationship to the function created in part b.

APPENDIX I: ELECTRIC POTENTIAL POSTTEST SCORING
GUIDE

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



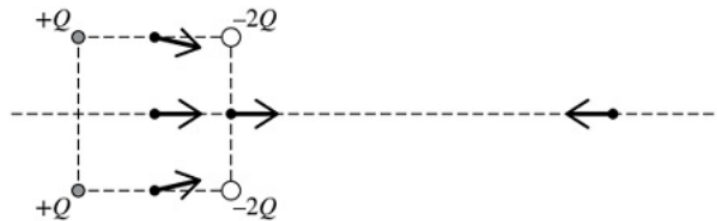
0	1	2	3
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The response accurately includes **all** the following criteria.

- ☐ 1 point is earned for an arrow indicating the field is toward the right at the center of the square.
- ☐ 1 point is earned for arrows indicating the field is:
 - toward the right at the midpoint of the right side of the square,

AND

- toward the left at the point on the far right of the figure.
- ☐ 1 point is earned for arrows indicating the field has components to the right and slightly inward at the midpoints of the top and bottom sides of the square.

Example Response**Part B**

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1	2	3	4
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The response accurately includes **all** the following criteria.

Figure A17. Electric Potential posttest scoring guide showing how the three points are earned for the directions of the electric field due to the configuration of charges.

- ☐ 1 point is earned for a multistep derivation that applies the electric potential energy expression $U_E = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$ or $k \frac{q_1 q_2}{r}$ to Sphere A and at least one of the four original spheres OR for using the definition of work with correct limits on the integral.
- ☐ 1 point is earned:
- for correct expressions of the electric potential energy for every pair consisting of an original corner sphere and Sphere A,
- OR**
- for correctly evaluating the electric potential due to the original four spheres at the center of the square.
- OR**
- for correctly evaluating the x -component of the net force
- ☐ 1 point is earned for indicating that the distance between Sphere A and each of the four original spheres is $\frac{s}{\sqrt{2}}$ OR for correct substitution into the work definition integral.
- ☐ 1 point is earned for a correct expression for the work done in terms of the indicated quantities and physical constants, as appropriate
- Scoring Note:** The correct expression is
- $$-4\sqrt{2} k \frac{Q^2}{s} \text{ or } -\sqrt{2} \frac{Q^2}{\pi\epsilon_0 s}$$

Example Response

The work done by the external force is equal to the change in electric potential energy:

$$\begin{aligned}
 W = \Delta U &= \sum k \frac{(2Q)q_i}{r_i} - 0 \\
 &= 2 \times k \frac{(2Q)Q}{s/\sqrt{2}} + 2 \times k \frac{(2Q)(-2Q)}{s/\sqrt{2}} \\
 &= (4 - 8)\sqrt{2} k \frac{Q^2}{s} \\
 &= -4\sqrt{2} k \frac{Q^2}{s} \text{ or } -\sqrt{2} \frac{Q^2}{\pi\epsilon_0 s}
 \end{aligned}$$

OR

Assume Sphere A is moved in from far to the right of the square. The sum of forces from the four charged spheres on the Sphere A is in the x -direction only, because of symmetry. The external force acting on Sphere A is thus also in the x -direction only, because it balances the sum of forces from the four other spheres. The external force can then be expressed as the negative of the sum of electric forces F_e :

$$\begin{aligned}
 F_x = -F_e &= -2 \frac{k(2Q)Q}{\left(x+\frac{s}{2}\right)^2 + \left(\frac{s}{2}\right)^2} \frac{\left(x+\frac{s}{2}\right)}{\sqrt{\left(x+\frac{s}{2}\right)^2 + \left(\frac{s}{2}\right)^2}} \\
 &\quad - 2 \frac{k(2Q)(-2Q)}{\left(x-\frac{s}{2}\right)^2 + \left(\frac{s}{2}\right)^2} \frac{x-\frac{s}{2}}{\sqrt{\left(x-\frac{s}{2}\right)^2 + \left(\frac{s}{2}\right)^2}}
 \end{aligned}$$

Figure A18. Electric Potential posttest scoring guide showing how points are distributed for the derivation of work done with four points possible.

$$F_x = -\frac{4kQ^2(x+\frac{s}{2})}{\left[(x+\frac{s}{2})^2+(\frac{s}{2})^2\right]^{\frac{3}{2}}} + \frac{8kQ^2(x-\frac{s}{2})}{\left[(x-\frac{s}{2})^2+(\frac{s}{2})^2\right]^{\frac{3}{2}}}$$

$$W = \int_{\infty}^0 F_x dx = -kQ^2 \int_{\infty}^0 \left(\frac{4(x+\frac{s}{2})}{\left[(x+\frac{s}{2})^2+(\frac{s}{2})^2\right]^{\frac{3}{2}}} - \frac{8(x-\frac{s}{2})}{\left[(x-\frac{s}{2})^2+(\frac{s}{2})^2\right]^{\frac{3}{2}}} \right) dx$$

$$W = -kQ^2 \left[\frac{-4}{\left[(x+\frac{s}{2})^2+(\frac{s}{2})^2\right]^{\frac{1}{2}}} - \frac{-8}{\left[(x-\frac{s}{2})^2+(\frac{s}{2})^2\right]^{\frac{1}{2}}} \right]_{\infty}^0$$

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1	2	3
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The response accurately includes **all** the following criteria.

- ☐ 1 point is earned for drawing a curve that asymptotically approaches zero as x approaches infinity.
- ☐ 1 point is earned for a value of U at $x = 0$ consistent with the answer in part (b), i.e., $U(0)$ and the part (b) answer are either both positive, both negative, or both zero.
- ☐ 1 point is earned for drawing a curve that
 - has the same sign everywhere as the answer to part (b),
 - has a slope at $x = 0$ consistent with the answer to part (a),
 - has a slope at the right end of the x -axis consistent with the answer to part (a)

AND

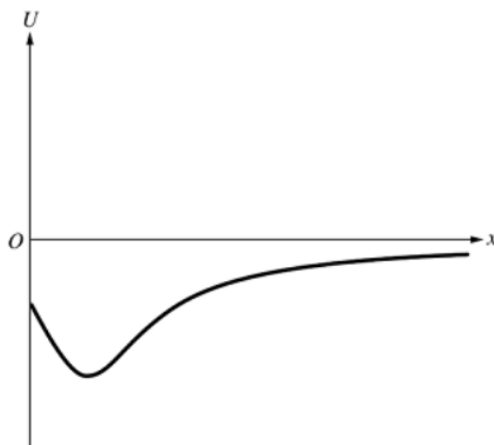
- has a single local minimum at a nonzero, positive value of x .

Scoring Note: If parts (a) and (b) were answered correctly, then

- U should be negative everywhere,
- the slope at $x = 0$ should be negative, and
- the slope at the right end of the x -axis should be positive.

Example Response

Figure A19. Electric Potential posttest scoring guide showing how points are distributed for part c with three total points possible.

**Part D**

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1	2
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The response accurately includes exactly **two** of the following criteria.

☐ 1 point is earned for a justification that uses either

- the relation $E_x = -\frac{dV}{dx}$ or $-\frac{1}{q} \frac{dU}{dx}$,
- the relation $q\vec{E} = F_x = -\frac{dU(x)}{dx}$,

OR

- the fact that the electric field points in the direction of lower electric potential or (since Sphere A is positive) lower electric potential energy

☐ 1 point is earned for a correct justification of whether the graph in part (c) is consistent or inconsistent with the field directions indicated in part (a) for the two locations.

Example Response

The electric field points in the direction of the electric force for positive Sphere A, which should point in the direction of lower electric potential energy ($E_x \propto F_x = -\frac{dU}{dx}$). This is toward the right at the square's center and toward the left at locations far to the right of the square, as I indicated in part (a) and as shown in the graph in part (c).

Figure A20. Electric Potential posttest scoring guide showing how points are distributed for part d with two total points possible.

APPENDIX J: FLIPPED CLASSROOM FEEDBACK

This survey contains a number of statements about the flipped classroom. You will be asked what you yourself think about these statements. There are no 'right' or 'wrong' answers. Your opinion is what is wanted.

For each statement select:

SA if you STRONGLY AGREE with the statement

A if you AGREE with the statement

NS if you are NOT SURE

D if you DISAGREE with the statement

SD if you STRONGLY DISAGREE with the statement

- I feel confident applying physics concepts to unfamiliar scenarios in free-response questions (FRQs).
- I am comfortable analyzing a physics problem I have never seen before.
- I feel prepared to solve complex physics problems using what I learned in class.
- I am better able to explain my reasoning when solving physics problems now than earlier in the year.
- Watching instructional videos before class helped me understand the material more deeply.
- In-class time was more helpful when I had already watched the lesson video beforehand.
- I learned physics concepts more effectively in the flipped classroom model than with traditional lectures.
- I had more opportunities to ask questions or clarify misconceptions during flipped lessons.
- I retained information better after solving problems in class rather than only practicing at home.
- I feel that I achieved a better understanding of the concepts during flipped classroom units.
- I feel my performance on assessments improved because of the flipped classroom approach.
- I was more engaged during flipped classroom lessons than during traditional lectures.
- I felt more in control of my learning during flipped classroom units.
- I was more likely to complete homework when it was video based.
- I understood homework assignments better when they followed flipped classroom lessons.
- I found it easier to keep up with the workload during flipped classroom weeks.
- I spent more time reviewing content independently in the flipped model.
- I preferred the flipped classroom over traditional lecture-based instruction.
- I would like more science units taught using a flipped classroom model.
- The flipped classroom helped me become a more independent learner.

APPENDIX K: STUDENT INTERVIEW QUESTIONS

Below is a list of some potential interview questions to be conducted among students and their lab groups 2-4 students. This will be an open-ended interview that can take whatever shape the conversation leads, but is guided by these potential questions.

- Can you describe what it was like learning in the flipped classroom compared to how you've learned in the past?
- Did it feel different coming into class already having watched the video? How did that affect your participation or confidence?
- When you saw FRQs or other unfamiliar problems, did the flipped classroom prepare you to tackle them? Why or why not?
- How did the flipped classroom affect your motivation to keep up with the work?
- Did the video lessons make learning easier or harder for you? Why?
- What would you change or keep the same if a future topic was to be taught this way?
- How did your approach to homework or studying change (if at all) during the flipped classroom units?
- Was it easier or harder to stay on top of your work compared to traditional instruction?
- Did you feel more responsible for your learning in the flipped model? What helped you stay accountable?
- Did it change how much you interacted with your classmates or teacher? How?
- If you could redesign the flipped classroom to make it better for you, what would it look like?