LAB SUMMARY METHOD AND THE IMPACT ON STUDENT LEARNING IN HIGH SCHOOL PHYSICS LABS

by

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ABSTRACT

A large portion of high school physics classes revolve around inquiry-based investigations. These investigations involve creativity, a fluid structure, and problem-solving skills. A classic lab report does not give students the freedom to authentically represent their learning from these investigations. This study investigated three different lab summary methods, a video lab report, claim, evidence, reasoning paragraph, and email home lab report for their effectiveness in student learning, perception of learning, and enjoyment. Student learning was assessed through pre-tests and post-tests and unit exams. Student enjoyment and perception of learning were judged through student opinion surveys and interviews. The results indicated that students learned the most from email home lab reports. Students enjoyed the methods that involved creative elements, the video lab report and the email home lab report. This action research showed the importance of ensuring that the summarization after a lab matches the higher-level thinking skills required of students during the lab process. The importance of giving students an outlet for their voice and creativity was also shown.

INTRODUCTION AND BACKGROUND

Context of the Study

Evanston Township High School (ETHS) is a suburban high school located in Evanston, Illinois, the suburb immediately north of Chicago. Evanston has a diverse population of 73,473 people, where 66.6% are white, 16.5% are Black or African American, and 11.7% are Hispanic or Latino. There is a large disparity of income in Evanston. The average per capita income in 2019 was $51,000, however 13.3% of the population lives at or below the poverty line (census.gov).

The student population of Evanston Township High School is not entirely representative of the larger population of Evanston. ETHS has a student population of 3,597 students and has been steadily increasing since 2017. Of the students enrolled, 45.8% are white, 26% black, 18.7% Hispanic, 5.8% Asian, and 3.3% are two or more races. Of the 3,597 students, 34.7% are low-income students, 11% have IEPs, and 5.1% are English Language Learners (illinoisreportcard.com).

At Evanston Township High School, I am currently teaching (Advanced Placement) AP Physics 1, which is an algebra-based course that is equivalent to an introductory college-level physics course. In this course students cover kinematics, dynamics, circular motion and gravitation, energy, momentum, simple harmonic motion, and torque and rotational motion. The College Board encourages students to build the concepts of each unit primarily through inquiry-based investigations. The College Board further stresses the importance of inquiry-based investigations by asking students an “Experimental Design” Free Response Question on the AP

Exam. As a part of this question students must design and write a procedure to solve a lab-based problem and then analyze data provided from a mock experiment of the lab.

At ETHS AP Physics 1 is an elective course taken primarily by juniors and a handful of seniors. Students taking AP Physics 1 have a wide variety of lab skills when entering the class depending on their previous science courses and science teachers. ETHS is a large school that has over 40 science teachers with different styles. Some teachers teach with a more traditional lecture style while others have embraced the NGSS and plan robust labs using the NGSS practices, cross cutting concepts, and the disciplinary core ideas to engage students.

I have been teaching my AP Physics 1 class with an inquiry model for the past three years. I have introduced each new topic with a lab activity or a demonstration. Each lab activity begins with students experiencing or watching some phenomenon or discrepant event. In lab groups, students then hypothesize what factors could contribute to and help explain the phenomenon they witnessed. Students share out the variables they believe could help understand the relationship present in the phenomenon. Once all the students share out, they then design and carry out an experiment to test their hypothesis regarding the relation of the variables. Students then analyze data and mathematically confirm or disconfirm their hypothesis. Students will then use a white board to present their data to the class. Students will draw a graph of their data and explicitly state the relationship they found from the lab. While students are working, they keep track of their findings in lab notebooks.

Once all student groups have a white board made, I give students time to perform a gallery walk where they look at each other’s data and experiments. Then, I will hold a discussion where students share out the main ideas, trends, and differences they noticed among every group’s experiments. This lab discussion has always functioned as the main summary of the lab activity. Around half of the time students will also have a lab skill check after the lab activity to assess their understanding of the main ideas and practices from the lab.

These lab discussions, assessments, and future assessments where students have been asked to apply their learning from the labs have revealed problems with my current method of summarizing labs. First, I have consistently noticed that a handful of students carry the lab discussion and the remainder of the class zone out and do not actively participate. In models where I have called on random students to share out their findings, I have found that students who would not usually participate do not often contribute new insights to the discussion. These students will mainly restate ideas that have already been stated or simply say they agree with another group.

I have also noticed a disconnect between the lab activity and the more traditional teaching of my class. Students have stated that they do not like labs and feel that it is not a good use of their time. Students often say that they would rather learn the lab material through a lecture and do not believe that lab activities are valuable.

When analyzing lab assessment data, I have noticed that there is a correlation between students who participate in the lab discussion and those who score highly on the assessments. Students who do not participate also show a weakness in the content that was developed in the lab activity and seem more unsure of themselves while designing and carrying out future lab activities. I hope that all students who take my AP Physics 1 class can learn content and lab practices from labs and apply this content to their future learning. The focus on lab-based learning and the disparities in how students engage in the summarization of the lab has led to the formation of my focus question.

Focus Question

My focus question was, How does the method of lab summarization impact student ability to learn the content and skills from a lab?

My sub-questions included the following:

1. How does the method of lab summarization impact student perception of their learning from the lab?
2. How does the method of lab summarization impact the student enjoyment of the lab process?

CONCEPTUAL FRAMEWORK

Inquiry Labs in the Science Classroom

The origin of inquiry labs in the science classroom can be dated back to 1910 when John Dewey proposed an educational shift from rote memorization of fact to a model where the focus hinges on critical thought, problem solving, and student action. This introduction to inquiry labs placed a lesser importance on the rigidity of the scientific method and encouraged students to engage in the search for answers using scientific practices. After this proposition by Dewey, the importance of inquiry has been widespread and has evolved to the point of becoming the cornerstone of educational standards such as Project 2061 from the American Association for the Advancement of Science and the National Research Council's Inquiry and the National Science Education Standards (Barrow, 2006).

Inquiry investigations can take many forms and involve various amount of teacher involvement, yet they are all held to the same base concepts. In an inquiry investigation, students are the ones asking the scientific question, planning possible solutions, carrying out procedures, collecting and analyzing data, and communicating their findings. The process that students undergo is a cyclical process and does not follow the strict rigidity of the traditional scientific method (Llewellyn).

Lab Reports and Traditional Lab Methods

Despite the rise in a cyclical, inquiry approach to scientific investigations, some educators still cling to a traditional, rigid lab report as the means for synthesizing information obtained from laboratory activities. The rigidity of traditional lab reports is best suited for traditional laboratory investigations and has not been adapted for an inquiry-based approach (Keys, 1999).

Lab reports typically ask students to summarize the procedure of a lab, report their data findings, analyze said data, and construct a conclusion based on the collected data (Gratz, 1990). However, traditional lab reports have evoked criticism for their inability to reflect the authentic ways in which science is typically performed devoid of a rigid scientific method. Due to the rigidity of lab reports, students either analyze their results to state the expected conclusion or if the expected conclusion is not found state that this is the product of experimental error. The lab report does not support revisions, meaningful data analysis, or the cyclical nature of inquiry labs (Alaimo et al., 2009).

While inquiry learning encourages students to reflect on their data and conclusions to answer a question, lab reports typically do not allow for this connecting and meta-cognitive thinking step. Lab reports instead act as a means for students and teachers to complete some superficial questioning related to the lab activity (Haagen-Schuetzenhoefer, 2012).

A push for lab reports to better reflect the inquiry lab model has begun in some science courses. One study of undergraduate physics from the University of Auckland cited the need for lab reports to better reflect the approach that students take with labs. The introductory physics course at University of Auckland were revamped to include inquiry labs and an inquiry approach to lab reports. The new lab report format placed an emphasis on argumentation from evidence, peer review, and concise communication. The result was labs and lab reports that students enjoyed more and an ability to build skills and scientific practices (Foote, 2018).

Video Lab Reports as an Alternative to Lab Reports

One new alternative to traditional lab reports is a video lab report. One such example of the video lab report is a Screencast Lab Report. During a Screencast Lab Report students create short video recordings with audio to summarize their lab findings. In a particular study of Screencast Lab Reports students collected data and performed lab activities over the period of three weeks. After students completed their lab, they summarized their findings with a 2-minute screencast. Students were prompted to state their initial question, explain their procedure, define their variables, describe the patterns they noticed, explain the reasoning for their relationships, and displayed data and videos of their lab procedure on their screen (Hazzard, 2014).

During this treatment, students were found to collaborate more than they did when writing traditional lab reports. This collaboration was noted when students were planning and writing scripts, delegating the recording into sections, and discussing areas where a specific speaker could have improved. Another noted benefit was students injecting more personality, humor, and culture into their report (Hazzard, 2014). Another trial of video lab reports conducted in Brazil noted a similar injection of personality. In this study students were able to display their culture and personality in their lab report using music, dramatization, pictures, and commentary (Pereira, 2012).

Screencast effectiveness is attributed to multiple aspects. Through creating a video, students were proud of their final product and the sense of an audience increased their motivation to create high quality work (Hazzard, 2014). Another reason for its success could be the fact that students today are digitally literate and generally passionate about creating and viewing short form video content. These video presentations can be more engaging and exciting for students to create when compared to a traditional slideshow (Lisec, 2018).

Another success of video lab reports is its ability to engage all students. Video lab reports allow all students to engage and play on the strengths of different students. Students who are not traditionally strong writers or English language learners can still confidently contribute to the creation of video lab reports. Sharing scientific findings through the creation and editing of videos is an equitable way for students to engage in summarizing labs (Yerrick, 2003).

Claim Evidence Reasoning as an Alternative to Lab Reports

The goal of the inquiry investigation is for students to be able to answer a scientific question posed by themselves or their instructor. A strong metric to assess whether students can answer a question is through a claim, evidence, reasoning style argument. The claim, evidence, reasoning model has students make a claim to answer a question. They then provide evidence through the data collected in a lab activity to help support their claim. Then by connecting their evidence and the laws of nature students provide a reasoning as to why their claim is correct or incorrect. Similar to a lab report, a claim, evidence, reasoning response allows students to construct an analysis of lab results (Allen, 2015). A claim, evidence, reasoning argument still allows students to argue and make sense of the lab activity they participated in. Requiring students to argue from their data allows for a more meaningful analysis. In a CER students practice scientific writing and sensemaking, all while helping them understand the content within the lab. They then use their own data to engage in the scientific practice of argumentation (McNeill, 2007).

Letter Home as an Alternative to Lab Reports

The letter home is an authentic alternative to a traditional lab report proposed by first year physics college professors. In this letter home, students write an email message to a family member or friend about their findings from the lab in a manner that their recipient can understand and learn from. Students must write in the tone of an email, describe the experiment, summarize the results of the experiment, and ensure that their recipient could learn the concepts from the email. These letters home also connect the lab to topics outside the classroom and help students work through misconceptions (Lane, 2014).

When students write letters, they engage in non-scientific writing. This style of writing allows them to place a greater focus on the concepts as opposed to relying on equations to explain their reasoning. Students must prove a strong grasp of the concept as opposed to memorizing facts or reciting an equation (Hicks, 2004).

When a student takes on the role of a teacher, both the student and the learner benefit (Ullah, 2018). A student who oversees teaching someone else must understand the level of the learner and explain the concept at this level. This requires a unique level of problem solving and creativity from students (Austin, 2008). To write this email home, students must review the material and learn the concepts, which in turn improves their understanding. Then, communicating this understanding helps to solidify what they have learned.

METHODOLOGY

The primary purpose of this research determined how the method of lab summarization impacted student ability to learn the content and skills from a lab. Specifically, how different lab summarization methods impacted student scores on a pre-test and post-test and how well students applied the content to future assessments was measured. A secondary purpose was to examine how the method of summarizing the lab impacted student perception of their learning from the lab. Then, how the method of summarizing the lab impacted student enjoyment of the lab process was examined. The findings were used to determine which lab summarization technique was most effective for high school physics students.

Demographics

The participants were juniors and seniors in one section of (Advanced Placement) AP Physics 1. AP Physics 1 was chosen because it is defined by the College Board to be a laboratory-based science and a large emphasis is placed on lab practices. The College Board states, “This course requires that 25% of instructional time be spent in hands-on laboratory work, with an emphasis on inquiry-based investigations that provide students with opportunities to demonstrate the foundational physics principles and apply the science practices.” (College Board, pg. 7) For all students AP Physics 1 was their first physics course. It was also one of the first science courses where students engaged in open-ended inquiry-based labs.

The treatment group was composed of 25 students. Of these students, 13 identified as male and 12 identified as female. There were 16 juniors and 9 seniors. There were 13 students who identified as white, 4 Asian, 3 black or African American, 4 Hispanic or Latino, and 1 who was two or more races. Of the 25 students, none had an IEP and 3 had a 504 Plan. One of these 504 plans was for ADHD and two of them were for anxiety. There were no English Language Learners in this class. Specific data for the socio-economic status of the group was not available.

The comparison group was another AP Physics 1 class taught by a coworker. This coworker planned and taught the same lessons in lockstep during the year. This other class learned the same content at the same pace. An equal emphasis on labs was placed in both classes.

These two groups are comparable in skill level and ability based on the comparison of unit exams. In the first semester, both classes were given two equivalent unit tests. On the Unit 1 test, the treatment group scored an average of 69.2% while the non-treatment group averaged 65.6% (Table 1). On the Unit 2 test, the treatment group averaged 65.6% while the non-treatment group averaged 67.8%.

Table 1. A comparison of Unit Exam scores between the treatment group, (*N*=25) and non-treatment group, (*N*=22).

	Unit 1 Exam			Unit 2 Exam		
Group	Average	Standard Deviation	Median	Average	Standard Deviation	Median
Treatment	67.5%	16.7%	71.2%	65.6%	16.9%	69.1%
Non-Treatment	65.6%	16.2%	69.2%	67.8%	11.0%	65.4%

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).

Treatment

In the Fall semester of the 2021-2022 AP Physics 1 students in both the treatment and non-treatment group participated in approximately ten inquiry-based labs. Students completed and concluded each of these labs in their science notebooks. Students glued the Lab Notebook Checklist into their science notebook and learned to include each step of the checklist as they progressed through their lab (Appendix B). When each group finished collecting and analyzing their data, students engaged in a class discussion. During this step, students sketched the graphical relationship they discovered on a whiteboard along with their derived mathematical model and any main ideas they discovered from the lab. Students also answered any focus questions from the lab on their whiteboard. Then, students displayed their whiteboards at their tables and engaged in a gallery walk. Students wrote in their science notebooks any similarities or differences they noticed from other group data while on this gallery walk. Then, students held a class discussion and stated their findings from the lab. At the beginning of the year these class discussions were heavily teacher-guided but have become more student-led as students have grown more comfortable with their ability to communicate scientific information. These discussions were typically led by the same group of vocal students while the quieter students rarely spoke up to participate. After the discussion, students answered a series of conclusion questions in their lab notebook to summarize their findings and discoveries from the discussion. At the end of the unit, these science notebooks were checked for accuracy and completion and graded with a lab notebook checklist.

The treatment was implemented in the spring semester of the 2021-2022 school year. Students engaged in the same science notebook practice outlined above, but in the treatment group an additional piece was added to guide the conclusion of the lab. One of the lab conclusion activities was implemented for the first three labs of the semester year.

<u>Video Lab Report</u>

The first lab that students completed in the second semester was the Circular Motion Lab. In this lab students manipulated washers, string, and a spinning rubber stopper to discover the relationship between force, mass, velocity, and radius in the context of centripetal force. To conclude the lab, students in the treatment group completed a video lab report. The assignment was described to students before they began the lab to help inform what additional pieces, such as videos and pictures they would need to acquire from the lab along with their data. Students were given the Video Lab Report Handout and Video Lab Report Rubric before starting the lab (Appendices C & D).

The video lab report instructed students to use Flipgrid, a video recording and hosting platform, to create a 2–4-minute video to summarize their results from the lab. An instructional video showing how to use Flipgrid was shown when students received the assignment. Students were instructed to include a purpose, hypothesis, procedure, graphs, conclusion, and a real-world application of the content learned in the lab in their video lab report. For the procedure, students had to include a picture of their experimental set up and a video of their group performing one trial of the experiment. Students were encouraged to make a slideshow to accompany their verbal explanations for the video lab report. In class students were given time to write a script and create their slides for their video. They recorded the video for homework. This video lab report was due three days after the laboratory discussion and was graded on the Video Lab Report Rubric.

Claim, Evidence, Reasoning Paragraph

The next lab students participated in was the Gravitation Lab. In this lab, students used the Gravity Force Lab PhET simulation to determine the mathematical and graphical relationship between gravitational force and mass and gravitational force and distance. Students in the treatment group wrote a Claim, Evidence, Reasoning Paragraph to summarize their findings from the lab. The assignment was described to students before they began the lab to help inform what additional pieces, such as screenshots, they would need to acquire from the lab along with their data. Students were given the Claim, Evidence, Reasoning Handout and Claim, Evidence, Reasoning Rubric before starting the lab (Appendices E & F).

The Claim, Evidence, Reasoning Handout instructed students to collect data and evidence from their lab to answer the scientific question, "What is a black hole? How are black holes able to apply such a strong gravitational force on objects that get near to them?" Students were instructed to write a claim, provide evidence from the lab in the form of graphs, data, and mathematical relationships. Then, students connected their claim and their evidence with their reasoning. The reasoning was a statement of a physics law or a trend noted in the lab or from previous learning. This CER paragraph was due three days after the laboratory discussion and was graded on the Claim, Evidence, Reasoning Paragraph Rubric.

Email Home Lab Report

The third lab students participated in was the Conservation of Energy Lab. In this lab, students designed their own lab investigation to experimentally demonstrate that energy is conserved within a system. Students in the treatment group wrote an email to a family member, friend, teacher, or sibling to summarize their findings from the lab. The assignment was described to students before they began the lab to help inform what additional pieces, such as pictures, videos, and screenshots of graphs, they would need to acquire from the lab along with their data. Students were given the Email Home Lab Report Handout and Email Home Lab Report Rubric before starting the lab (Appendices G & H).

The email home lab report instructed students to summarize and explain their lab findings to someone who does not know physics. The intent was that if a student could explain physics at an appropriate level to someone who does not know the concepts, then they were masters of the material. Before students began the lab, they were shown the handout, explained the rubric, and were shown both a strong and weak example of an email home written by the instructor for a previous lab (Appendices I & J). Students were instructed to include a purpose, procedure, and conclusion for their lab. The procedure had to include pictures, diagrams, or videos of the lab set up. For the conclusion, students were told to focus less on the mathematics of the lab and instead place a greater emphasis on the concepts that they found. Students were told that the email must be written in the tone of an email and in such a way that it made sense to their audience. Students were told that they would be penalized for using scientific language or terminology without a proper, audience-appropriate definition. The email home was due three days after the laboratory discussion and was graded on the Email Home Lab Report Rubric.

Student Choice Lab

The final lab students engaged in was the Exploding Carts Lab. In this lab students analyzed various explosion collisions and from this graphically derived the conservation of momentum. Students in the treatment group chose one of the three lab summary methods (Video Lab Report, Claim, Evidence, Reasoning Paragraph, or Email Home) to use to summarize their findings from this final lab.

Data Collection and Analysis Strategies

To collect data on student learning of content from the Video Lab Report students completed the Unit 3: Circular Motion Lab Pre-Test before they began the lab (Appendix K). This pre-test was three questions, two regarding content from the lab and one about lab skills. The first question asked students to quantitatively predict how a change in mass would change the velocity and period of a spinning stopper given a constant force. The second question asked how the speed changes of an object spinning in a circle with the radius changes. The third question asked students to explain how they would accurately measure the period of a spinning object. After each question students were asked to rank their confidence in their answer on a scale of 1 to 5 where 1 represented "The answer was a guess" and 5 represented "Fully confident." To fully assess student learning from the lab, students completed the Unit 3: Circular Motion Lab Post-Test three days after the conclusion of the lab (Appendix L). Three days after the conclusion of the lab corresponded with the due date of the lab summary method for students in the treatment group. The Unit 3: Circular Motion Lab Post-Test was also made up of three questions. Students were asked a comparable question about how a change in force changes the velocity and period of a spinning object, a question about how a change in radius changes speed, and to describe a process to accurately measure the period of a rotating object. Again, students were asked to rank their confidence in their answers on the same 1-5 scale. To determine student learning, the questions on the pre-test and post-test were graded. The averages and standard deviations between the treatment group and non-treatment group were compared. Normalized gains were calculated to check for student growth between the treatment and non-treatment group. The average confidence was also calculated across the treatment and non-treatment to assess student perception of learning from the video lab report.

To collect data about student learning from the Claim, Evidence, Reasoning Paragraph students were given the Unit 3: Gravity Lab Pre-Test before they began the lab (Appendix M). This pre-test was four questions, three about the content that was covered in the lab and one about the process of the lab. The first question asked students about Newton's Third Law for objects exerting gravitational forces on each other. The next question asked how the gravitational force would change between two objects if both of their masses doubled. The third question asked students to identify the graph of force vs. distance for a rocket ship moving away from the Earth. The final question asked students to identify how to measure the distance between two objects when measuring the gravitational force between them. After each question students were asked to rank their confidence in their answer on a scale of 1 to 5 where 1 represented "The answer was a guess" and 5 represented "Fully confident." To fully assess student learning from the lab, students completed the Unit 3: Gravity Lab Post-Test three days after the conclusion of the lab (Appendix N). Students were asked four comparable questions to the pre-test. The first question asked about Newton's Third Law, the second about force vs. distance, and the third to identify a graph of force vs. mass for a rocket unloading its cargo at a constant distance. The final question was the same question and asked students to identify how to measure the distance between two objects. Again, students were asked to rank their confidence in their answers on the same 1-5 scale. To determine student learning, the questions on the pre-test and post-test were graded. The averages and standard deviations between the treatment group and non-treatment group were compared. Normalized gains were calculated to check for student growth between the treatment and non-treatment group. The average confidence was also calculated across the treatment and non-treatment to assess student perception of learning from the claim, evidence, reasoning paragraph lab report.

To collect data on student learning of content from the Email Home Lab Report students completed the Unit 4: Energy Lab Pre-Test before they began the lab (Appendix O). This pre-test was three questions, two regarding content from the lab and one about lab skills. The first question asked students to predict the height a ball would reach if rolling down a ramp with no friction. The second question asked about the relative amount of kinetic and potential energy at a given location for a ball that was dropped. The third question asked students to predict a source of error in an energy lab. After each question students were asked to rank their confidence in their answer on a scale of 1 to 5 where 1 represented “The answer was a guess” and 5 represented “Fully confident.” To fully assess student learning from the lab, students completed the Unit 4: Energy Post-Test three days after the conclusion of the lab (Appendix P). Three days after the conclusion of the lab corresponded with the due date of the lab summary method for students in the treatment group. The Unit 4: Energy Lab Post-Test was also made up of three questions. Students were asked comparable questions to the pre-test. Again, students were asked to rank their confidence in their answers on the same 1-5 scale. To determine student learning, the questions on the pre-test and post-test were graded. The averages and standard deviations between the treatment group and non-treatment group were compared. Normalized gains were calculated to check for student growth between the treatment and non-treatment group. The average confidence was also calculated across the treatment and non-treatment to assess student perception of learning from the email home lab report.

To collect data on student learning of content from the final lab report students completed the Unit 5: Momentum Pre-Test before they began the lab (Appendix Q). This pre-test was three questions, two regarding content from the lab and one about lab skills. The first two questions asked about the momentum gained or lost by objects in a collision. The third asked students to interpret a momentum graph. After each question students were asked to rank their confidence in their answer on a scale of 1 to 5 where 1 represented "The answer was a guess" and 5 represented "Fully confident." To fully assess student learning from the lab, students completed the Unit 5: Momentum Post-Test three days after the conclusion of the lab (Appendix R). Three days after the conclusion of the lab corresponded with the due date of the lab summary method for students in the treatment group. The Unit 5: Momentum Post-Test was also made up of three questions. Students were asked comparable questions to the pre-test. Again, students were asked to rank their confidence in their answers on the same 1-5 scale. To determine student learning, the questions on the pre-test and post-test were graded. The averages and standard deviations between the treatment group and non-treatment group were compared. Normalized gains were calculated to check for student growth between the treatment and non-treatment group. The average confidence was also calculated across the treatment and non-treatment to assess student perception of learning from their chosen lab report.

To collect data on student learning of content and skills from the labs, focus questions were intentionally placed on the unit summative exams. These exams were taken by both the treatment group and the non-treatment group on the same days. The Unit 3: Circular Motion and

Gravitation Exam had two focus questions relating directly to the content learned from the Circular Motion Lab, which was summarized with the Video Lab Report (Appendix S). One of these focus questions asked students to predict the centripetal force required of an object if the speed of the object doubled. The other question asked students to choose which graph best fit for an object with a centripetal force acting on it while its radius decreased. There were five focus questions on the Unit 3: Circular Motion and Gravitation Exam that directly related to the Gravitation Lab, which was summarized with the Claim, Evidence, Reasoning Paragraph. These questions asked students to predict the gravitational force between celestial bodies if the mass or distance changed, predict how forces change with distance, and state how the gravitational force changes at different locations in an orbit. The Unit 4: Energy Exam had four focus questions that directly related to content learned from the Conservation of Energy Lab, which was summarized with the Email Home Lab Report (Appendix T). All these focus questions dealt quantitatively with situations where energy was transferred from one form to another. The Unit 5: Momentum Exam had one focus questions that directly related to content learned from the Exploding Carts Lab, which students chose the method of summarization (Appendix U). This question asked students to predict the velocity ratio after an explosion collision with a known mass ratio. To determine student learning between the treatment group and non-treatment group for each lab summary method, the average score on each focus question was calculated as well as the standard deviation. The average of the focus questions was compared between groups.

To collect data on student learning of content and skills from the labs, student lab summaries were graded using the Video Lab Report Rubric, Claim, Evidence, Reasoning Paragraph Rubric, and the Email Home Lab Report Rubric for the respective lab report. The

Video Lab Report Rubric graded students on the purpose, hypothesis, procedure, graphs, conclusion, application, presentation, and timeliness of their project. The Claim, Evidence, Reasoning Paragraph Rubric graded students on their claim, first piece of evidence, first reasoning, second evidence, second reasoning, structure, and timeliness. The Email Home Lab Report Rubric graded students on their choice of recipient, tone, teachability/vocabulary, purpose, procedure, conclusion. The Email Home Lab Report also had a category for extra credit if the recipient responded with a question and students replied with a cohesive, factual answer. To assess learning from each lab summary, the average scores of content and lab skills off the rubric were calculated and compared within the treatment group.

The secondary focus analyzed how the method of summarizing labs impact student perception of their learning from the lab. Another secondary focus question analyzed how the method of summarizing labs impacted student enjoyment of the lab.

Quantitative and qualitative data was collected to answer this question in the Post Lab Summary Opinion Survey (Appendix V). This instrument was given to students on the day they turned in the lab summary method and before the post test. It was given before the post-test to ensure student perception of learning was measured, not their confidence in their responses on the post-test. In the Post Lab Summary Opinion Survey students were first asked to state how much time it took them to complete the lab summary. This was because a negative correlation between the time it took to complete the summary method and student enjoyment was anticipated. Then, students answered a series of Likert style questions about their learning, opinion about labs, and enjoyment of the labs. These Likert questions were on a 5 point scale where 1 represented “Strongly Disagree” and 5 represented “Strongly Agree.” The Likert style questions asked students to directly state their perception of learning and enjoyment of the lab with questions like, the lab summary helped me learn, I enjoyed using the lab summary method, the lab summary will help me remember the material, and the lab summary will help me with future labs. Other questions on the survey were asked to gauge student perception of labs such as I like doing labs and I learn better from doing labs than from lectures. Students then answered open-ended questions to gain more insight on their perceived learning from the lab. These questions asked students if they felt more confident after the lab summary, what their favorite and least favorite parts were, and if they enjoyed the lab summary method. The quantitative responses from the Likert questions were graphed and compared between the three lab summary methods. The open-ended survey questions were analyzed, grouped into categories, and compared to gain qualitative insight about student perception of learning and their enjoyment of the lab.

Qualitative data was also collected in the Post Lab Interview (Appendix W). A handful of focus students from various demographics were selected to participate in an interview after each lab summary method. Students were asked questions about their opinion about labs, the lab summary method, and their perceived learning from the lab summary method. Some of these questions were used to gain baseline information about students' perceptions of labs and their history with lab reports. These questions were, do you like doing labs, do you think labs help you learn material, how did you summarize labs in previous science courses. Then, questions were asked about the lab summary method such as, how did you feel about the lab summary method, what did you like about the lab summary method, what didn't you like about it, and did it help you learn. This was used to gain qualitative insight into student perception of learning and their enjoyment of the lab summary methods. The qualitative responses were grouped and assessed for the major trends.

After each lab summary method had been used, students engaged in one final lab, the Exploding Carts Lab. After the lab, students were instructed to use the Student Choice Survey to choose which lab summary method they wanted to use to summarize their findings (Appendix X). Students were asked to choose the method and explain their reasoning for choosing the method. This quantitative data was graphed to see how many students preferred a given method. The qualitative data was collected and analyzed to see what factors led a student to make their choice. The data was further used to see which lab summary method students learned the most from when compared within the treatment group.

Table 2. Data triangulation matrix showing the data sources used to further each focus question.

Focus Questions	**Data Source 1**	**Data Source 2**	**Data Source 3**
Primary Question:	Unit 3: Circular Motion Lab Pre-Test Unit 3: Circular Motion Lab Post-Test Unit 3: Gravity Lab Pre-Test Unit 3: Gravity Lab Post Test Unit 4: Energy Lab Pre-Test Unit 4: Energy Lab Post-Test Unit 5: Momentum Pre-Test Unit 5: Momentum Post-Test	Unit 3: Circular Motion and Gravitation Exam Focus Questions Unit 4: Energy Exam Focus Questions Unit 5: Momentum Exam Focus Questions	Video Lab Report Rubric Claim, Evidence, Reasoning Paragraph Rubric Email Home Lab Report Rubric
How does the method of lab summarization impact student ability to learn the content and skills from the lab?			
Secondary Questions:			
How does the method of summarizing the lab have an impact on student perception of their learning from the lab?	Post Lab Opinion Survey	Student Interviews	Student Choice Survey
How does the method of summarizing the lab have an impact on student enjoyment of the lab process?	Post Lab Opinion Survey	Student Interviews	

DATA ANALYSIS

Results

Student Learning

According to the Post Lab Opinion Survey, 81% of students agreed that the Video Lab Report helped them learn (*N*=21). Seventy-one percent of students agreed that the Claim, Evidence, Reasoning Paragraph helped them learn and 71% agreed that the Email Home Lab Report helped them learn. To assess student learning from each lab summary, students were given a pre-test before the lab and a post test after the lab summary was due. The Unit 3 Circular Motion Pre and Post test assessed learning from the Video Lab Report. The Unit 3: Gravitation Pre and Post test assessed learning from the Claim, Evidence, Reasoning Paragraph, and the Unit 4: Energy Pre and Post test assessed learning from the Email Home Lab Report. The treatment group who completed the lab summary methods was given the same pre-test and post-test as the non-treatment group for each lab summary. The treatment group had an increase of 24% from the Unit 3: Circular Motion Pre-Test to Post-Test, going from an average of 32.0% to 56.0% (Figure 1). The percent increase of the non-treatment group on the same tests was 10.1%, moving from 35.0% to 45.1%. The treatment group had an increase of 23.0% from the Unit 3: Gravitation Pre-Test to Post-Test, going from 38.5% to 61.5%. The non-treatment group had a percent increase of 12.0% (39.3% to 51.3%). On the Unit 4: Energy Pre-Test to Post-Test, the treatment group's average score increased by 20.9% (45.8% to 66.7%). The non-treatment group had an increase of 26.3% (40.4% to 66.7%).

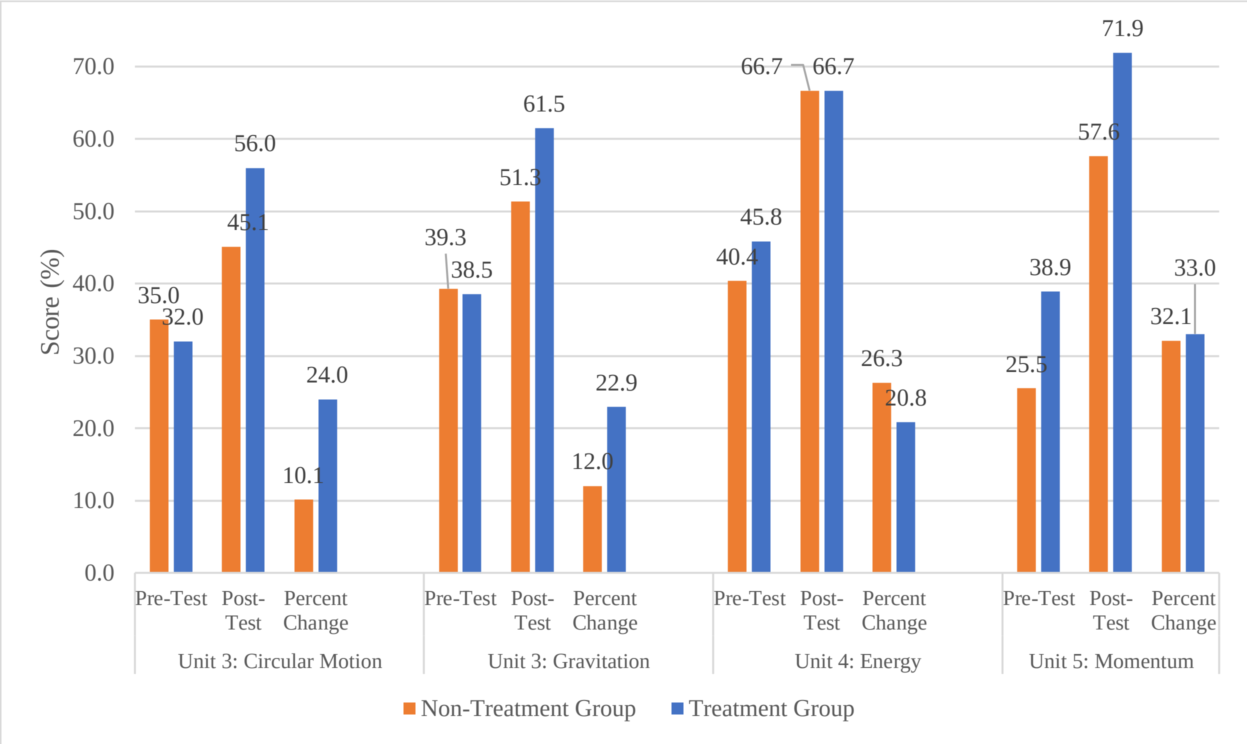

Figure 1. Average Pre-test and Post-test score between the treatment group and the non-treatment across all assessments, (*N* =21).

To better compare the treatment and non-treatment group, the normalized gain of each group was calculated for each pre- and post-test. For the Unit 3: Circular Motion tests, the average normalized gain for the treatment group was 35.0% while the average normalized gain was 16.0% for the non-treatment group (Figure 2). According to Hake (1998), the treatment group had a medium gain while the non-treatment group had a low gain. For the Unit 3: Gravitation tests, the average normalized gain for the treatment group was 37.0% while the average normalized gain was 20.0% for the non-treatment group. According to Hake (1998), the treatment group had a medium gain while the non-treatment group had a low gain. For the Unit 4: Energy tests the average normalized gain for the treatment group was 38.0% while the average normalized gain was 44% for the non-treatment group. According to Hake (1998), both groups had a medium gain.

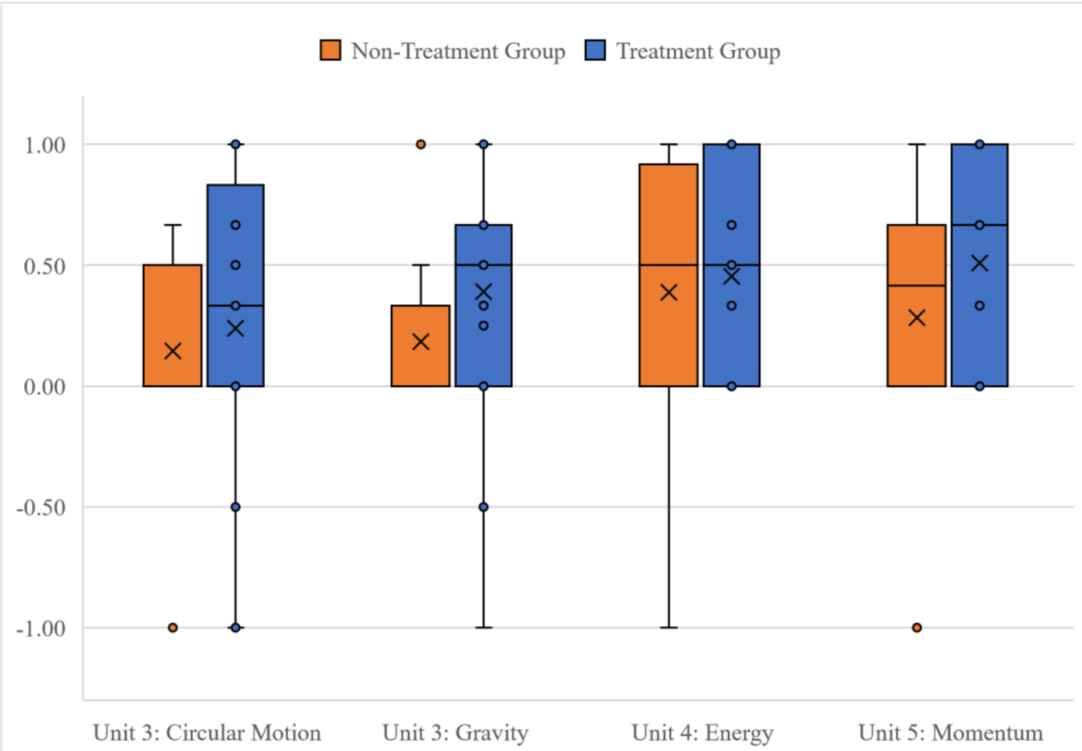

Figure 2. Average normalized gain between treatment group and non-treatment group for each pre-test and post-test, (*N*=21).

Video Lab Report

Sixty-seven percent of students said in the Post Lab Opinion Survey agreed that the Video Lab Report would help them on future assessments (*N*=21). When asked about their learning from the Video Lab Report and its application to future assessments, one student in the treatment group claimed it led to an increase in understanding, stating, "Something that I wasn't really expecting was how the video lab report made me understand the equations more because I was having to explain my reasonings. And so I ended up using the equations as evidence, which helped me think through the process and how the equations backed up my claims." The Unit 3: Circular Motion assessment had two focus questions that directly corresponded to student learning from the lab (Figure 3). Students had to evaluate the relationship between centripetal force and speed (Question 6). Forty-six percent of students in the treatment group evaluated this relationship correctly (*N*=24). Fifty percent of students in the non-treatment group got Question 6 correct (*N*=18). Students were asked students to choose a centripetal acceleration vs. time graph for a ball moving in a circular path with a constantly decreasing radius (Question 7). Seventy-nine percent of students in the treatment group answered this question correctly and 72% of students in the non-treatment group answered correctly.

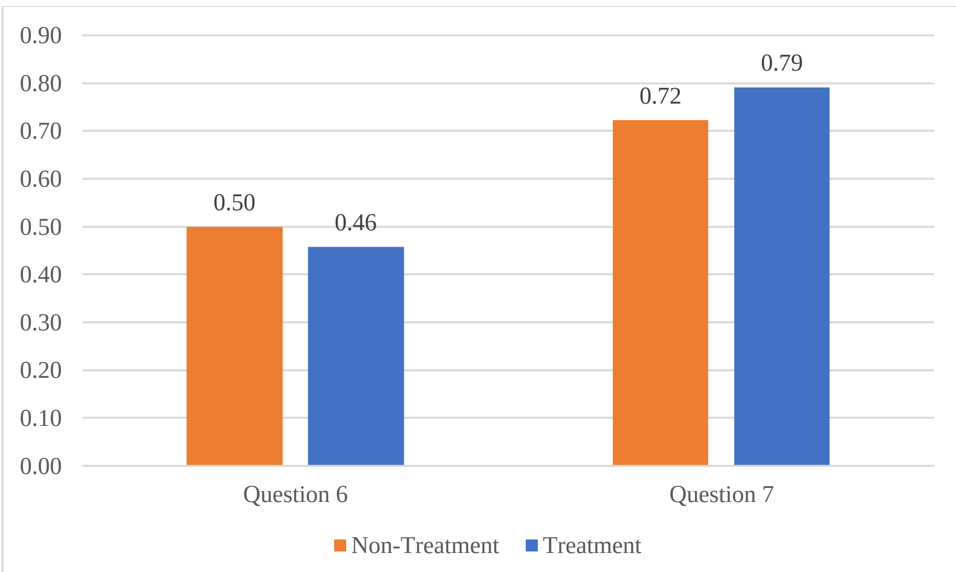

Figure 3. Comparison of percentage of students who correctly answered the circular motion focus questions, (*N* = 24). Note: Question 6=A car with speed v and an identical car with speed 2v both travel the same circular section of an unbanked road. If the frictional force required to keep the faster car on the road without skidding is F, then the frictional force required to keep the slower car on the road without skidding is; Question 7=A ball of mass swings in a horizontal circle at the end of a string of radius at a constant tangential speed. A student gradually pulls the string inward such that the radius of the circle decreases while keeping the tangential speed of the ball constant, as shown above. Which of the following graphs best represents the acceleration of the ball as a function of time?

The Video Lab Report was graded with the Video Lab Report Rubric. On average, students scored a 91.6% on the Video Lab Report. The average score for lab skills on the rubric (purpose, hypothesis, procedure, and graphs) was 90.2%. The average score for students summarizing and applying their knowledge of the centripetal force equation was 88.3%.

<u>Claim, Evidence, Reasoning Paragraph Lab Report</u>

Sixty-seven percent of students said in the Post Lab Opinion Survey agreed that the CER would help them on future assessments (*N*=21). In a student interview, one student stated, "I found myself looking back at the CER to study for the tests." The Unit 3: Circular Motion assessment had three focus questions that directly corresponded to student learning from the lab (Figure 4). The first focus question asked students to evaluate the relationship between gravitational force and an increasing distance (Question 8). Fifty-four percent of students in the treatment group got Question 8 correct (*N*=24). Fifty-six percent of students in the non-treatment group got Question 8 correct (*N*=18). Question 8 had one distractor answer that still displayed a basic understanding of content covered in the lab. This answer showed an understanding that increasing the distance between objects results in a decrease in gravitational force, however not at the correct 1/r squared ratio. Twenty-five percent of students in the treatment group chose this distractor answer and 28% of students in the non-treatment group chose it. In total, 79% of students in the treatment group and 83% of students in the non-treatment group chose an answer that displayed some learning from the lab. The next focus question asked about the relationship between mass, distance, and gravitational force between two objects (Question 11). Students had to use qualitative relationships between the variables to determine which of the two objects had a larger force acting on it. Seventy-nine percent of students in the treatment group answered this question correctly and 67% of students in the non-treatment group answered correctly. The third focus question asked students about the relationship between force and distance for an object in orbit (Question 14). Ninety-six percent of students in the treatment group and 93% of students in the non-treatment group correctly identified that as the planet's distance increased its gravitational force would decrease.

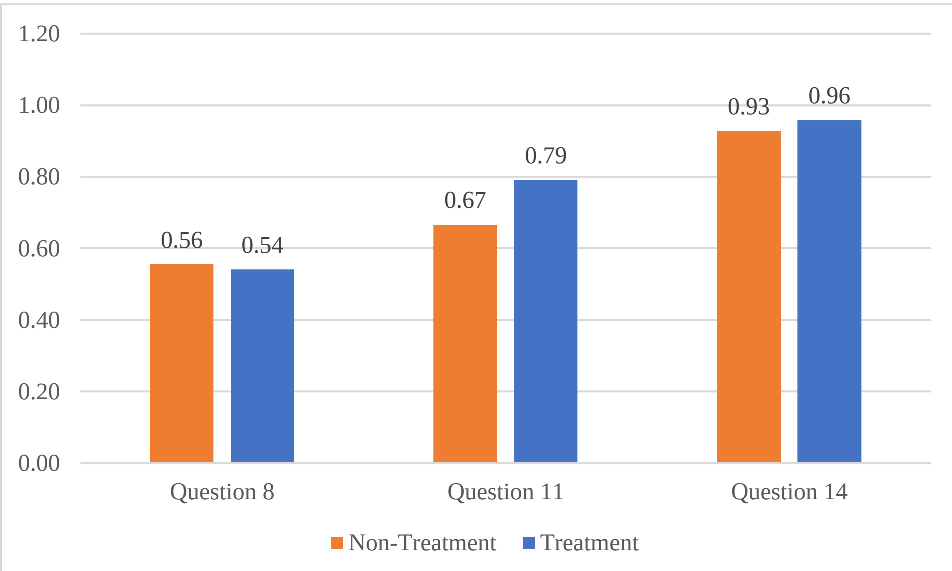

Figure 4. Comparison of percentage of students who correctly answered the gravitation focus questions, (*N*=24). Note: Question 8=An object has a weight W when it is on the surface of a planet of radius R. What will be the gravitational force on the object after it has been moved to a distance of 4R from the center of the planet?; Question 11=The masses of the two moons are determined to be 2M for Moon A and M for Moon B. It is observed that the distance between Moon B and the planet is two times that of the distance between Moon A and the planet. How does force exerted from the planet on Moon A compare to the force exerted from the planet on Moon B?; Question 14=As the moon orbits the planet from position A to position B, is the magnitude of the planet's force due to gravity exerted on the moon constant? Why or why not?

The CER was graded on with the Claim, Evidence, Reasoning Paragraph Rubric. On average, students scored an 89.9% on the CER. The average score for lab skills on the rubric (claim, evidence 1, and evidence 2) was 91.6%. The average score for students summarizing and applying their knowledge of the gravitational force equation was 82.3%. A student who received a perfect score on the CER was able to claim, “A black hole is somewhere in space where gravity is so strong that not even light can escape it; the reason they are able to apply an incredibly strong gravitational force on other objects is due to the fact that matter can get very close to them and their large mass pulls things inwards.” As evidence, this student said, “In the experiment that measured the relationship between $Mass_1$ and the force between the two objects, it was illustrated that as the mass increased, the amount of gravitational force between the two masses increased. As portrayed in *Graph 1* (Figure 5), there was a linear relationship and significant upward trend between the amount of mass and the force between the two objects.”

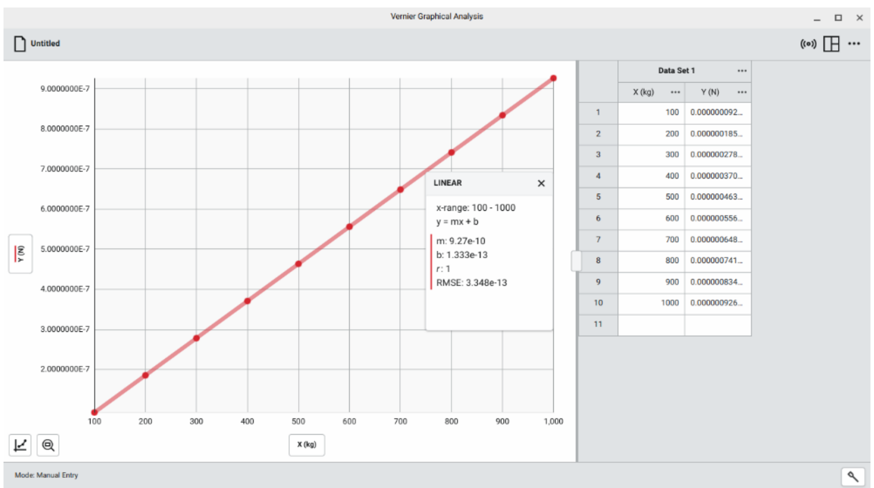

Figure 5. An example of a graph a student made as evidence for the relationship between mass and force.

<u>Email Home Lab Report</u>

Seventy-one percent of students said in the Post Lab Opinion Survey agreed that the Email Home Lab Report would help them on future assessments (N=24). The Unit 4: Energy Assessment had four focus questions that directly corresponded to student learning from the lab (Figure 6). The first focus question asked students to calculate the transfer of potential energy to kinetic energy for a falling pendulum (Question 3). Fifty-six percent of students in the treatment group got Question 3 correct (*N*=25). Thirty-five percent of students in the non-treatment group got Question 3 correct (*N*=20). The next focus question asked students to analyze a falling pendulum and assess through which displacement the pendulum bob has the greatest transfer from potential energy to kinetic energy (Question 6). Forty-four percent of students in the treatment group chose correctly and 35% of students from the non-treatment group chose correctly. The third focus question was a pure energy conservation question asking students to calculate the speed of a block after falling a certain height down a ramp (Question 8). Seventy-six percent of students in the treatment group got this question correct and 80% in the non-treatment group got it correct. The final focus question asked about a situation where energy was lost after a ball bounces on the ground (Question 13). Sixty-eight percent of students in the treatment group got this question correct while 70% in the non-treatment group got it correct.

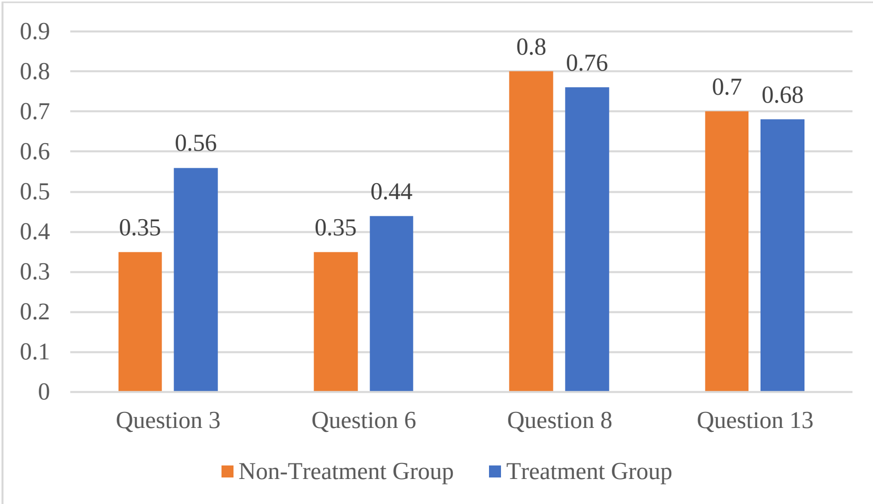

Figure 6. Comparison of percentage of students who correctly answered the energy focus questions, (*N*=24). Note: Question 3=A 0.5kg pendulum bob is raised to 1.0 m above the floor, as shown in the figure to the right. The bob is then released from rest. When the bob is 0.8m above the floor, its speed is most nearly; Question 6=A ball is suspended by a lightweight string, as shown in the figure to the right. The ball is displaced to position 1 and released. The four labeled positions are evenly spaced along the arc of the ball's motion. Between which adjacent pairs of positions is the change in kinetic energy of the ball greatest; Question 8=A 2kg block, starting from rest, slides 20m down a frictionless inclined plane from X to Y dropping a vertical distance of 10 m as shown to the right. The speed of the block at point Y is most nearly; Question 13=A rubber ball with mass 0.20kg is dropped vertically from a height of 1.5m above a floor. The ball bounces off of the floor, and during the bounce 0.60J of energy is dissipated. What is the maximum height of the ball after the bounce?

The Email Home Lab Report was graded on with the Email Home Lab Report Rubric. On average, students scored an 82.8% on the Email Home Lab Report. The average score for lab skills on the rubric (purpose and procedure) was 93.4%. The average score for students summarizing and applying their knowledge of energy conservation was 81.5%. As an example of summarizing and applying their knowledge of energy conservation, one student wrote, "Remember a couple of months ago when we went sledding in Park City Utah and were wondering how the different heights of each hill related to the final speed of the sled. Today in physics class we did a lab that helped me figure out why! In our lab today we tested how energy is conserved. The principle of the conservation of energy says that energy within an isolated system is not taken or made, it is simply transferred from one type of energy to another. To check how the different heights of each hill changed the speed, we set up an experiment that was a lot like the sledding example. First, we set up two photogates right on top of each other to find the velocity. A photogate is a device we use to find the speed of an object going through its arms. Next what we did was drop a tennis ball through a photogate at different heights and find the velocity of the ball as it went through the photogate to determine if energy is conserved like in the sledding example." A student who scored highly on the Email Home Lab Report was able to show her understanding of her data by stating, "My lab group graphed the amount of energy in the ball at its maximum height versus the amount of energy in the ball when it was first launched. You can see in the graph above (Figure 7) that the line has a slope of 1.043. You're pretty good at math, so I'm sure you know this means that the energy values remained pretty much the same when the ball was first launched and when it was at its highest point. Of course, if it was a perfect experiment, the slope would be closer to 1, but the additional 0.043 probably comes from error in the experiment. Since it's pretty hard to get a 100 percent accurate height measurement, this can account for some of the error. Additionally, it's nearly impossible to get the exact speed of the ball when it's immediately launched, so this also makes up some of the error. Regardless, the numbers show that the lab was pretty much accurate with very few errors."

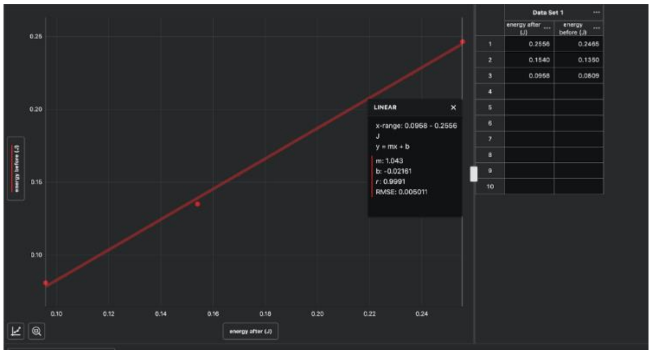

Figure 7. A graph a student used as evidence in her Email Home Lab Report.

Student Choice

After all three lab summary methods had been used, students were allowed to choose any of the three methods to summarize their conservation of momentum lab. Students were given the Unit 5: Momentum Pre-Test before the lab and the Unit 5: Momentum Post-Test after turning in the lab report. Students in the treatment group who chose the Video Lab Report had an average normalized gain of 0.28, low according to Hake (1998) (Figure 8).

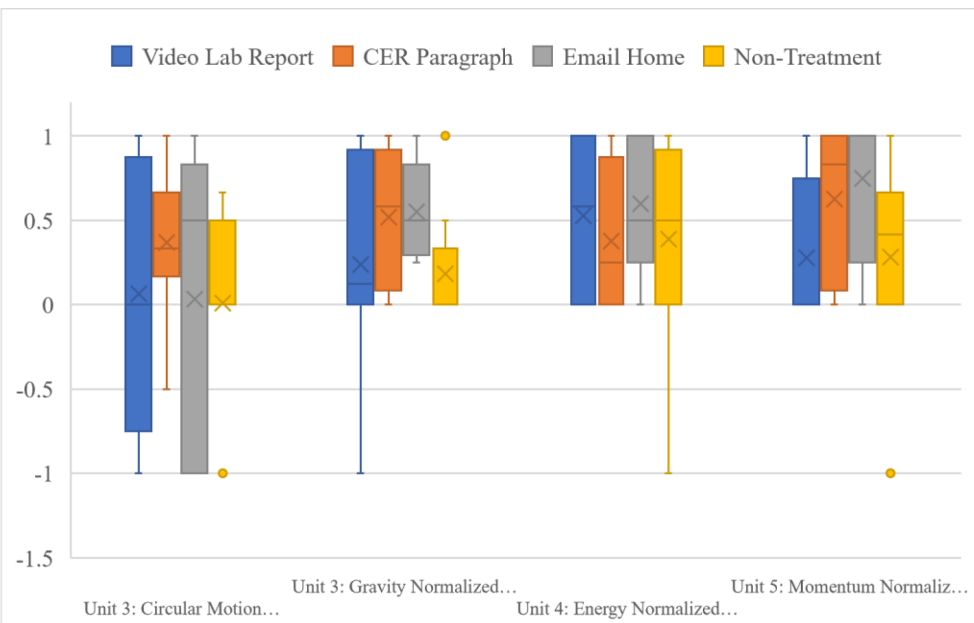

Figure 8. Average normalized gain between pre-test and post-test separated by final choice of lab summary method, (*N*=24).

Students who chose the Claim, Evidence, Reasoning Paragraph had an average normalized gain of 0.63, medium according to Hake (1998). Students who chose the Email Home Lab Report had an average normalized gain of 0.75, high according to Hake (1998). Students in the non-treatment group had an average normalized gain of 0.28. On the Unit 5: Momentum Test there was one question that correlated directly to the content covered in the lab. This question asked students to predict the velocity ratio of two carts after an explosion collision based on the mass ratio (Question 7). Fifty-seven percent of students who chose to summarize their lab with the Video Lab Report answered this question correctly (Figure 9). Seventy-eight percent of students who chose the CER answered this question correctly and 100% of students who chose the Email Home Lab Report got this question correct. On average, 73% of students in the treatment group answered this question correctly. Eighty percent of students in the non-treatment group answered this question correctly.

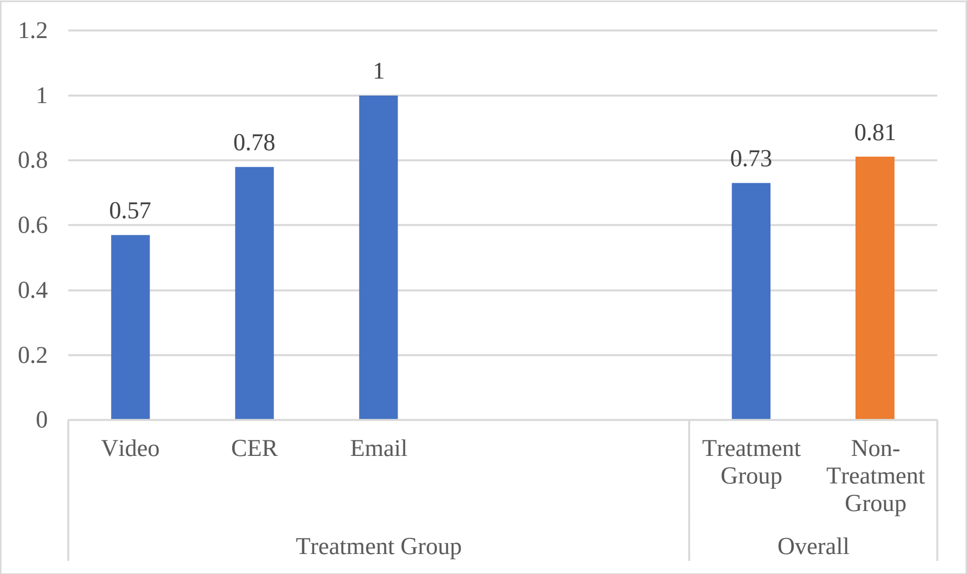

Figure 9. Percentage of students who accurately answered the momentum focus question, (*N*=24). Note: Question = Two objects, A and B, initially at rest are exploded apart by the release of a coiled spring that was compressed between them. As they move apart, the velocity of object A is 5m/s and the velocity of object B is -2m/s. The ratio of the mass of object A to the mass of object B, is?

<u>Perception of Learning in Treatment vs. Nontreatment Group</u>

According to the Post Lab Opinion Survey students in the treatment group agreed that a lab summary method helped them better learn the material from the lab (Figure 10). Students in the treatment group were asked to answer the question, “The lab summary helped me learn.” The average response among all lab summary methods was a 3.9 with a standard deviation of 0.83 (*N*=66).

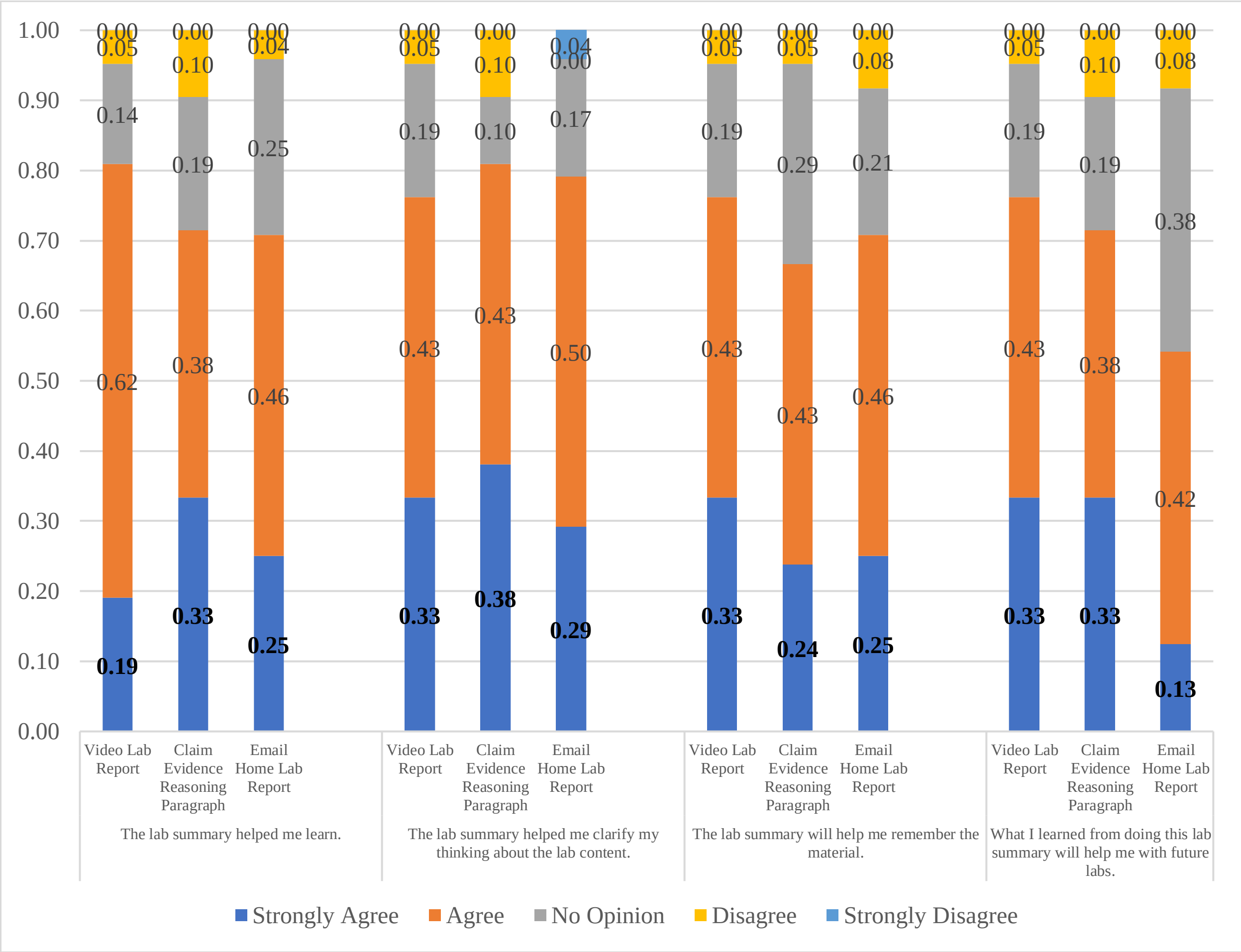

Figure 10. Post lab opinion survey data showing student responses to Likert questions regarding the perception of their learning, (*N*=24).

This change in student perception of learning is reflected in student confidence rankings from each Pre-test and Post-test (Table 3). Students were asked to rank their confidence on a 5-point scale after each question on the pre-test and post-test where 5 represented fully confident. The treatment group and non-treatment group began with similar confidence values, 2.43 vs. 2.50. The treatment group showed a greater average increase in confidence of 1.36 points, while the non-treatment group's confidence grew by 0.68 points. When asked about their confidence in their learning after a lab summary a student in the treatment group said, "I felt more confident because the lab summary helped me solidify my knowledge of the content, and review what I had learned." This trend was consistent among content confidence and lab skills confidence. Students in the treatment group's confidence in content questions grew by 1.31 points and their confidence in lab questions grew by 1.50 points. Students in the treatment group were asked to answer the question, "The lab summary helped me clarify my thinking about the lab content" on a 5-point Likert Scale. The average response among all lab summary methods was a 4.05 with a standard deviation of 0.89 (*N*=66). Students also agreed with the statement, "The lab summary will help me remember the material," with an average Likert rating of 3.92. When asked about their content confidence in their learning after a lab summary a student in the treatment group said, "After going back and looking through my lab notes again and putting them into full thoughts and explaining them the content sunk in more." Student confidence in lab skills was also assessed. Students in the treatment group were asked to answer the question, "What I learned from doing this lab summary will help me with future labs." The average response among all lab summary methods was a 3.85 with a standard deviation of 0.89 (*N*=66). In an interview a student said, "I was more mindful of thinking through what we were doing for the procedure. I wanted to understand it on another level so I could explain it."

Table 3. Average confidence in pre- and post- test answers between treatment and non-treatment groups.

	Average Confidence Pre-Test			Average Confidence Post-Test			Average Change in Confidence		
	Content	Lab Skills	Overall	Content	Lab Skills	Overall	Content	Lab Skills	Overall
Treatment Group	2.43	2.36	2.43	3.74	3.86	3.79	1.31	1.50	1.36
Non-Treatment Group	2.47	2.55	2.50	3.12	3.28	3.18	0.64	0.73	0.68

Student Perception of Learning from Video Lab Report

According to the Post Lab Opinion Survey, 81% of students agreed that the Video Lab Report helped them learn (*N*=21*)*. Nineteen percent of students strongly agreed that the Video Lab Report helped their learning. Seventy-six percent of students agreed that the Video Lab Report helped clarify the content from the lab and 76% agreed that the report would help them with future labs. Before the video lab report, students in the treatment group answered questions about the content covered in the lab in the Unit 3: Circular Motion Lab Pre-Test with a confidence level of 2.35. Upon completion of the Video Lab Report students completed the Unit 3: Circular Motion Lab Post-Test and answered questions with an average confidence level of 3.97, a growth of 1.63 points. The non-treatment group took the same pre-test and post-test and had a change in confidence of 0.57 points (from 2.68 to 3.25).

On the Post Lab Opinion Survey 90% of students stated that they felt more confident about their understanding of the lab and lab content after completing the video lab report. Of the students who felt more confident, 75% attributed being able to review the lab material as their primary reason for a growth in confidence (Table 4). Students who cited having an outlet to review the information for their main increase in confidence on average gave a Likert score of 3.83 to the statement “The lab summary helped me learn.” One student said, “I definitely feel more confident about my understanding of the lab. Because I sat down, created the slideshow/Flipgrid, and actually thought through what the lab was teaching us, I was able to understand it better in the end.” Twenty-five percent of students attributed their increase in confidence towards having an outlet to synthesize their learning in the Video Lab Report.

Table 4. Student main reason for increase in confidence after Video Lab Report, (*N*=21).

Main Reason for Increase in Confidence	Percent of Students who Increased in Confidence
Reviewing Lab Content	75%
Synthesizing Lab Content	25%

Students who cited using the lab to synthesize the information for their main increase in confidence on average gave a Likert score of 4.25 to the statement “The lab summary helped me learn” (Figure 11). In an interview, a student who felt she learned from the Video Lab Report said, “I think making the video for the lab report definitely helped me sort through my thoughts more and just helped me come to my own understanding of what we were learning.” In the Post Lab Opinion survey another student said, “I feel more confident. Having to present my explanations helped me think through my thoughts and the video presentation helped me better communicate my understanding of the physics concepts we learned.” Students who did not feel that the Video Lab Report increased their confidence cited feeling as if they already learned the material from the lab, saying, “I feel roughly equally confident, since the summary was more of me just restating everything rather than learning it for the first time.”

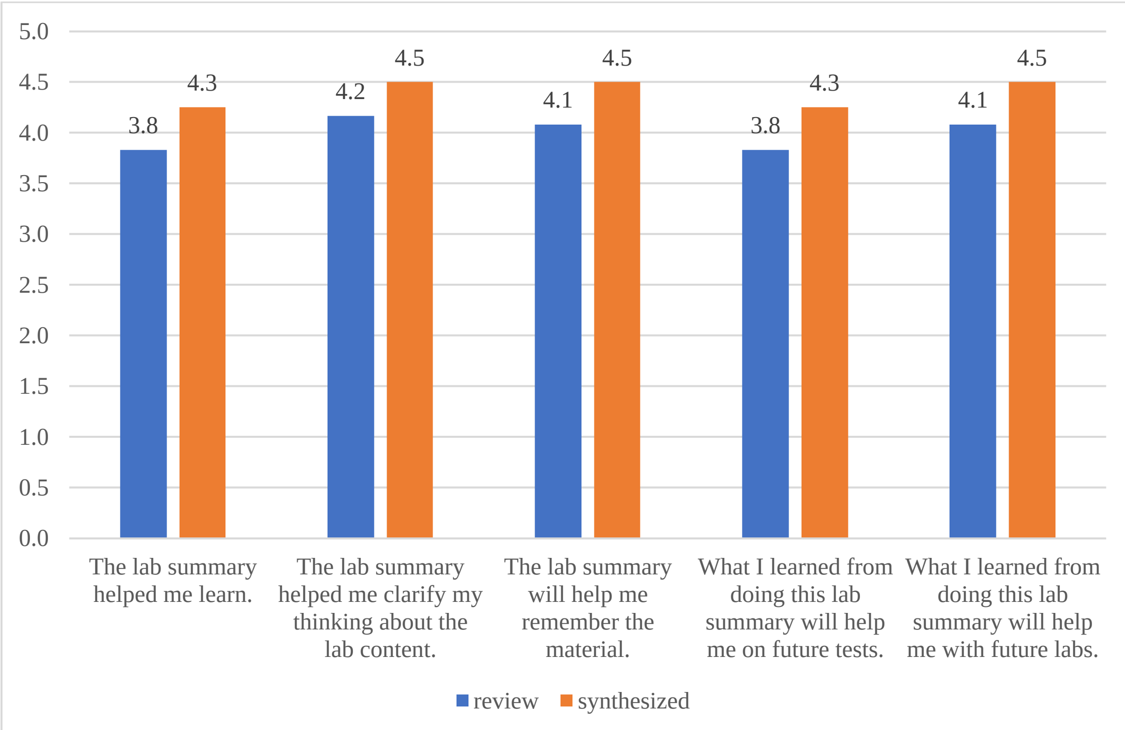

Figure 11. Post lab opinion Likert survey data for student learning questions vs. their primary reason for saying the Video Lab Report increased their confidence, (*N* =21).

Student Perception of Learning from Claim, Evidence, Reasoning Paragraph

According to the Post Lab Opinion Survey, 71% of students agreed that the Claim, Evidence, Reasoning Paragraph helped them learn (*N*=21). Thirty-three percent of students strongly agreed that the CER helped their learning. Eighty-one percent of students agreed that the CER helped clarify the content from the lab and 71% agreed that the report would help them with future labs. Before the CER, students in the treatment group answered questions about the content covered in the lab in the Unit 3: Gravitation Pre-Test with a confidence level of 2.59. Upon completion of the CER students completed the Unit 3: Gravitation Post-Test and answered questions with an average confidence level of 3.82, a growth of 1.23 points. The non-treatment group took the same pre-test and post-test and had a change in confidence of 0.89 points (from 2.62 to 3.51).

On the Post Lab Opinion Survey 86% of students stated that they felt more confident about their understanding of the lab and lab content after completing the CER. Of the students who felt more confident, 39% attributed using the CER to synthesize their learning from the lab as the primary reason for a growth in confidence (Table 5). One student said, “I did feel more confident after completing the lab summary because I was able to go over the evidence more in depth and understand the relationships in a clearer way.” Twenty-eight percent of students attributed their increase in confidence towards having to better understand the quantitative relationship between variables in the lab. Students who cited using the CER to better understand the quantitative relationships for their main increase in confidence on average gave a Likert score of 4.8 to the statement “The lab summary helped me learn.” Regarding the quantitative relationships a student said, “I did feel more confident about my understanding of the lab and lab content after completing the summary because I got to work with the numbers that involve calculating gravitation.”

Table 5. Student main reason for increase in confidence after CER, (*N*=21).

Main Reason for Increase in Confidence	Percent of Students who Increased in Confidence
Quantitative Relationships	28%
Synthesizing Lab Content	39%
Reviewed Content from Lab	22%
Applied Learning	11%

When writing the CER students had to explain what a black hole was based on the relationships derived in the lab. Eleven percent of students cited this real-world application as the main reason they felt the CER impacted their confidence of the lab material. Of these students, the average Likert score indicating their learning from the lab was a 4.5 (Figure 12). One student said, “I feel like I know a lot more about the graphical and mathematical relationship between my variables now, which I can apply to the real world.” Students stated they were more cognizant during the lab knowing they needed to apply their learning to answer a question. In an interview a student said, “I was more mindful about focusing on the big question during the lab for the CER.”

Fourteen percent of students said they did not gain confidence from the CER according to the Post Lab Opinion Survey. These students felt they learned from the lab and did not have a change in understanding from working on the CER. One student said, “Not really. I was already pretty confident on my understanding of the lab and the CER couldn't really add that much to my confidence.”

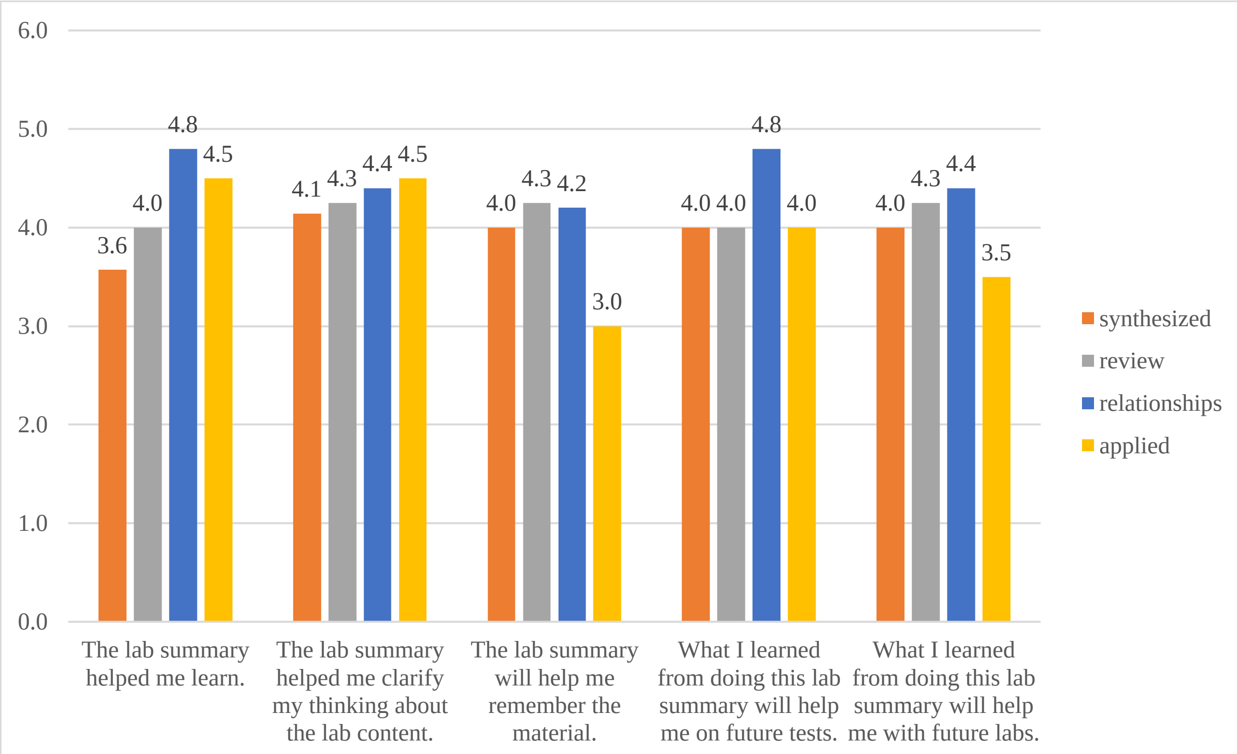

Figure 12. Post lab opinion Likert survey data for student learning questions vs. their primary reason for saying the CER increased their confidence, (*N* =21).

<u>Student Perception of Learning from Email Home Lab Report</u>

According to the Post Lab Opinion Survey, 71% of students agreed that the Email Home Lab Report helped them learn (*N*=24). Twenty-five percent of students strongly agreed that the Email Home Lab Report helped their learning. Seventy-nine percent of students agreed that the Email Home helped clarify the content from the lab and 55% agreed that the report would help them with future labs. Before the Email Home Lab Report, students in the treatment group answered questions about the content covered in the lab in the Unit 4: Energy Pre-Test with a confidence level of 2.45, where 5 represents "full confidence." Upon completion of the Email Home Lab Report students completed the Unit 4: Energy Post-Test and answered questions with an average confidence level of 3.62, a growth of 1.17 points (Figure 13). The non-treatment group took the same pre-test and post-test and had a change in confidence of 0.54 points (from 2.47 to 3.01).

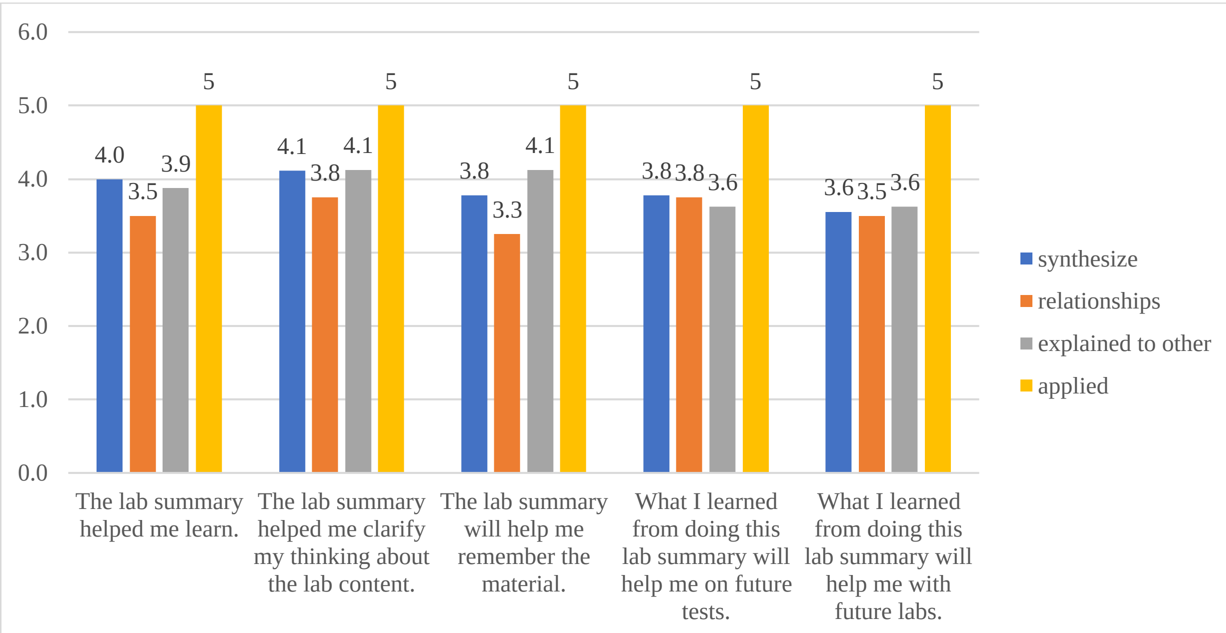

Figure 13. Post lab opinion Likert survey score for student learning questions vs. their primary reason for saying the Email Home Lab Report increased their confidence, (*N* =24).

On the Post Lab Opinion Survey 96% of students stated that they felt more confident about their understanding of the lab and lab content after completing the Email Home Lab Report. Of the students who felt more confident, 36% attributed having to explain their learning to someone else in a non-scientific way as the primary reason for a growth in confidence (Table 6).

Table 6. Student main reason for increase in confidence after Email Home Lab Report, (*N*=24).

Main Reason for Increase in Confidence	Percent of Students who Increase in Confidence
Quantitative Relationships	18%
Synthesizing Lab Content	41%
Explained to Someone	36%
Applied Learning	5%

One student said, “Yes, it helped me ‘dumb it down’ so that I understood the concept in a more simple way.” This theme appeared in interview data as well. One interviewed student said, “I understood the lab but then I was kind of confused about the conclusion because we were talking about one Joule in, one Joule out. And then when I was explaining it to my mom and looking back I was like, oh, that made sense!” Students also cited in the post lab opinion survey and interviews that knowing they had to send it to someone forced them to pay more attention during the lab. One student said, “I had to pay more attention. Then I enjoyed the lab more naturally because I was more involved in it, so I think that’s a consequence to needing to summarize it.” In the Post Lab Opinion Survey and interviews students indicated that sending this to someone allowed them to deepen their learning by having further conversations with their recipient. One student said, “The email home was the spark that created that discussion and the further interest my mom had… You're excited to have future conversations.” In the Post Lab Opinion survey 13% of students who cited explaining the lab to others as their main reason for a change in confidence indicated that having to explain the learning to someone hindered their ability to learn from the lab. One student said, “I feel like saying everything in the simplest terms doesn't give me room to actually think about the outcome.”

Student Choice based on Perception of Learning

After each lab summary method, students completed one final lab where they were allowed to choose one of the three lab summary methods to use. Sixty percent of students chose the lab summary method that corresponded to their highest perception of learning based on the Likert Survey question, “This lab summary method helped me learn.” Twenty percent of students chose the summary they said they learned the least from. On the Student Choice Survey

40% of students said they chose their lab summary method based on how it impacted their learning. One student who chose the video lab report said, “I process my thoughts best when I am able to talk about them out loud and this allows me to do this.” On the Unit 5: Momentum Pre-lab and Post-lab students were asked to rank their confidence when answering each question. Students who chose the CER as their lab summary method recorded the greatest average change in confidence at 1.5 points (Figure 14). The change in confidence for those who chose the email and the video lab report were both 1.2. All were greater than the non-treatment group at 0.7.

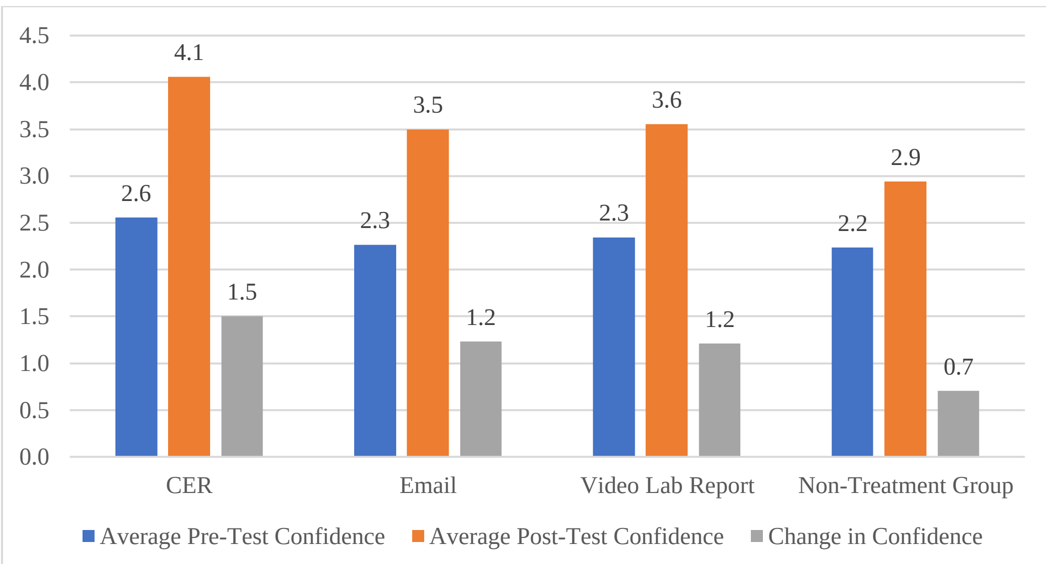

Figure 14. Student confidence change from pre-test to post-test based on lab summary method, (*N*=24).

<u>Student Enjoyment of Labs</u>

The treatment group is a population that generally enjoys using labs in science classes and prefers learning through labs than lectures.

After each lab students in the treatment group completed the Post Lab Opinion Survey about their attitude towards labs as a whole and the specific lab summary method they had just completed. The first eleven questions were set up using a Likert scale.

Question #6 on the Post Lab Opinion Survey asked students to use the Likert scale to respond to the statement "I like doing labs." The first time students were given the Post Lab Opinion Survey, 24% strongly agreed that they liked doing labs (*N*=21*)*. Fifty-seven percent agreed that they liked doing labs and 10% held no strong opinion about labs (Figure 15). Student interviews conducted after each treatment further the idea that the treatment group enjoys performing labs. Of the students interviewed, 4 responded favorably to the question "I like doing labs" (*N*=5*)*. Fifty percent of interviewed students who said they enjoyed labs cited the tangible nature of the lab. One student said, "I like how you can take kind of abstract knowledge and see it represented in real life."

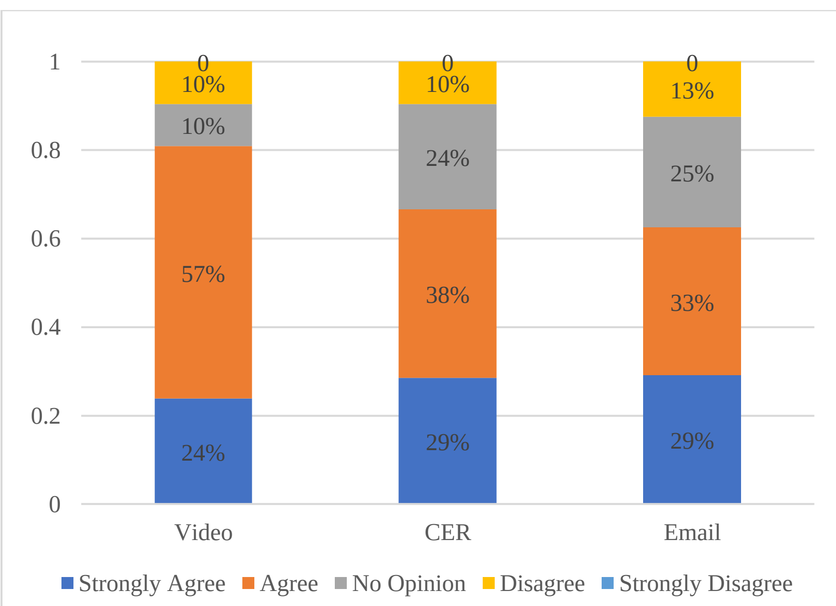

Figure 15. Post lab opinion survey response to the question, "I like doing labs," (*N*=24).

Ten percent of students answered with a dislike for labs (*N*=21*)*. One of the interviewed students fell in this category. This student cited a dislike for the openness of inquiry style labs and the lack of there being one right answer. This student said about labs, "I kind of just want it to be clear cut."

Student Enjoyment of Video Lab Report

The results of the Post Lab Opinion Survey indicated that 62% of students enjoyed using the Video Lab Report as a lab summary method (*N*=21). Twenty-four percent of the treatment group indicated a strong enjoyment of the Video Lab Report. The average response was a 3.71 and there was a standard deviation of 0.98.

Participants were asked in an open response style question to justify the primary reason for their enjoyment of the Video Lab Report. These primary reasons can be grouped into five main categories: novel/new, helped understanding, time, collaborative, creativity (Table 7).

Table 7. Primary reason for student enjoyment of Video Lab Report, (*N*=21).

Primary Reason Cited for Enjoyment	Percent of Respondents	Average Score of Enjoyment
Novel/New	33%	4.57
Helped Understanding	24%	3.60
Time	19%	2.75
Collaborative	14%	4.33
Creativity	10%	5

Thirty-three percent of participants cited the novel/newness of the lab summary method when gauging their enjoyment of the Video Lab Report. The average Likert score of participants who cited the newness of the Video Lab Report as their main reason for enjoyment was a 4.57. One student who said they strongly enjoyed the lab summary method was because "it was fun to try something new." Interview data supported the idea that students enjoyed the newness of the format. In one interview a student was asked what he had done in previous science classes to summarize labs. He stated, “We just summarized the lab in a Google Doc. Basically we just typed up what we learned, the conclusion, our results, procedure, hypothesis, all that stuff. They were pretty boring. They were tedious and felt like I had to do it to get it out of the way.” When asked about his enjoyment of the Video Lab Report, he stated, “It was a change in pace. I liked it. It was a bit more different than what I usually do so I enjoyed it. There's a lot of freedom in the format that you gave us, we could do anything we wanted. All we had to do was just present our findings and results but we could do anything.”

Ten percent of participants cited the creativity of the lab summary method when gauging their enjoyment of the Video Lab Report. The average Likert score of participants who cited the creativity of the Video Lab Report as their main reason for enjoyment was a 5. One student said, “Overall, I enjoyed it, and I think that this was a fun outlet for my creativity and a good way to enjoy a project.” Ninety-two percent of the video lab reports included some creative element. Seventy-one percent of students used a theme for their slides and 75% of students included images and graphics throughout their presentation beyond what was asked of them (Table 8). One of the students who included creative edits spent approximately four hours creating his video lab report (Figure 16). This student strongly agreed that he enjoyed the video lab report and stated, “I really liked editing it, since editing and Photoshop are already things that I do for fun.”

Table 8. Percent of students who included a creative element in their Video Lab Report, (*N*=24).

Creative Element	Percent of Projects with Creative Element
Editing	8%
Graphics	75%
Slide Theme	71%
Fun/Meme	8%

When asked about their favorite part of the Video Lab Report in the Post Lab Opinion Survey, 57% of students said the creative aspect of making their slides or materials for their video was their favorite part (Table 9). One student said their favorite part was, “Making my slides look pretty.”

Table 9. Student response to their favorite part of the video lab report, (*N*=21).

Favorite Part of Video Lab Report	Percent of Students
Making the Material for the Video	57%
Recording the Video	29%
Collaborative Features of Flipgrid	5%
Understanding	10%

Figure 16. An example of student creativity in the Video Lab Report.

Nineteen percent of students cited the time commitment of the Video Lab Report to be the biggest factor in rating their enjoyment of it (Table 10). Students who cited time as the biggest factor in their enjoyment gave the Video Lab Report the lowest average enjoyment rating of 2.75. One factor with the time commitment of the Video Lab Report was glitches with the recording software. One student said in the Post Lab Opinion Survey, "I also got frustrated doing multiple takes." In an interview when asked about her least favorite part of the video lab report another student said, "This was more technical, but I had to retake a lot of [the video]. You can't do one take and then just take parts of that one take. You had to restart the video over and over again." When students were asked about their least favorite part of the Video Lab Report, 29% stated an issue with the recording of the report. One student said, "My least favorite part of doing the lab summary was actually recording the video, because I feel like I messed up a few times. I liked giving the video presentation though; I just didn't like re-taking my clips."

Table 10. Student response to their least favorite part of the video lab report, (*N*=21).

Least Favorite Part of Video Lab Report	Percent of Students
Making the Material for the Video	57%
Recording the Video	38%
Time Commitment	5%

According to the Post Lab Opinion Survey, the video lab report took on average the most time to complete at 84.7 minutes (Figure 17). The video lab report also had the largest standard deviation of 59.3 minutes. According to the Post Lab Opinion Survey 76% of students agreed that the Video Lab Report was worth their time. In total, 38% of these respondents strongly agreed that it was worth their time.

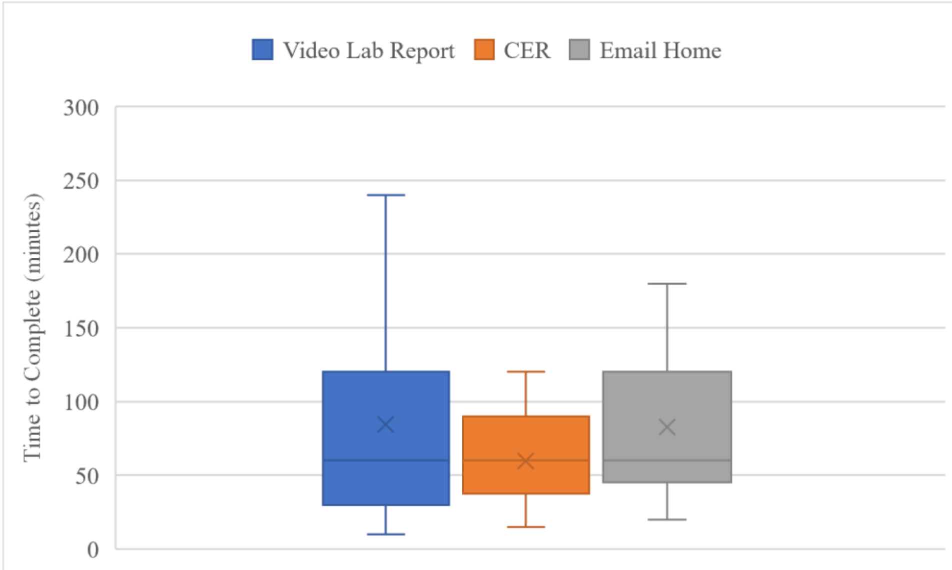

Figure 17. The distribution of time commitment for each lab summary method, (*N*=24).

<u>Student Enjoyment of Claim, Evidence, Reasoning Paragraph</u>

The results of the Post Lab Opinion Survey indicated that 34% of students enjoyed using the Claim, Evidence, Reasoning Paragraph as a lab summary method (*N*=21*)*. Ten percent of the treatment group indicated a strong enjoyment of the CER. The average response was a 2.9 and there was a standard deviation of 1.15.

Participants were asked in an open response style question to justify the primary reason for their enjoyment of the CER. These primary reasons can be grouped into five main categories: understanding, time, difficulty, and written format (Table 11).

Table 11. Primary reason for student enjoyment of CER lab report, (*N*=21).

Primary Reason Cited for Enjoyment	Percent of Respondents	Average Score of Enjoyment
Understanding	33%	3.5
Written Format	39%	2.57
Difficulty	17%	2.67
Time	11%	4

Thirty-three percent of students cited enjoying the CER because they felt that it changed their understanding of the lab content. Students who cited a change in understanding as their main reason for enjoying the CER gave it an average ranking of a 3.5 on the Likert scale with a standard deviation of 1.05. When given the Post Lab Opinion Survey, thirty-three percent of students strongly agreed that the CER helped them learn. This was a higher percentage than the Video Lab Report (19%) and the Email Home Lab Report (25%). In an interview a student stated, “I liked the CER. It just really helped restate what I learned and helped solidified the concepts.” Other students cited applying the concepts to a real-world phenomenon increased their enjoyment of the lab, stating, “I did enjoy my experience because I was able to learn more about the universe and how planet stayed in orbit without hitting each other.” When asked about their favorite part of the CER in the Post Lab Opinion Survey, 33% of students liked applying the lab concept to a real-world phenomenon of black holes (Table 12). One student stated, “My favorite part of doing the lab summary was creating my claim and finding evidence to back it up because it was really cool to be able to connect what we learned in a lab to black holes.”

Table 12. Student response to their favorite part of the CER lab report, (*N*=21).

Favorite Part of CER	Percent of Students
Scientific Arguing	33%
Writing	22%
Application	33%
Time	11%

Thirty-three percent of students based their enjoyment of the CER on the written format. Students who cited writing gave it an average ranking of a 2.57 on the Likert scale with a standard deviation of 0.98. When asked if they enjoyed the CER, one student stated, “Not really, I usually don't enjoy writing long paragraphs.” On the Post Lab Opinion Survey students were asked their least favorite part of the CER 60% cited the written format (Table 13). When asked about his least favorite part a student said, “Writing. It felt like the worst part of English class mixed with a good part of physics (labs).” Students who did not like writing cited the rigidity of the format stating, “I didn’t like having to write it very formally.” In an interview a student said, “I like the structure, but it wasn't as fun. I didn't have as much freedom in choosing how I wanted to express myself.” This formality displayed itself in the final CER products from students as 0% of submissions included any graphics or creative aspects. Nine percent of students gave the CER personality by changing the font (Figure 18). Zero percent of students wrote in a non-formal tone.

Table 13. Student response to their least favorite part of the CER lab report, (*N*=21).

Least Favorite Part of CER	Percent of Students
Writing	60%
Scientific Argumentation	33%
Time	7%

What is a black hole? How are black holes able to apply such a strong gravitational force on objects that get near to them?

Claim: Black holes are a space phenomenon whereas extreme gravitational forces prevent anything from escaping. They have a large mass and exert stronger gravitational forces with objects closer in range.

Evidence: According to experiment #1 of the gravitational force lab, as distance increases, the force decreases in an inverse^2 relationship. We recorded a range of (radii, force) points, including the following: (1, 0.000 000 166 852), (5, 0.000 000 006 674) and (10, 0.000 000 001 669). This is represented by the mathematical model of F = (1.6685 * 10^7) / r^2 and the graph of:

Figure 18. Example of personality represented in CER lab report.

Eleven percent of students based their enjoyment of the CER on the time commitment it entailed. Students who cited time as their main reason for enjoyment gave it an average ranking of a 4 on the Likert scale. When asked about their enjoyment on the Post Lab Opinion Survey one student said, “I thought it was pretty quick and was easy to do.” According to the Post Lab

Opinion Survey, the CER took on average the least time to complete at 59.5 minutes (Figure 17). The CER also had the smallest standard deviation of 26.8 minutes. According to the Post Lab Opinion Survey 57% of students agreed that the CER was worth their time. In total, 19% of these respondents strongly agreed that it was worth their time.

<u>Student Enjoyment of Email Home Lab Report</u>

The results of the Post Lab Opinion Survey indicated that 59% of students enjoyed using the Email Home Lab Report as a lab summary method (*N*=24*)*. Twenty-one percent of the treatment group indicated a strong enjoyment of the Email Home Lab Report. The average response was a 3.45 and there was a standard deviation of 1.26.

Participants were asked in an open response style question to justify the primary reason for their enjoyment of the Email Home Lab Report. These primary reasons can be grouped into four main categories: audience, fun, improve learning, difficulty (Table 14).

Table 14. Primary reason for student enjoyment of email home lab report, (*N*=24).

Primary Reason Cited for Enjoyment	Percent of Respondents	Average Score of Enjoyment
Audience	38%	3.5
Fun	31%	3.125
Improve Learning	15%	3.5
Difficulty	15%	3.33

Thirty-eight percent of participants cited that writing their lab summary to an audience when gauging their enjoyment of the Email Home Lab. The average Likert score of participants who cited having an audience as their main reason for enjoyment was a 3.5. One student who strongly enjoyed the Email Home Lab Report said, “I enjoyed this lab experiment because I was doing it for my mom, not for a grade.” When asked their favorite part of the Email Home Lab

Report, 56% of students said their favorite part writing the lab report for a specific person (Table 15). One student said, “My favorite part of doing the lab summary was writing it in a way that someone who’s not familiar with physics would understand. It was cool to see the results and see how physics can be explained in different ways.” In an interview a student who does not typically enjoy doing labs stated, “I really like [the email home lab report] because I was talking to my mom, and I feel like explaining it to a person that’s not in the class makes it easier because I have to know what I'm talking about to explain it to her. And then, when I was explaining it to her I kind of understood what we were talking about even more because it was in simpler terms.”

Table 15. Student response to their favorite part of the Email Home lab report, (*N*=24).

Favorite Part of Email Home Lab Report	Percent of Students
Audience	56%
Writing	19%
Creativity	25%

Students were graded on their ability to cater their Email Home Lab Reports to their audience. The Email Home Lab Report Rubric had a category for tone and teachability/vocabulary. The highest possible score in the tone category challenged students to make the assignment read like an email and not a report for their audience. The teachability/vocabulary category gave points for writing the email in a way that their audience could learn physics from it. Students who received high marks in these categories were able to relate their physics learning to their audience in a way that was approachable. An example of a student who received a perfect score in these categories related the lab to a situation that happened to their audience member, stating, “Remember when we visited our uncle Juan's previous house six years ago and you threw that rock up into the air that we had to rush you to the hospital so they could stitch up your head from the cut the rock created when it came back down? In physics class I did a lab about energy that is similar to the situation of your head being cut open by a rock being pulled down by gravity." The average score in the tone category was a 51% with a standard deviation of 17.9%. The average score in the teachability/vocabulary category was a 69% with a standard deviation of 25%. The average grade on the Email Home Lab Report was an 83% with a standard deviation of 27% (Table 16).

Table 16. Student grade on email home lab report rubric, (*N*=24).

Category	Average Grade
Tone	51%
Teachability/Vocabulary	69%
Overall Grade	83%

Students cited the audience as a reason for liking the Email Home Lab Report, but 26% cited it as a reason they did not like the Email Home Lab Report (Table 17). A student who said he strongly disliked the Email Lab Report gave it a poor rating because, "I can't explain it but the idea of forcing someone who doesn't really care about physics to read about [physics] is terrible." Forty-seven percent of students said their least favorite part of the lab was explaining the concepts in a way that made sense to their audience (Table 17). A student who strongly disliked the Email Home Lab Report did not like catering his email to an audience and said, "I feel like saying everything in the simplest terms doesn't give me room to actually think about the outcome."

Table 17. Student response to their least favorite part of the Email Home lab report, (*N*=24).

Least Favorite Part of Email Home Lab Report	Percent of Students
Format	26%
Explaining	47%
Audience	26%

The audience response did not have an impact on student enjoyment. The average enjoyment of students who received a response was 3.4 and the average response of students who did not receive a response was 3.5 (Table 18).

Table 18. Email Home Lab Report recipient and rate of response, (*N*=24).

Recipient							
Parent		Friend		Sibling		Teacher	
12		9		2		1	
Response		Response		Response		Response	
Yes	No	Yes	No	Yes	No	Yes	No
8	4	5	4	0	2	1	0

Student Choice Based on Enjoyment

After each lab summary method, students completed one final lab where they were allowed to choose one of the three lab summary methods to use. Sixty percent of students chose the lab summary method that corresponded with the highest enjoyment from previous Post Lab Opinion Survey data (*N*=20) (Table 19). Twenty percent of students chose the lab summary method that they indicated that they enjoyed the least. Of the students who chose their least favorite, 50% indicated they made their choice due to a grade. The Email Home Lab Report was the only lab report where students could receive extra credit. If a student's recipient sent them a question and the student answered correctly, they became eligible for extra credit. One student said he chose the email lab report because, "the option of extra credit is nice." Another student looked back at her grades on all of the lab reports and chose the video lab report because, "I got the best grade on my video lab report." Twenty-five percent of students who chose their least favorite option did so because of its relative difficulty. The student stated they chose the CER because, "it's the most simple."

Table 19. Student ranking of enjoyment and choice of final lab report method, (*N*=20).

Likert Ranking of Enjoyment	Percent of Students Chose
Most Enjoyed	60%
Middle Enjoyed	20%
Least Enjoyed	20%

CLAIM EVIDENCE AND REASONING

Claims From the Study

Students learned the most using the Email Home Lab Report. Students who completed the Email Home Lab Report slightly outperformed students in the non-treatment group. From the first set of data the gains may not seem significant; however, it is important to note that the Email Home Lab Report was the most unfamiliar lab summary method of the three options. After receiving feedback from the first email home lab report, students displayed a stronger ability to learn when they used the email home lab report the second time. Students who used the Email Home Lab Report two times had a significantly stronger grasp on the material than their peers in the non-treatment group and those who chose other summary methods.

The reason why students learned the most from the email home lab report is that it required the highest degree of thinking. The Email Home Lab Report required the highest levels of Bloom's Taxonomy (Figure 19). Students were required to understand the lab content, apply their learning to an outside situation, analyze their data, evaluate their conclusions, and create an instructional piece that someone could use for learning. The Email Home Lab report required students to not just learn the material but be a teacher. To write this email home, students must review the material and learn the concepts, which in turn improves their understanding. Then, communicating this understanding helps to solidify what they have learned.

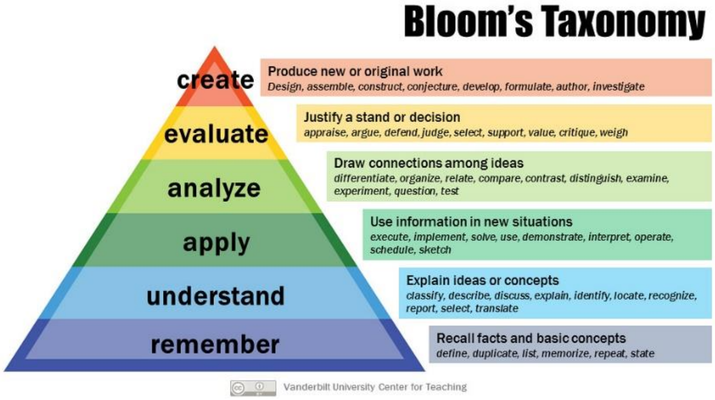

Figure 19. Bloom's Taxonomy, a pedagogical device showing a hierarchy of learning.

Students most enjoyed the Video Lab Report and the Email Home Lab Report. The main reason why students enjoyed the Video Lab Report and Email Home Lab Report were the creative aspects of these lab reports and the ability to include their voice in these summaries. This creativity came at the expense of time. Students reported spending the most time on the Video Lab Report and the Email Home Lab Report. However, student ability to express themselves, involve their personality in the lab report, and be creative was important to them. Students value the lab summaries that involve creativity, personality, and voice.

Value of the Study and Considerations for Future Research

The driving force of this study was my feeling that all my students were not getting the most out of their lab experiences as possible due to a lack of some form of lab report. Through this research I have found better ways to engage my students at the end of a lab. I have become more informed how each individual student processed and understood the information from the lab in a meaningful way. Some lab summaries allowed me to learn more about the individual students as well with the injections of personality they placed in their summaries. I also felt that student grades the quarter that I did this research were much more representative of student knowledge. Some sort of lab summary will be essential in my future teaching to ensure that student grades are accurate reflectors of their abilities.

The data I have collected has shown me that a creative method of summarizing a lab that encourages students to create, evaluate, and analyze information is beneficial to both the teacher and the student. The creativity and functioning at a higher level of learning makes the lab summary a learning opportunity that does not feel tedious or like simply restating information.

An area of my research that I would like to further explore in the future is adding a social element to each lab report. One of the reasons that students enjoyed the Video Lab Report was that they could watch each other's videos and make comments on them. This was not a required piece of the lab report, but many students ended up doing it any way and cited it as a piece they enjoyed. In an interview a student told me that she wished that all the lab summaries had a collaborative component like the Video Lab Report. If I continue using Video Lab Reports I will consider requiring comments on other videos to encourage the social aspect of learning. If I continue using the Email Home Lab Report I will consider having students send their email to each other first to check that it makes sense and is factual. There could be a feedback session where students help improve each other's emails before sending them.

In my conclusion I noted that the Email Lab Report went a lot better for students during its second use. If I were to do this study again, I would have had students use each lab summary method twice or three times. This would have greatly increased the amount of data I had but would have made my research more reliable.

At the start of the next school year, I plan to implement the Email Home Lab Report for every lab in one of my classes. I plan to collect data about student opinion on this method and their learning compared to students this year on the same exams. Students will choose one correspondent of which they will communicate their learning with during the entirety of the school year. I hope that this consistency allows students to figure out the format of the Email Home Lab Report and increases student learning.

Impact of Action Research on the Author

Engaging in the action research process has been impactful on my teaching and the way that I approach teaching. At the beginning of this research, I was entering my fourth year of teaching and coming off a year of almost completely online learning. I had entered the stage where I felt that I had a strong foundation for the curriculum in all the classes I taught and was ready to make more substantial changes to increase the learning of my students. Learning about and implementing the action research process has showed me the ease, value, and importance of implementing action research in my classroom. Although the process of writing this paper has taken a lot of work and a substantial amount of time, the meat of the action research has been relatively easy and enjoyable and something that I now know I can successfully implement in my classroom. I have learned that finding, reading, and analyzing research articles is not challenging very enjoyable. When writing my conceptual framework, I found myself reading through multiple physics teaching magazines not because I thought I would find articles for this paper, but because I liked reading the ideas that other teachers have come up with. This practice has become a part of my routine and teaching. I learned that writing, giving, and analyzing pre-test and post-test data can be difficult, but gives a wealth of information about student learning. I have also learned that asking students for their opinion, whether its in the form of Likert data or interviews can be insightful and incredibly valuable. My students are honest, helpful, and want to make me the best teacher I can be. This time I took asking them to help me in data collection was well spent and something I plan to implement in my future teaching.

One of my biggest takeaways that I will implement in my future teaching (and action research) is student interviews. This process has allowed for me to sit down with my students one-on-one and ask them for their opinions about what is happening in class. I have never done this before, but the qualitative data that each interview provided was extremely beneficial. Not only did I get a lot out of each interview, but every student I talked to voiced to me that they liked being interviewed. Students told me they have never been interviewed by their teachers and liked the ability to have their thoughts about the class heard and used in a meaningful way in their learning. These interviews empowered me to make better decisions in my research but also gave students an important voice in the classroom.

One thing that I learned about the action research process is the importance of organization and thoughtfulness. To perform more powerful action research, I must better think through the data that I need to make meaningful conclusions. There were many times while working on my data analysis where I had wished that I asked students a more targeted pre and post-test question that would better bring out what they learned or had not learned from a lab. I now better understand the preparation and thoughtfulness that must go in to research to ensure the question being asked can be fully answered with the data collected.

The action research process may seem daunting, but I learned that it is doable and rewarding. I have gained immense amounts of insight from reading and analyzing my student data. This action research has made me more confident in not only making changes in my classroom, but doing so in an effective, data-driven way. From this process I am now more willing to make changes in my classroom in a way that is meaningful to both myself and my students.

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APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

MONTANA STATE UNIVERSITY
Request for Designation of Research as Exempt
MSSE Research Projects Only
(6/16/14)

****

THIS AREA IS FOR INSTITUTIONAL REVIEW BOARD USE ONLY. DO NOT WRITE IN THIS AREA.
Confirmation Date: 12/20/21 Mark J. Quinn
Application Number:

****

DATE of SUBMISSION: December 8, 2021

-Okay as exempt
-MSSE Classroom assessment
-Little/no risk
-Director approved
-No concerns
MQ 12/20/21

Address each section – do not leave any section blank.

I. INVESTIGATOR:

Name: Andrew Beck
Home or School Mailing Address: 1112 Grove Street Apartment 1B, Evanston, IL 60201
Telephone Number: 847-387-9485
E-Mail Address: abeck1221@gmail.com
DATE TRAINING COMPLETED: February 26, 2021 *[Required training: CITI training; see website for link]*

Investigator Signature _______Andrew Beck _______

Name of Project Advisor: (Carl) John Graves
E-Mail Address of Project Advisor: carl.graves@ecat1.montana.edu

II. TITLE OF RESEARCH PROJECT: Lab Summary Method and the Impact on Student Learning in High School Physics Labs

III. BRIEF DESCRIPTION OF RESEARCH METHODS (If using a survey/questionnaire, provide a copy).

To test the effectiveness of three different lab summary methods, one section of AP Physics 1 will be the treatment group. Another section of AP Physics 1 taught by another teacher will function as the non-treatment group. The treatment group and non-treatment group will be given a two-question pre-test before the lab activity about the content and practices to be covered in the lab. Then, students will undergo their usual lab design, implementation, and analysis that was used through the first semester. Students will then be taught the new lab summary technique. Students will be given three days to complete their lab summary and submit it for grading. This lab summary will be graded on a rubric.

Students will then complete the Post Lab Summary Opinion Survey. In this survey students will be asked 11 Likert style questions about their opinions and perception of learning from the lab. Students will then be asked 10 open ended survey questions to gain more insight about their perception, enjoyment, and learning of the lab and lab summary method.

After the Lab Summary Opinion Survey students in the treatment and non-treatment groups will take a two-question post-test covering their learning of the content and practices from the lab. The normalized gains between the treatment and non-treatment group will be analyzed.

After the post-test students will be selected to be interviewed using the Post Lab Interview questions. This instrument asks for more insight into opinions about the lab summary method. This process will be repeated for the three lab summary methods: video lab reports, claim-evidence-reasoning paragraph, and letter home.

APPENDIX B

LAB NOTEBOOK CHECKLIST

AP Physics 1 Lab Notebook Checklist Mr. Beck 2021-2022

For **EVERY** lab we do in class this year, you must include these things in your lab notebook. Keep this sheet in your lab notebook to check over each time before you turn your notebook in!

- All writing in your lab notebook should be NEAT, CLEAR, and LEGIBLE.
- You should never erase, but you may cross out typographical mistakes (NEVER cross out or erase data, even if you realized it was wrong later - make a note of this)
- Every entry must have a TITLE and DATE; pages must be numbered
- Every entry must be included in the table of contents with a page number

1. Pre-Lab Notes	• Take **notes** from class as we discuss the lab • Identify **independent & dependent variables**
2. Purpose	• "The purpose of this lab is to determine the mathematical and graphical relationship between…"
3. Hypothesis	• **Graphical** hypothesis • Explanation of **why** you predicted the graph (what prior knowledge led you to that prediction?)
4. Procedure	• **Diagram** of set-up, with any physical measured values • **Numbered list of steps** • Be specific - how exactly did you measure all values?
5. Data	• Tables include **labels and units** • Include measured values that were **constant** (e.g. mass, height of ramp, length of string, etc)
6. Graphs	• Include **all graphs**, original and linearized • These can be neat sketches (with maximum x & y values labeled for scale) or printouts • Every linear graph must include a **slope value & y-intercept value** (the computer can calculate these) • Every linear graph must include a **mathematical model** (you must write this below each graph)
7. Post-Lab Notes	• Take **notes** in class following our discussion of each group's lab outcome • Report similarities, differences, and observations • What was the **big idea** from the lab? It may be an equation, a physical relationship, or concept
8. Concluding Questions	• These will be different for each lab and **posted on Google Classroom** • Answers must be **recorded in lab notebook** (either handwritten or printed)

APPENDIX C

VIDEO LAB REPORT HANDOUT

Video Lab Report

Objective: Create a video lab report to summarize and apply your findings from the lab assignment.

Directions:

1. After the class lab discussion, you will create a 2-4 minute video summarizing the lab
2. Use Flipgrid to create your video. An instructional video of how to use Flipgrid is posted in Google Classroom. Be sure to check out this video.
    a. I would recommend creating a Google Slides presentation and recording a narration of your presentation in Flipgrid.
3. In your video lab report, include the key points shown below
4. Your video lab report will be graded based on the attached rubric
5. Submit your video lab report on Flipgrid by:

Note: The video lab report asks you to include images and videos from the lab. Be sure to read through the below "What to Include" section and be prepared to **take videos/pictures throughout the lab!**

What to Include:

- **Purpose**
    - A statement explaining what was being studied in the lab.
    - "The purpose of this lab is to determine the mathematical and graphical relationship between..."
- **Hypothesis**
    - A sketch of your graphical hypothesis
    - An explanation of why you predicted the graph (what prior knowledge led you to that prediction?)
- **Procedure**
    - Include a picture of your experimental set up
    - Include a video of you and your group members performing one trial of the experiment
        - Explain what you're doing in this trial
        - How did you measure your dependent variable?
        - How did you keep your control variables constant?
- **Graphs**
    - Include all graphs, original and linearized
    - Include your mathematical model for your linearized line of best fit
- **Conclusion**
    - What was the big idea from the lab? It may be an equation, a physical relationship, or concept
- **Application**
    - Apply the concept you learned from the lab to a phenomena from everyday life
    - Include a video or image showing this phenomena
        - You may find a video or image on the internet, you do not need to create it

APPENDIX D

VIDEO LAB REPORT RUBRIC

Video Lab Report Rubric

Criteria	Excellent 4	Proficient 3	Needs Improvement 2	Unsatisfactory 1	Score
Purpose	Purpose statement is explicitly stated in the format given in the handout.	Purpose statement is stated in a similar format to the one given.	Purpose statement is unclear. The format is very different.	Purpose statement is incorrect. Independent variable and dependent variable are not accurate.	X 1
Hypothesis	A sketch of a graphical hypothesis is clearly displayed. A complete explanation with appropriate prior knowledge is given	A sketch of a graphical hypothesis is displayed. A minor explanation with prior knowledge is given.	A sketch of a graphical hypothesis is shown. No explanation is given or backed with no prior knowledge	A graphical hypothesis is not shown. There is no explanation for the thought behind the experiment.	X 1
Procedure	A clear picture of the experimental set up is shown. A clear video of a trial of the experiment being performed with an explanation is shown and narrated. The method for measuring dependent variables, and keeping controls constant is shown.	A picture of the experimental set up is shown. A video of a trial of the experiment being performed is given. The video lacks narration, the method of measuring the dependent variable, or controlling variables is missing.	A picture of the experimental set up is shown. A video of a trial of the experiment being performed is given. The video lacks 2 of the following: narration, the method of measuring the dependent variable, or controlling variables is missing.	A picture of the experimental set up is shown. No video is included or video lacks all of the required portions.	X 2.5
Graphs	Original and linearized graphs are presented and labeled. The mathematical model with units is given to the linearized line of best fit.	Original and linearized graphs are presented and labeled.	Original graph is only given. The linearized graph and mathematical models are missing. Labels are missing on the graph.	Graph is unclear and not labeled. Missing linearized graph and mathematical model.	X 1
Conclusion	The big idea from the lab is clearly and correctly stated. Conclusion matches the data. The conclusion is presented as an equation, physical relationship, or concept.	The big idea from the lab is stated. Conclusion matches the data. The conclusion is presented as an equation, physical relationship, or concept.	The big idea from the lab is stated with some inaccuracies. Conclusion does not match the data. The conclusion is presented as an equation, physical relationship, or concept.	The big idea from the lab is unclear. Conclusion does not match the data. The conclusion is presented as an equation, physical relationship, or concept.	X 2
Application	The main idea of the lab is properly applied to an outside phenomena. A video or image of the phenomena is presented and explained correctly.	The main idea of the lab is properly applied to an outside phenomena. A video or image of the phenomena is presented and explained with some inaccuracies.	The main idea of the lab is applied to an outside phenomena. A video or image of the phenomena is presented and explained with many inaccuracies	The main idea of the lab is improperly applied to an outside phenomena. A video or image of the phenomena is presented and explained incorrectly.	X 2
Presentation	The presentation is done on Flipgrid. It includes visuals, is narrated, and is coherent. It is creative and visually interesting.	The presentation is done on Flipgrid. It includes visuals, is narrated, and is coherent.	The presentation is done on Flipgrid. It lacks either visuals, narration, or coherency.	The presentation is not done on Flipgrid. It lacks visuals, narration, and coherency.	X 2.5
Time	Video is 2-4 minutes in length and submitted on time	Video is 2-4 minutes in length and submitted one day late	Video is not 2-4 minutes in length or submitted two days late	Video is not 2-4 minutes in length or submitted three days late	X 1

APPENDIX E

CLAIM EVIDENCE REASONING HANDOUT

Claim Evidence Reasoning Paragraph

Objective: Write a claim evidence reasoning paragraph to completely answer a question posed in a scientific investigation.

Directions:

1. Participate in the lab activity in class
2. On a Google Doc, write a Claim Evidence Reasoning Paragraph to fully answer the scientific question.

What's Included in a CER

Claim:

- A claim is a statement that answers the question.
- It will usually only be one sentence in length.
- The claim does not include any explanation, reasoning, or evidence so it should not include any transition words such as "because."

Evidence:

- The evidence is the data used to support the claim.
  - This evidence is the data you collected in the lab.
- Evidence can be either quantitative or qualitative depending on the question and/or lab.
- The evidence will often be a graph that you created from your experiment with a line of best fit to show the relationship between variables
- At this point you are simply presenting your evidence and discussing the relationship among variables.
- You should include charts, graphs, and images as your evidence, but you must also use words to discuss your data.
- You may need to cite multiple pieces of evidence or different experiments to fully support your argument.
- You should only use data within your evidence that directly supports the claim.

Reasoning:

- The reasoning is the explanation of "why and how" the evidence supports the claim.
- It states what relationship your data showed between your variables that supports the claim
- It should include an explanation of the underlying science concept that produced the evidence or data.
  - This may require outside research or your notes from the post-lab discussion

Structure:

- Your final response will be formatted as a logical, internally consistent paragraph.
- You may include graphs, charts, images as a part of your response, but they must be discussed with words.

APPENDIX F

CLAIM EVIDENCE REASONING RUBRIC

Claim Evidence Reasoning Paragraph Rubric

Criteria	Excellent 4	Proficient 3	Needs Improvement 2	Unsatisfactory 1	Score
Claim	The paragraph includes a strong claim statement. The statement answers the question and is only 1-2 sentences in length. It includes no explanation, reasoning, or evidence.	The paragraph includes a claim statement. The statement answers the question and is only 1-2 sentences in length. It includes no explanation, reasoning, or evidence.	The paragraph includes a claim statement. The statement answers the question and is more than 1-2 sentences in length. It includes some explanation, reasoning, or evidence.	The paragraph includes a claim statement. The statement answers the question and is more than 1-2 sentences in length. It provides an explanation, reasoning, or evidence.	X 1
Evidence #1	The data from one of your lab's experiments is properly used to support the claim. The data is fully and properly discussed and displayed. The data is relevant.	The data from one of your lab's experiments is used to support the claim. The data is discussed and displayed. The data is mostly relevant.	The data from one of your lab's experiments is used to support the claim. The data is not discussed and only displayed. The data is somewhat relevant.	The data from one of your lab's experiments is used to support the claim. The data is not discussed and only displayed. The data is not relevant.	X 2
Evidence #2	The data from another of your lab's experiments is properly used to support the claim. The data is fully and properly discussed and displayed. The data is relevant.	The data from another of your lab's experiments is used to support the claim. The data is discussed and displayed. The data is mostly relevant.	The data from another of your lab's experiments is used to support the claim. The data is not discussed and only displayed. The data is somewhat relevant.	The data from another of your lab's experiments is used to support the claim. The data is not discussed and only displayed. The data is not relevant.	X 2
Reasoning #1	A multiple sentence paragraph is constructed to fully explain why and how the first piece of evidence supports the claim. The relationship discovered from the data is cited to support the claim. An explanation of the underlying science concept that produced the evidence or data is completely discussed.	A multiple sentence paragraph is constructed to explain why and how the first piece of evidence supports the claim. The relationship discovered from the data is cited to support the claim. An explanation of the underlying science concept that produced the evidence or data is discussed.	1-2 sentences are used to explain why and how the first piece of evidence supports the claim with some error. The relationship discovered from the data is mostly accurately cited to support the claim. An explanation of the underlying science concept that produced the evidence or data is discussed.	1-2 sentences are used to explain why and how the first piece of evidence supports the claim with error. The relationship discovered from the data is inaccurately cited to support the claim. An explanation of the underlying science concept that produced the evidence or data is discussed.	X 2
Reasoning #2	A multiple sentence paragraph is constructed to fully explain why and how the second piece of evidence supports the claim. The relationship discovered from the data is cited to support the claim. An explanation of the underlying science concept that produced the evidence or data is completely discussed.	A multiple sentence paragraph is constructed to explain why and how the second piece of evidence supports the claim. The relationship discovered from the data is cited to support the claim. An explanation of the underlying science concept that produced the evidence or data is discussed.	1-2 sentences are used to explain why and how the second piece of evidence supports the claim with some error. The relationship discovered from the data is mostly accurately cited to support the claim. An explanation of the underlying science concept that produced the evidence or data is discussed.	1-2 sentences are used to explain why and how the second piece of evidence supports the claim with error. The relationship discovered from the data is inaccurately cited to support the claim. An explanation of the underlying science concept that produced the evidence or data is discussed.	X 2
Structure	The CER is a coherent, paragraph length argument that uses the information presented in the question and lab and proceeds in a logical, expository fashion to arrive at a strong conclusion. It is consistent. The response clearly presents the student's thinking to the reader.	The CER is a mostly coherent, paragraph length argument that uses the information presented in the question and lab and proceeds in a logical, expository fashion to arrive at a strong conclusion. The response presents the student's thinking to the reader.	The CER is a somewhat coherent argument. It uses some information from the question and the lab. There is some trouble following the logic in the steps. It is unclear at points.	The CER is an incoherent argument. It uses some information from the question and the lab. There is trouble following the logic in the steps. It is unclear.	X 1
Time	The CER was turned in on time	The CER was 1 day late	The CER was 2 days late	The CER was more than 2 days late	X 1

APPENDIX G

EMAIL HOME LAB REPORT HANDOUT

Email Home Lab Report

Objective: Communicate your findings and understanding from the lab activity to someone at home. This could be a parent, guardian, friend who doesn't take physics, neighbor, etc.

The idea is that you can explain your physics learning to someone who doesn't know physics. It has been said if you can't explain something clearly and simply, then you don't understand it.

Directions:

1. After the class lab discussion, you will construct an email message to someone at home (parent, guardian, grandparent, sibling, friend who isn't in physics, cousin, etc.) explaining the lab
2. In your email home you will include the key points shown below
3. Your email home will be graded based on the attached rubric
4. To submit your email home, send an email to your person. Include me (becka@eths202.org) in the Cc: line.
5. You will receive extra credit if your recipient responds and you provide a satisfactory answer.

What to Include:

- **Purpose**
  - Explain to your email recipient what you were trying to find or study in the lab.
  - Answer the question: why were you doing the lab?

- **Procedure**
  - Explain in detail how you did your experiment
  - Include **pictures or diagrams** of your set up to help the reader understand what you did
  - Explain how your procedure helped you answer the question in your purpose

- **Conclusion**
  - Explain your main findings from the lab
  - Include a verbal description of your results.
    - You can use math and graphs to help your explanation.
  - Explain what your experiment showed and why it showed what it did.
  - The conclusion is written in an appropriate way for the reader to understand.

- **Considerations**
  - You must write your email in a way that your reader can understand it
  - Do not use only technical, physics language
    - If you need to use a physics vocabulary word, you must define it in a way that your reader can understand

APPENDIX H

EMAIL HOME LAB REPORT RUBRIC

Email Home Lab Report Rubric

Criteria	Excellent 4	Proficient 3	Needs Improvement 2	Unsatisfactory 1	Score
Recipient	An appropriate recipient has been chosen. The recipient does not already know the physics explored in the lab.	X	X	An inappropriate recipient has been chosen. The recipient is another physics student or already knows the physics explored in the lab.	x1
Tone	An appropriate tone is used throughout the email. The assignment reads naturally like an email and not a lab report.	An appropriate tone is used mostly throughout the email. The assignment reads naturally like an email and not a lab report.	An appropriate tone is barely used throughout the email. The assignment reads more like a lab report than an email.	An appropriate tone is rarely used in the email. The assignment reads like a lab report, not an email.	x1
Teachability/ Vocabulary	The email is written in a way such that the audience can learn physics from it. The content is correct and expressed in a clear manner. The student does not use complicated physics words. If a physics word is used, it is clearly defined in a way that the reader can understand.	The email is written in a way such that the audience can learn physics from it. The content is mostly correct and expressed in a fairly clear manner. The student uses some physics terms.. If a physics word is used, it is defined in a way that the reader can understand.	The audience may have some trouble learning physics from the email. There are some errors, inconsistencies, or the writing is somewhat unclear. The student uses some physics terms.. They are somewhat in a way the reader can understand.	The audience has trouble learning physics from the email. There are errors, inconsistencies, or the writing is unclear. The student uses physics terms.. They are not defined in a way the reader can understand.	x2
Purpose	The email clearly explains why the lab was done. The reader can easily understand why the student performed the lab and what question was meant to be answered.	The email explains why the lab was done. The reader can understand why the student performed the lab and what question was meant to be answered.	The email does not fully explain why the lab was done. The reader has some trouble understanding why the lab was performed and what question was meant to be answered.	The email does not explain why the lab was done. The reader cannot understand why the student performed the lab and what question was meant to be answered.	x1
Procedure	The experimental procedure is explained in detail. Pictures or diagrams are used to further the explanation. The reader can understand how the procedure helps to answer the question posed in the purpose.	The experimental procedure is explained. Pictures or diagrams are used to further the explanation. The reader can mostly understand how the procedure helps to answer the question posed in the purpose.	The experimental procedure is explained. No pictures or diagrams are used to further the explanation. The reader can mostly understand how the procedure helps to answer the question posed in the purpose.	The experimental procedure is barely explained. Pictures or diagrams are not used to further the explanation. The reader cannot understand how the procedure helps to answer the question posed in the purpose.	x2
Conclusion	The main findings from the lab are clearly and correctly explained. A verbal description of the results is included. Graphical and mathematical results are included, but are not the only way of explaining the findings. It is at an appropriate level for the reader.	The main findings from the lab are explained. They are mostly correct. A verbal description of the results is included. It is at an appropriate level for the reader.	The main findings from the lab are explained with some errors. Graphical and mathematical results are used, but there is no verbal description. It is not at an appropriate level for the reader.	The main findings from the lab are not clearly explained. They have many errors. Graphical and mathematical results are used, but there is no verbal description. It is not at an appropriate level for the reader.	x2
Extra Credit	The reader responds to the email with a question. The student provides a complete, satisfactory answer to the question.	X	X	X	x1

APPENDIX I

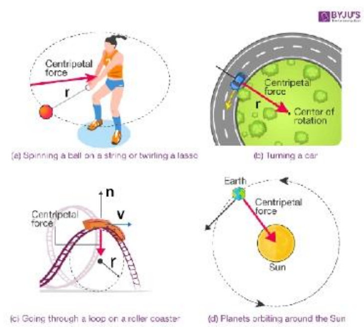
STRONG EXAMPLE OF EMAIL HOME LAB REPORT

Email Home Example

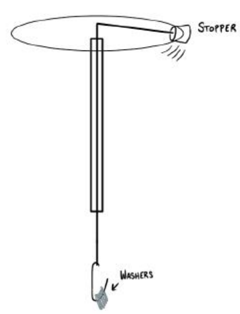
Hi Mom,

Remember last month when we were going driving on the highway and we were wondering why the speed limit on the curvy interchange was so much lower than the speed limit on the highway? Today in physics class we did a lab that helped me figure out why! In our lab we tested how the centripetal force affected how fast a rotating object spins.

All that the centripetal force is is a force that pulls an object inwards to keep it on a circular path. Imagine spinning a tetherball around a pole. At each moment the ball wants to fly away. But, the string pulls the ball inwards keeping it on a circular path. In that case, the tension in that rope is the centripetal force. But, for other objects a different force can pull an object towards the middle of the circular path like in the images below.



To check how the centripetal force changed the speed, we set up an experiment that was a lot like the tetherball example. We took a rubber stopper and tied it to a string. We were able to spin the stopper around in a circle. On the other end of the string we attached washers. When we added more washers, this pulled down more on the rope, increasing the centripetal force.

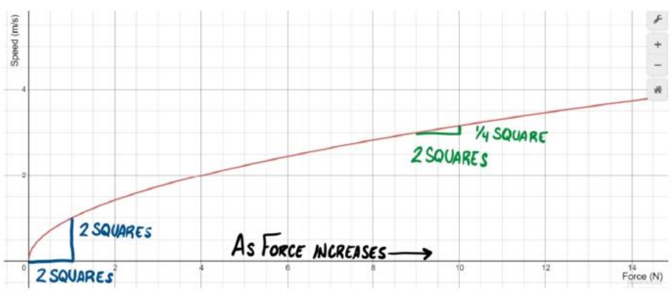


Measuring the speed was a little difficult. Speed is a measurement of how far an object goes in a certain amount of time. This is why the car's speedometer measures speed in miles per hour.

This is a distance measurement (miles) divided by a time measurement (hours). We did the same thing with our stopper to measure its speed. The only hard part was that the stopper was moving in a circle. To measure its distance, we found the circumference of the circular path and divided it by the time it took to make one full rotation.

Once we got our data, we graphed it. We found that as the centripetal force increased, the speed of the moving object increased too. This increase didn't happen at the same rate, though. When the force was small, a tiny change in the force resulted in a large change of speed. But, as the force was larger, a tiny change in force resulted in a smaller change of speed.

This is shown in the graph below. When the force is small, a tiny change in force results in a large change in speed. This is shown by the blue drawings on the graph. When the force is larger, a tiny change in force results in a tiny change in speed. This is shown by the green drawings on the graph.



As the centripetal force acting on an object increases, its speed will increase. This also explains the highway interchange! When we drive faster, we need more centripetal force to keep us moving in a circle! If we drive too fast, there won't be enough force to keep us moving in a circle and we could accidentally hit the wall, which would be bad.

Love,

Andrew

APPENDIX J

WEAK EXAMPLE OF EMAIL HOME LAB REPORT

Email Home Example

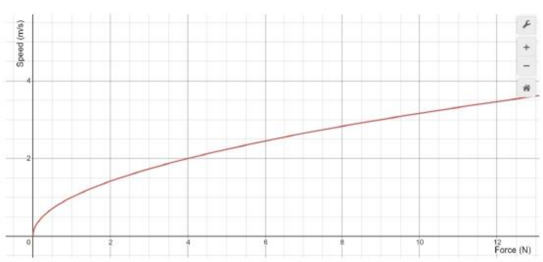
Hi Mom,

Today in physics class we did a lab about centripetal force. We wanted to test how the centripetal force of a rotating object affected the speed of the object.

To do this we had a clear plastic straw. We fed a string through the clear plastic straw. On one end of the string we attached a paperclip. From the paperclip we hung washers. These washers changed the gravitational force acting on the string. This changed the tension, which was the centripetal force.

On the other end of the string we had a rubber stopper. We spun the rubber stopper above our heads in a horizontal circle. We used our phone's stopwatches to measure the period of the stopper's rotation. We used the period and measured circumference to determine the speed of the stopper as it rotates.

When we graphed our centripetal force vs. speed data we found that there was a square root relationship between the variables. Our mathematical model was v = 5.45 sqrt(F). This means that as the force increases with a constant radius and constant mass, the speed of the circularly moving object must increase. But, it is not a linear increase. As the force gets bigger, the speed grows at a lesser rate.



Best Regards,

APPENDIX K

UNIT 3: CIRCULAR MOTION PRE-TEST

Unit 3: Circular Motion Lab Pre-Test

becka@eths202.org Switch account

Your email will be recorded when you submit this form

* Required

Name *

Your answer

AP Physics 1 Teacher *

- ◯ Beck
- ◯ Habbert

A centripetal force of 5.0 Newtons is applied to a rubber stopper moving at a constant speed in a horizontal circle. If the same force is applied, but the mass of the stopper is made smaller, what happens to the speed, v, and the period ,T, of the stopper? The radius of the stopper's motion is made to remain constant. *

- ◯ v increases and T increases
- ◯ v decreases and T decreases
- ◯ v increases and T decreases
- ◯ v decreases and T increases

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

A ball attached to a string is whirled around in a horizontal circle having a radius R. If the radius of the circle is changed to 4R and the same centripetal force is applied by the string, the new speed of the ball is which of the following?

- One-quarter the original speed
- One-half the original speed
- The same as the original speed
- Twice the original speed

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

A student is tasked with measuring the period, T, of an object spinning in a horizontal circle. Describe a procedure that could be used to ACCURATELY measure the period using supplies found in a typical science classroom.

Your answer

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

Submit Clear form

APPENDIX L

UNIT 3: CIRCULAR MOTION POST-TEST

Unit 3: Circular Motion Lab Post-Test

becka@eths202.org Switch account

Your email will be recorded when you submit this form

* Required

Name *

Your answer

AP Physics 1 Teacher *

- ◯ Beck
- ◯ Habbert

A centripetal force of 10.0 Newtons is applied to a rubber stopper moving at a constant speed in a horizontal circle. If the same force is applied, but the mass of the stopper is increased, what happens to the speed, v, and the period ,T, of the stopper? The radius of the stopper's motion is made to remain constant. *

- ◯ v increases and T increases
- ◯ v decreases and T decreases
- ◯ v increases and T decreases
- ◯ v decreases and T increases

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

A ball attached to a string is whirled around in a horizontal circle having a radius R. If the radius of the circle is decreased to (1/4)R and the same centripetal force is applied by the string, the new speed of the ball is which of the following?

- One-quarter the original speed
- One-half the original speed
- The same as the original speed
- Twice the original speed

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

A student is tasked with measuring the period, T, of an object spinning in a horizontal circle. Describe a procedure that could be used to ACCURATELY measure the period using supplies found in a typical science classroom.

Your answer

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

Submit Clear form

APPENDIX M

UNIT 3: GRAVITY LAB PRE-TEST

Unit 3: Gravity Lab Pre-Test

becka@eths202.org Switch account

Your email will be recorded when you submit this form

* Required

Name *

Your answer

AP Physics 1 Teacher *

- ◯ Beck
- ◯ Habbert

If F(1) is the magnitude of the force exerted by the Earth on a satellite in orbit about the Earth and F(2) is the magnitude of the force exerted by the satellite on the Earth, then which of the following is true?

- ◯ F(1) is much greater than F(2)
- ◯ F(1) is slightly greater than F(2)
- ◯ F(1) is equal to F(2)
- ◯ F(2) is slightly greater than F(1)

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

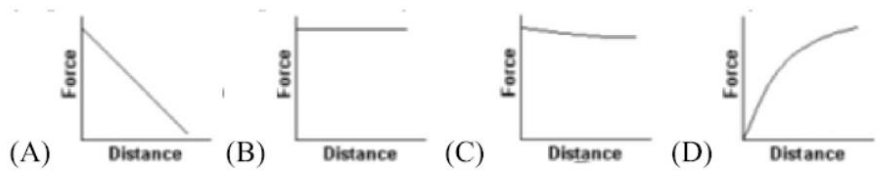
What happens to the force of gravitational attraction between two small objects if the mass of each object is doubled?

- ○ It is doubled
- ○ It is quadrupled
- ○ It is halved
- ○ It remains the same

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

As a rocket blasts away from the earth with a cargo for the international space station, which of the following graphs would best represent the gravitational force on the cargo versus distance from the surface of the Earth?



- A
- B
- C
- D

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

You are tasked with measuring the experimental relationship between the gravitational force and distance between two planets in a simulation. Describe where you would put the "0 mark" of a ruler if you were attempting to measure an orbital radius. Where would you stop the measurement to accurately measure the orbital radius?

Your answer

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

Submit Clear form

APPENDIX N

UNIT 3: GRAVITY LAB POST-TEST

Unit 3: Gravity Lab Post-Test

becka@eths202.org Switch account

Your email will be recorded when you submit this form

* Required

Name *

Your answer

AP Physics 1 Teacher *

- Beck
- Habbert

If F(1) is the magnitude of the force exerted by the Earth on the Moon. If F(2) is the magnitude of the force exerted by the Moon on the Earth, then which of the following is true?

- F(1) is much greater than F(2)
- F(1) is slightly greater than F(2)
- F(1) is equal to F(2)
- F(2) is slightly greater than F(1)

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

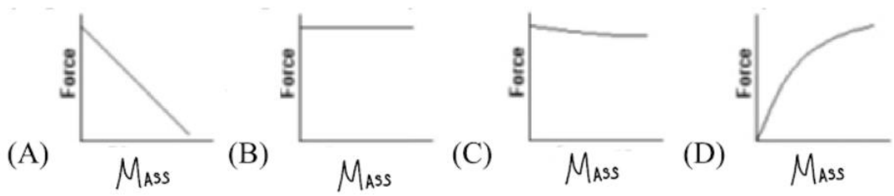
What happens to the force of gravitational attraction between two small objects if the distance between them is halved?

- ○ It is doubled
- ○ It is quadrupled
- ○ It is halved
- ○ It is quartered
- ○ It remains the same

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

A rocket orbits the earth at a constant radius with a load of cargo. Suddenly, the rocket begins to unload its cargo. Which of the following graphs would best represent the gravitational force on the rocket versus its mass?



- A
- B
- C
- D

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

You are tasked with measuring the experimental relationship between the gravitational force and distance between two planets in a simulation. Describe where you would put the "0 mark" of a ruler if you were attempting to measure an orbital radius. Where would you stop the measurement to accurately measure the orbital radius?

Your answer

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

Submit Clear form

APPENDIX O

UNIT 4: ENERGY PRE-TEST

Unit 4: Energy Lab Pre-Test

becka@eths202.org Switch account

Your email will be recorded when you submit this form

* Required

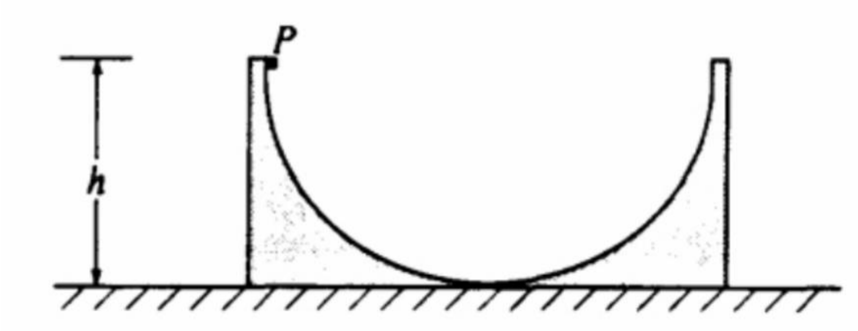
Name *

Your answer

AP Physics 1 Teacher *

- Beck
- Habbert

The figure shows an icy, perfectly smooth semicircular track whose ends are at a vertical height h. A block placed at point P at one end of the track is released from rest and slides past the bottom of the track. Which of the following is true of the height to which the block rises on the other side of the track?



- It is equal to h/4
- It is equal to h/2
- It is equal to h
- It is between zero and h; the exact height cannot be determined

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

An object is projected vertically upward from ground level. It rises to a maximum height H. If air resistance is negligible, which of the following must be true for the object when it is at a height H/2

- Its speed is one fourth of its initial speed
- Its speed is half of its initial speed
- Its kinetic energy is half of its initial kinetic energy
- Its potential energy is half of its initial potential energy

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

You design an experiment to prove that energy is conserved. In your experiment, you find that an object's final energy is equal to 1/4 the initial energy. What source or sources of error could lead to this finding?

Your answer

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

APPENDIX P

UNIT 4: ENERGY POST-TEST

Unit 4: Energy Lab Post-Test

becka@eths202.org Switch account

Your email will be recorded when you submit this form

* Required

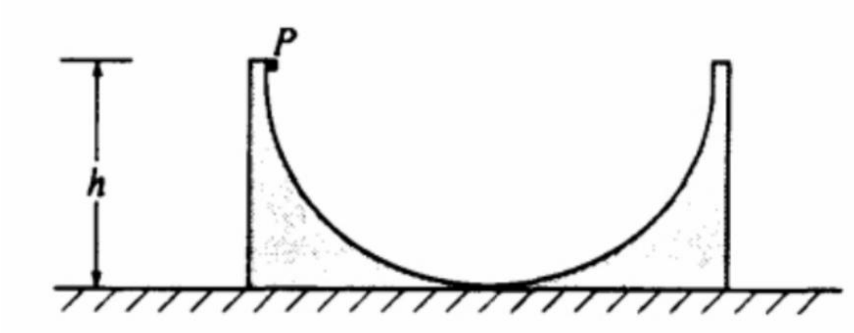
Name *

Your answer

AP Physics 1 Teacher *

- Beck
- Habbert

The figure shows a rough semicircular track whose ends are at a vertical height h. A block placed at point P at one end of the track is released from rest and slides past the bottom of the track. Which of the following is true of the height to which the block rises on the other side of the track?



- It is equal to h/4
- It is equal to h/2
- It is equal to h
- It is between zero and h; the exact height depends on how much energy is lost to friction

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

An object is projected vertically upward from ground level. It rises to a maximum height H. If air resistance is negligible, which of the following must be true for the object when it is at a height H/4?

- ◯ Its speed is one fourth of its initial speed
- ◯ Its speed is half of its initial speed
- ◯ Its kinetic energy is one fourth of its initial kinetic energy
- ◯ Its potential energy is one fourth of its initial potential energy

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	◯	◯	◯	◯	◯	Fully confident

You design an experiment to prove that energy is conserved. In your experiment, you find that an object's final energy is equal to 1/4 the initial energy. What source or sources of error could lead to this finding?

Your answer

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	◯	◯	◯	◯	◯	Fully confident

[redacted] Clear fo[redacted]

APPENDIX Q

UNIT 5: MOMENTUM PRE-TEST

Unit 5: Momentum Pre-Test

becka@eths202.org Switch account

Your email will be recorded when you submit this form

* Required

Name *

Your answer

AP Physics 1 Teacher *

- ◯ Beck
- ◯ Habbert

A 50 kg skater at rest on a frictionless rink throws a 2 kg ball, giving the ball a velocity of 10 m/s. Which statement describes the skater's subsequent motion?

- ◯ 0.4 m/s in the same direction as the ball's motion.
- ◯ 0.4 m/s in the opposite direction of the ball's motion.
- ◯ 2 m/s in the same direction as the ball's motion.
- ◯ 2 m/s in the opposite direction of the ball's motion.

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

A student initially at rest on a frictionless frozen pond throws a 1 kg hammer in one direction. After the throw, the hammer moves off in one direction while the student moves off in the other direction. Which of the following correctly describes the above situation?

- ○ The hammer will have the momentum with the greater magnitude
- ○ The student will have the momentum with the greater magnitude
- ○ The hammer will have the greater kinetic energy
- ○ The student will have the greater kinetic energy

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

A student is undergoing a lab to prove that momentum is conserved. On the vertical axis the student graphs the final momentum of the system. On the horizontal axis the student graphs the initial momentum of the system. They find that their graph is linear and has a slope of 0.45. Interpret the meaning of this slope.

Your answer

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

Submit Clear form

APPENDIX R

UNIT 5: MOMENTUM POST-TEST

Unit 5: Momentum Post-Test

becka@eths202.org Switch account

Your email will be recorded when you submit this form

* Required

Name *

Your answer

AP Physics 1 Teacher *

- ◯ Beck
- ◯ Habbert

A 100 kg skater at rest on a frictionless rink throws a 2 kg ball, giving the ball a velocity of 20 m/s. Which statement describes the skater's subsequent motion?

- ◯ 0.4 m/s in the same direction as the ball's motion.
- ◯ 0.4 m/s in the opposite direction of the ball's motion.
- ◯ 2 m/s in the same direction as the ball's motion.
- ◯ 2 m/s in the opposite direction of the ball's motion.

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

A student initially at rest on a frictionless frozen pond throws a 2 kg hammer in one direction. After the throw, the hammer moves off in one direction while the student moves off in the other direction. Which of the following correctly describes the above situation?

- ○ The hammer will have the momentum with the greater magnitude
- ○ The student will have the momentum with the greater magnitude
- ○ The student and the hammer will have momentums with equal magnitude
- ○ The hammer has a greater impulse than the student
- ○ The student has a greater impulse than the hammer

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

A student is undergoing a lab to prove that momentum is conserved. On the vertical axis the student graphs the final momentum of the system. On the horizontal axis the student graphs the initial momentum of the system. They find that their graph is linear and has a slope of 0.98. Interpret the meaning of this slope.

Your answer

On a scale of 1-5, rank your confidence in your previous answer.

	1	2	3	4	5	
The answer was a guess	○	○	○	○	○	Fully confident

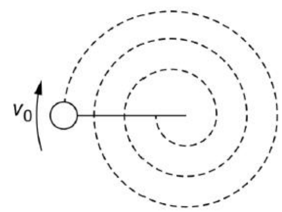
Submit Clear form

APPENDIX S

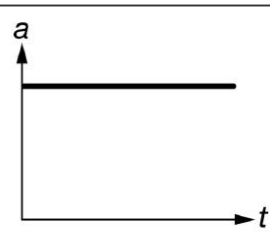
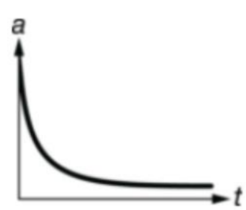
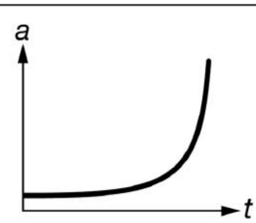
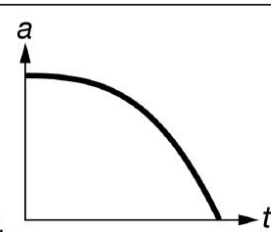
UNIT 3: CIRCULAR MOTION AND GRAVITATION EXAM FOCUS QUESTIONS

6. A car with speed v and an identical car with speed 2v both travel the same circular section of an unbanked road. If the frictional force required to keep the faster car on the road without skidding is F, then the frictional force required to keep the slower car on the road without skidding is

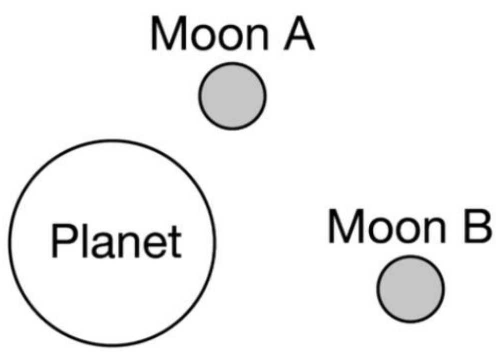
   a. 4F
   b. 2F
   c. F
   d. F/2
   e. F/4



7. A ball of mass swings in a horizontal circle at the end of a string of radius at a constant tangential speed . A student gradually pulls the string inward such that the radius of the circle decreases while keeping the tangential speed of the ball constant, as shown above. Which of the following graphs best represents the acceleration of the ball as a function of time?

 a.	 c.
 b.	 d.

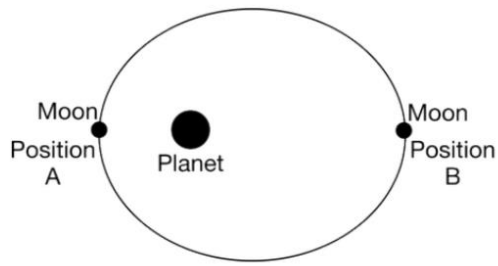
8. An object has a weight W when it is on the surface of a planet of radius R. What will be the gravitational force on the object after it has been moved to a distance of 4R from the center of the planet?
    a. 16W
    b. 4W
    c. W
    d. $\frac{1}{4}$W
    e. $\frac{1}{16}$W



A planet has two moons, Moon A and Moon B, that orbit at different distances from the planet's center, as shown. Astronomers collect data regarding the planet, the two moons, and their obits. The astronomers are able to estimate the planet's radius and mass.

11. The masses of the two moons are determined to be 2M for Moon A and M for Moon B. It is observed that the distance between Moon B and the planet is two times that of the distance between Moon A and the planet. How does force exerted from the planet on Moon A compare to the force exerted from the planet on Moon B?

    a. The gravitational force exerted from the planet on Moon A is two times larger than the gravitational force exerted from the planet on Moon B.
    b. The gravitational force exerted from the planet on Moon A is eight times larger than the gravitational force exerted from the planet on Moon B.
    c. The gravitational force exerted from the planet on Moon A is two times smaller than the gravitational force exerted from the planet on Moon B.
    d. The gravitational force exerted from the planet on Moon A is eight times smaller than the gravitational force exerted from the planet on Moon B.



The figure above shows the position of a moon that orbits a planet in an elliptical path. Two specific locations of the moon, position A and position B, are labeled.

14. As the moon orbits the planet from position A to position B, is the magnitude of the planet's force due to gravity exerted on the moon constant? Why or why not?
    a. Yes, because the masses of the planet and moon remain constant.
    b. Yes, because the elliptical path that the moon travels around the planet is the same for all revolutions.
    c. No, because the tangential speed of the moon is always changing.
    d. No, because the moon's distance from the planet is always changing.

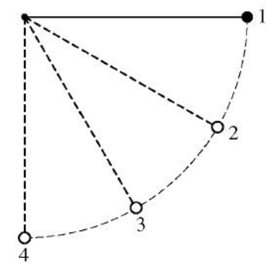
APPENDIX T

UNIT 4: ENERGY EXAM FOCUS QUESTIONS

3. A 0.5 kg pendulum bob is raised to 1.0 m above the floor, as shown in the figure to the right. The bob is then released from rest. When the bob is 0.8 m above the floor, its speed is most nearly

  a. 5 m/s
  b. 4 m/s
  c. 2 m/s
  d. 1 m/s

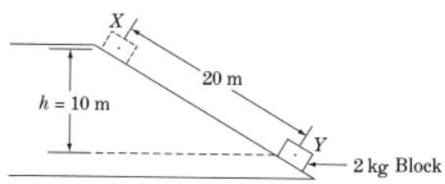
6. A ball is suspended by a lightweight string, as shown in the figure to the right. The ball is displaced to position 1 and released. The four labeled positions are evenly spaced along the arc of the ball's motion. Between which adjacent pairs of positions is the change in kinetic energy of the ball greatest?



  a. 1 and 2
  b. 2 and 3
  c. 3 and 4
  d. The change is the same for all adjacent pairs.

8. A 2 kg block, starting from rest, slides 20 m down a frictionless inclined plane from X to Y, dropping a vertical distance of 10 m as shown to the right.

The speed of the block at point Y is most nearly



  a. 7 m/s
  b. 10 m/s
  c. 14 m/s
  d. 20 m/s
  e. 100 m/s

13. A rubber ball with mass 0.20 kg is dropped vertically from a height of 1.5 m above a floor. The ball bounces off of the floor, and during the bounce 0.60 J of energy is dissipated. What is the maximum height of the ball after the bounce?

    a. 0.30 m
    b. 0.90 m
    c. 1.2 m
    d. 1.5 m

APPENDIX U

UNIT 5: MOMENTUM EXAM FOCUS QUESTIONS

7. Two objects, A and B, initially at rest, are "exploded" apart by the release of a coiled spring that was compressed between them. As they move apart, the velocity of object A is 5 m/s and the velocity of object B is -2 m/s. The ratio of the mass of object A to the mass of object B, m_a/m_b, is
    a. 4/25
    b. 2/5
    c. 1/1
    d. 5/2
    e. 25/4

APPENDIX V

POST LAB OPINION SURVEY

Participation or non-participation will not affect your grade or class standing.

1. Which lab summary technique are you reviewing? (Circle one)

Video Lab Report   Claim Evidence Reasoning Paragraph   Letter Home

2. Approximately how much time did it take you to complete the lab summary assignment?

3. Please answer the questions below on a scale of 1-5.

1	2	3	4	5
Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree

1. The lab summary method helped me learn.	1	2	3	4	5
2. I gave the lab summary assignment my best effort.	1	2	3	4	5
3. The lab summary method was worth my time.	1	2	3	4	5
4. The lab summary method helped me clarify my thinking about the lab content.	1	2	3	4	5
5. I enjoyed using this lab summary method.	1	2	3	4	5
6. I like doing labs.	1	2	3	4	5
7. The lab summary method will help me remember the material.	1	2	3	4	5
8. I would like to use this lab summary method with future labs.	1	2	3	4	5
9. I learn better doing labs than from lectures.	1	2	3	4	5
10. What I learned from doing this lab summary method will help me on future tests.	1	2	3	4	5
11. What I learned from doing this lab summary method will help me with future labs.	1	2	3	4	5

Please answer the questions below with complete sentences. Please explain your answers fully.

1. What content did this lab cover?
2. What part of the lab did you struggle with when doing the lab?
3. What part of the lab were you confident about while doing the lab?
4. What part of the lab did you find easiest to explain when doing the lab summary?

5. What part of the lab did you find hardest to explain when doing the lab summary?
6. What was the biggest thing about the content you learned when doing the lab summary?
7. Did you feel more confident about your understanding of the lab after completing the lab summary? Explain.
8. What was your favorite part of doing the lab summary method?
9. What was your least favorite part of doing the lab summary method?
10. Do you have anything else to share with me?

APPENDIX W

POST LAB INTERVIEW

Interview questions asked of focus students after the lab summary method. **Participation or non-participation will not affect your grade or class standing.**

1. Do you like doing labs?
2. Do you think labs help you learn the material?
3. In previous science classes what did you do to summarize a lab?
4. How did you feel about these previous lab summary methods?
5. In class we previously have been summarizing our labs with discussions and lab notebook writing. How have you felt this has impacted your learning?
6. How did you feel about (lab summary method?) Explain?
7. What did you like about the lab summary method?
8. What didn't you like about the lab summary method?
9. Did the lab summary method change your enjoyment of the lab process?
10. Do you think it has affected your perception of the lab?
11. Did the lab summary method help you learn? Explain.
12. Do you have anything else to share?

APPENDIX X

STUDENT CHOICE SURVEY

Student Choice Form

With this lab you will be allowed to choose any of the three previous lab summary methods to summarize your lab. These choices are Video Lab Report, Claim Evidence Reasoning Paragraph, or Letter Home. **Participation or non-participation will not affect your grade or class standing.**

1. Which lab summary method are you choosing? (Circle one)

Video Lab Report | Claim Evidence Reasoning Paragraph | Letter Home

2. Briefly explain why you are choosing this lab summary method.