

THE EFFECT OF GROUP CREATED LAB DESIGNS ON STUDENTS
UNDERSTANDING OF CONTENT AND
SCIENCE PRACTICES

by

Steven M. Merriman, MS

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ABSTRACT

Community college health and engineering students often have difficulty understanding physics on a conceptual level, as well as general science practices used in experimentation and data analysis. This often leads to low levels of confidence in both, which effects classroom moral. For my intervention, I have students design their own physics labs as a means of having them think deeply about content and lab analysis, and measure the outcomes on both their understanding of each, as well as confidence.

To measure student understanding of course content, each lab will have an associated pre and post-test to compare. I will also make use of their first exam to compare to past semesters, and the Force Concept Inventory (FCI) to compare nationally. Growth in confidence makes use of pre-intervention and post-intervention surveys, as well as student interviews. Growth in data analysis and science practices use pre- and post-tests, given before and after the intervention.

Through the intervention I have observed increases in content understanding, as evident by increases in average pre-posttests scores for each lab. Students also showed growth in the normalized gains on the FCI (higher then past semesters and the national average). Student confidence also increased in terms of both their understanding of physics, science and data analysis. Student understanding of analyzing data was also greatly increased, and is what I consider the most successful part of the intervention.

INTRODUCTION AND BACKGROUND

Introduction

For the past four years I have been teaching physics, engineering and astronomy at Moraine Valley Community College. A former student of the college, I was overjoyed when asked to return to serve the community that I grew up in at a school that put me on the path to earning my Masters of Science in Physics. While teaching at Moraine Valley I have come to find that many of the prospective engineering and natural science students working through our program gain strong problem solving skills, but seem to lack in application of physics and engineering content knowledge as well as do not have a strong understanding of scientific and engineering practices, experimental design and data analysis. My goal for this action research project is to find a way to help students gain these necessary skills.

Student Background

School Demographics

Moraine Valley Community College serves a diverse population whose district is composed of 26 communities with a total population of just under 400,000 residents. The school is located in Palos Hills, Illinois, a suburban region roughly 18 miles southwest of Downtown Chicago. The communities are 74-percent Caucasian, 16-percent Hispanic, 10-percent African American and four percent other non-Hispanic minorities. The median household income of the district was \$60,385. A total of 86-percent of adults in the district hold high school diplomas and 31-percent hold a college degree (associates and higher). A total of five-percent of adult (18+) residents attended the college in 2013.

In the fall semester of 2015 a total of 17,166 students registered for college courses (both credit and non-credit), 53.0-percent of students were female and 47.0-percent male. The student body was 54.6-percent Caucasian, 21.9-percent Hispanic, nine-percent African American, and 2.4-percent Asian. The mean student age was 24.8 years old, and the median age was 21 years old.

Classroom Environment

A typical university level physics course at Moraine Valley Community College is mostly male (usually a 3:1 ratio or greater), largely Caucasian population. Many of them are first generation college students, and many have taken lower level physics in the past (either in high school or algebra based physics in college). Most students are middle to lower-middle class, and many begin at Moraine Valley underprepared for the college experience. Many were guided into the field by high school science and mathematics instructors who felt that they showed an aptitude. Roughly half of a typical class has never taken physics before this course, and so have little to no background knowledge in the subject matter.

Project Background

Project Statement

My action research project is based around the students' conceptual understanding of physics concepts, experimental design, data analysis, mathematical modeling and presentation of a result. It is my belief that community college physics and engineering students spend so much time growing their problem solving skills that they do not gain a

strong conceptual understanding of physics concepts or the methods and purpose of science.

To help my students gain this needed knowledge, I plan to fundamentally change the way I have labs completed in my Physics I course to move away from “cookie-cutter” traditional labs and move into student designed group based learning teams. I will present students with a question at the beginning of lab and each group will have to design an experiment to answer the question, collect and analyze data (keeping data and notes in a well-organized notebook), draw a conclusion that links what was observed in lab to classroom content, and then present their findings in a short presentation to the class.

Focus Questions

The focus of my action research project is based around the introduction of problem-based group learning activities on content and experimental knowledge growth. Questions I would like to gain some insight on are those that follow. What is the effect of problem based, cooperative labs on student understanding of physics content? In what way (if any) does designing an experiment, collecting data and performing analysis help students understand the scientific process? Will having students present their experimental design and conclusions help the students to grow confidence in discussing matters of science and engineering openly with their peers?

CONCEPTUAL FRAMEWORK

A course in physics is often regarded as one of the more difficult that a college student will endure. Physics seems to have a stigma which can largely be associated with

a students' lack of experience with the science (Ornek, 2008). This stigma is making many turn away from the study of physics and engineering, leading to a future problem in which not enough scientists and engineers will be produced to fit the needs of research and technology (Angell, 2003).

Students find physics to be difficult due to its cumulative nature and the need to apply background theory to situations in order to solve problems (Ornek, 2008). It is not simply a matter of practice makes perfect, as studies have found no correlation between excessive practice in problem solving and an understanding of physics concepts, or even the ability to decipher and solve similar problems (Byun, 2014). Despite the level of difficulty, many students find enjoyment in learning the fundamental nature of the science, and describe the issue as resulting from a lack of understanding about the link between physics (and science in general) and experimental procedure (Angell, 2003).

Many students who choose to study physics or engineering display problems with applying necessary concepts to an understanding of real world situations, evident in the difficulty many students have shown in solving problems that are similar, but not exactly like, problems they have encountered in the past (Taejin, 2014). It is evident that physics and engineering students need to gain a stronger conceptual understanding of physics, as well as how to apply the conceptual understanding to real world situations. It is my belief that the best place to give students this understanding is in the laboratory environment.

The physics laboratory classroom is a setting in which students engage in hands-on learning exercises and build understanding of subject matter from real world

experience. Studies show that traditional, step-by-step laboratory experiments do not do a very good job of enhancing student learning beyond the general lecture (Szott, 2014). The American Association of Physics Teachers define the lab environment as a place where students should engage in the experimental process, build on experimental designs with their own ideas, engage in the process of formulating and asking questions, grow their data analysis skills and gain a broad understanding of the role of experiment in science (AAPT Committee on Laboratories, 1998). Knowledge gained in the classroom becomes a tool applied in the physical world, and observations of this application will lead to a deeper understanding of nature. This environment also gives a great opportunity to promote problem based learning, inquiry as well as group collaboration.

Problem based learning is an approach in which students are presented with situations and then given the opportunity to generate a solution to the situation (Raine, 2012). This is done with a focus on six key elements: it is student centered, implemented in small groups, involves learning through real world problems, demands the use and growth of problem solving skills, learning is self-directed and instructors take a guiding role (Batdi, 2014). This approach differs from traditional classroom styles in that problem based learning begins with a problem which is then used to drive the learning environment. By starting with a problem students then need to determine what kind of data they would need to collect to solve the problem, making them more familiar with the content as well as the scientific process (Polacek, 2005). The use of problem based learning has been shown to have a positive effect on academic achievement, increases student motivation, and aids in the retention of subject matter (Batdi, 2014).

When problem based learning is implemented in a physics lab environment, students are given an open ended question and then asked to design an experiment, carry it out, gather and analyze the data and then present their result. In a traditional lab, students are presented with a procedure, apparatus and generally led to expected outcomes (Szott, 2014). The problem based approach forces students to think about the content on a higher level, in which they can apply it to a real world situation, making them take ownership of the experimental design and analysis of the results (Polacek, 2005).

The physics laboratory and problem based learning approach share an important focus, they are both driven by cooperative learning activities. Cooperative learning is grounded in two theories of learning: social interdependence theory, which states that the way group experience is structured will determine how individuals interact, which determines outcomes (in this case, learning); and cognitive-developmental theory, which states that working cooperatively with instructors and peers will result in cognitive development (Johnson, 1998). Cooperative learning has been shown to increase higher individual achievement, foster a sense of community and grow a student's social skills (Johnson, 1998). In a cooperative learning environment, individual students change their role from a passive learner to an active group participant, and the group dynamic spurs intellectual growth (Simonson, 2013).

Problem based, cooperative lab techniques have been shown as having positive results on student learning and understanding as long as the method is applied in a useful manner. Szott's (2014) study found the following:

...as more experiments unfolded, and as our students got used to this style of investigation, we found that it was an effective way to address many curricular objectives. Engagement in open-ended labs generally instilled a greater sense of interest in students with respect to the material under investigation. (p.20)

The same study found that the problem based lab style helped students to gain a deep understanding and acquisition of various scientific skills such as solving open ended questions, designing an experiment and developing models to fit the collected data (Szott, 2014).

In a case study performed by Sarasola et al. (2015), the author found that many students displayed positive results when using problem based approaches in lab. The authors changed the lab in one major way, students had to design their own labs to test a given principle. On the first day of lab, the authors spent their time discussing the experimental method, explaining the structure of future labs, and going of data analysis techniques. When students entered the lab room for future meetings, they were given a general discussion of available equipment, and asked their students to follow a guide for conducting their research. The guide begins by asking students what the purpose of the experiment is, to summarize their knowledge of the subject matter, and then to design the experiment itself. They then had to take measurements following the proposed method, analyze the results, and report on their conclusions. They reported increases in understanding of the nature of science. It was also found that student engagement in the classroom also commonly increased as a result of the approach, as did student understanding of the graphical data analysis.

Another study by Bowe (2003) highlights the use of problem based learning in a first year physics classroom in Ireland, and found increases in content understanding, classroom retention rates, and group work skills. The author of this study uses student team of roughly six students with a tutor observing their process. These student teams would be challenged with a problem, and would have to brainstorm a solution to the problem. Students have to continually explain their thoughts to their peers, which can then be challenged. The tutor observing these sessions would be able to determine where the students are having the most trouble, and intervene if necessary. Once a solution to the problem is determined, the teams would have to present the solution and have the solution challenged by their peers in the class.

Though problem based, cooperative learning techniques have overall positive attributes, they are not without their problems. One of the negative aspects of cooperative learning stems from a problematic group dynamic. This issue can range from a student feeling as if their talents are not being utilized, to “free-riders”, students who do not pull their own weight, bringing down group morale (Dingel, 2013). One way to deal with this is to set standards and expectations early on, and students who do not participate need to be dealt with in a timely manner. Many instructors try to enforce a grading system in which peer review plays a part, but Dingel et al. (2013) found that there is no correlation between a student’s peer evaluations and their overall course performance, showing that some students may evaluate based on unfair criteria. Peer evaluations play the important role of making sure “free-riders” do not benefit from the work of their group, but it is important to consider what factors are important to take into account

during the evaluation and make sure students stick to these factors as honestly as possible through a workable rubric (Dingel, 2013).

Many students enter the physics classroom with a feeling of discomfort that remains with them throughout the semester. This is caused by a number of factors including the need for a deep understanding of content, the cumulative nature of the content, as well as a lack of understanding of science. Problem based, cooperative learning strategies have been shown to have positive outcomes on student growth and performance. Students instructed with these methods show a broader understanding of classroom content. The use of problem based, cooperative learning in the physics classroom has been shown to help students understand how to apply classroom content to real world situations, displaying a deep understanding of the subject matter. If incorporated properly, problem based learning approaches in the physics laboratory environment can help students gain a strong understanding of the science concepts, as well as the methods of science in general.

METHODOLOGY

Engineering and natural science students in community college physics courses tend to focus primarily on the acquisition of problem solving skills while not putting an emphasis on conceptual knowledge of physics or experimental design and data analysis. The purpose of this research project is to attempt to help students grow in their conceptual knowledge and understanding of experimental designing and analyzing data through the use of project-based group learning activities in the classroom lab environment. Students will be given a problem to solve in which they need to design an

experiment, build the apparatus, collect and analyze data, draw a conclusion from the analysis and present the results.

Participants

The participants of the action research project are the students of a Physics 1 course for science and engineering majors. The intervention group contains 30 students, and the demographics are 60% male (18 students) and 40% female (12 students). The students are 70% Caucasian (21 students), 20% Hispanic (6 students), and 7% African American (2 students) and 3% Asian (1 student).

Intervention

My intervention will last for the first unit of the course, which will take the first five weeks of the spring semester and cover the topics of the scientific method and data analysis, kinematics in two dimensions, and Newton's Laws. The intervention group will work through a problem based lab classroom environment. Students will be presented with a question or scenario and asked to work with their lab team to design and implement an experiment to test the problem and follow the data to a logical conclusion. The labs will deal with the subjects of determining the acceleration due to gravity, frictional forces and projectile motion (the lab write ups, along with their associated pre/post-tests, are available in Appendices A, B and C). In doing so students will have to work through the entire scientific process, and then analyze their data. Upon completing the experiment and analysis students will be asked to create a short presentation on the experiment design and conclusion (this is meant to mimic the process of peer review). I believe this will help students gain a deeper understanding of physics content as they

think through the concepts to come up with a viable experiment design, as well as help their understanding of scientific processes.

A typical lab period will begin with a ten minute discussion on the different materials available for the lab, but students were allowed to use any materials they wished (some students would design labs involving their cell phone cameras). For example, when students began the free fall lab, I discussed the photogates and Vernier software, stopwatches, meter sticks and rulers, and the concept of reaction time. Students were then given 90 minutes to design and run an experiment, collect their data, and perform their analysis of the data. I walk around from group to group to answer any questions, drive their conversation, and try to get them to realize if there exists a weak spot in their design (I will never come out and tell them this, as part of the learning process is that they realize it) so they can either change the experiment or find some way to account for it. While walking around I will also make observations using the guide in Appendix G. Once the experiment was completed the students would have 20 minutes to make a short presentation, and the remaining 40 minutes of the class would be spent with students presenting their design and analysis, as well as answering questions from myself and their peers.

Data Collection

To measure the degree that labs help students gain concept knowledge, a pre and post-questionnaire will be given to both sections before and after each lab. The questions will require students to write short answers to display their knowledge, which will then be rated by myself on a five point scale ranging from “displays high level of

understanding (five points)” to “little to no understanding (zero points)”. The questionnaires are available for each lab in the appendices. I will also make use of the Force Concept Inventory, a tool used worldwide to gauge student physics understanding in the concepts of force and motion. Students will be given the Force Concept Inventory on the first day of class, and they will take it again at the end of the unit. I will compare these results with those from my students in the previous semester. Finally, upon completing the unit, students will take the same exact exam on the content material as students in the same course the past semester. I will be able to compare the results from the exams taken in both classes to determine whether or not this approach helps understanding of content.

To measure the degree in which designing your own lab helps students gain an understanding of science processes and data analysis, a pre and post-test will be given before the first lab and after the final lab to both groups (available in Appendix D). In the tests students will be given a small data set and asked to analyze it to the best of their ability. A 40 point rating system will be used based on what students do as part of the analysis (using averages, graphing, accounting for error, etc.). The rating scheme is also available in the appendices. I will also personally view the student thought process and analysis methods as they work through the three labs, and will keep notes on my personal observation using the observation protocol (available in Appendix G).

Finally, I would like to determine whether the problem based approach to lab helps students become more confident with using their personal understanding of physics concepts and scientific processes. I will gauge this using a pre-survey given before the

first lab, and a post-survey after the final one (available in Appendix E). The survey will consist of a set of 10 questions based on the even-point Likert scale. I will also conduct student interviews after the final lab (available in Appendix F), in which students will be chosen at random based on grades. I will classify students in each section into groups: those above 85%, those between 70%-85%, and those below 70%. I will then interview two students from each group (six students will be interviewed in total).

Table 1
Triangulation Matrix

Focus Question: What is the effect of using student group designed experiments in a problem based laboratory environment on student physics conceptual understanding?			
Subquestions	Data Source		
Subquestion 1: What is the effect of a problem based lab environment on student understanding of physics concepts?	Pre-Test	Force Concept Inventory	Post-Test & Exam 1
Subquestion 2: Does designing and implementing an experiment give students more confidence with physics content?	Pre-Survey	Student Interviews	Post-Survey
Subquestion 3: What is the effect of a problem based lab environment on student understanding of scientific processes and data analysis?	Pre-Test	Group Lab Analysis	Post-Test
Subquestion 4: Does designing and implementing an experiment give students more confidence and understanding of scientific processes?	Pre-Survey	Student Interviews	Post-Survey

DATA AND ANALYSIS

Introduction

Upon completion of the intervention I began to work my way through the gathered data and analyze the results. Each question listed in the Triangulation Matrix has multiple means of data collection that need to be analyzed. The various types of

surveys, tests, etc. have different metrics for success, and so each will be discussed and analyzed separately.

Conceptual Understanding

To measure the effect of the intervention on conceptual understanding of physics concepts I used three separate data sources. For each intervention lab there was a pre- and post-test to analyze, gathering data on growth in understanding that compares the students with themselves. I also measured the conceptual understanding of my intervention class with my past physics course based on analyzing their first exam score. Finally, I measured growth in conceptual understanding using the Force Concept Inventory to draw a comparison with the intervention group and my past courses, as well as nationally. Each case will be discussed separately.

Results from each intervention lab pre- and post-test displayed growth in student conceptual understanding as a result of the lab. The first lab, in which students were tasked with measuring the acceleration due to gravity, had a fairly low performance for the class as a whole with a mean score of 8.16 out of 15 (SD=2.38). The associated post lab showed improvement with a mean score of 10.38 out of 15 (SD=2.38). The comparative growth was statistically significant, $t(58)=3.73$, $p<0.05$. The second lab, in which students studied projectile motion, had a higher initial performance with a mean score of 11.03 (SD=3.23). The associated post lab showed slight improvement with the mean score rising to 12.90 (SD=2.25). The growth was statistically significant, $t(58)=2.57$, $p<0.05$. The final lab, in which students studied the concept of friction, had a pre-test mean score of 11.20 (SD=3.12), and a post-test mean score of 13.73 (SD=2.79).

The comparative growth was statistically significant, $t(58)=3.39$, $p<0.05$. Each intervention lab pre/post test showed significant student growth in concept understanding.

Results from comparing the conceptual portion of the first exam taken between my fall semester 2015 class and my intervention class show no significant growth. My fall 2015 class consisted of 21 students who received a mean score of 30.76 (SD=6.19) out of 40 points on the conceptual portion. The intervention class received a mean score of 31.83 (SD=5.65). A comparison of the two yields a t-test score of $t(48)=0.63$, $p>0.05$. The low level of significance tells that there is no significant difference between the performances of the two classes, and so there is no significant growth on the exam score due to the intervention.

The Force Concept Inventory is a standardized test in the field of physics education. The traditional way to measure the results of the test are through the average normalized gains, a comparison of the difference in the posttest and pretest average with the total possible average student gain (Hake, 1998).

$$NG = \frac{\textit{Posttest Average} - \textit{Pretest Average}}{100 - \textit{Pretest Average}}$$

The typical normalized gain for a traditional lecture/lab college physics course is 0.22 ± 0.05 (Knight, 2004), which means students would be expected to have a score increase of 22%. My fall 2015 physics course, which was taught through a traditional lecture and lab model, had a normalized gain of 0.24 ± 0.08 , with a t-test score of $t(40)=12.18$, $p<0.05$. The intervention course had a normalized gain of 0.34 ± 0.08 with a t-test score of $t(56)=8.13$, $p<0.05$. This shows that, comparing between two of my

courses, but also compared to a national average, the intervention does help in growing student conceptual physics knowledge when compared to a traditional lab structure.

Student interviews showed contrasting opinions on how helpful the intervention was in terms of helping growth of conceptual understanding. One student gave a very positive review when they said “Designing the lab with your group forces you to think deeply about what you are doing, as well as discuss it with everyone. Putting so much thought into the lab really helps you understand the concept.” Another student’s opinion contrasts this. “I can see how the lab is helpful if you come in with some understanding of the concept, but if you come in already very confused, then you are being asked to design a lab with knowledge that you don’t have, and that just makes you more confused.” From my personal observation, it would appear that the students who had the most benefit from the intervention were those who already performed fairly well (the “A” and “B” students), but I do feel there was a level of growth across the board. Students who were normally quiet and not involved in lecture became more involved in the lab, asked questions of their colleagues and so learned from the experience.

Confidence with Content

To determine if the intervention had any effect on student confidence with physics content, pre and post surveys (available in Appendix E) were utilized, as well as student interviews. The survey contained Likert Scale questions designed to measure student confidence in three major course outcomes: understanding of forces and motion, problem solving, and general comfort with physics. I will discuss the results of the survey for each outcome separately, followed by the survey results.

The first three questions are meant to measure student confidence in their understanding of two concepts in forces and motion which I have noticed students struggle with, which are viewing orthogonal components of a system as independent, and the relationship between force and velocity. The first question asks students if they feel they have a strong understanding in the purpose of breaking up vectors into independent components, of which 26 students (roughly 90%) stated that they either disagree or strongly disagree in the pre-survey, but this changed to 24 students (roughly 83%) saying either agree or strongly agree in the post-survey. The third question asks something similar, whether the student feels they understand that forces acting horizontally do not affect acceleration vertically. On the pre-survey, 16 students (55% of students) said they agree or strongly agree, which grew to 24 students in the post-survey (83%). Combined, these show that students grew more comfortable dealing with vectors. The second question asks students whether they understand that constant velocity doesn't imply no force acting on the system, but balanced forces acting on the system. On the pre-survey, 16 students (55%) said they either agreed or strongly agreed with this statement, which grew to 24 students (83%) on the post-survey. This shows students comfort level with the relationship between forces and acceleration has grown. The results are depicted in Figure 1.

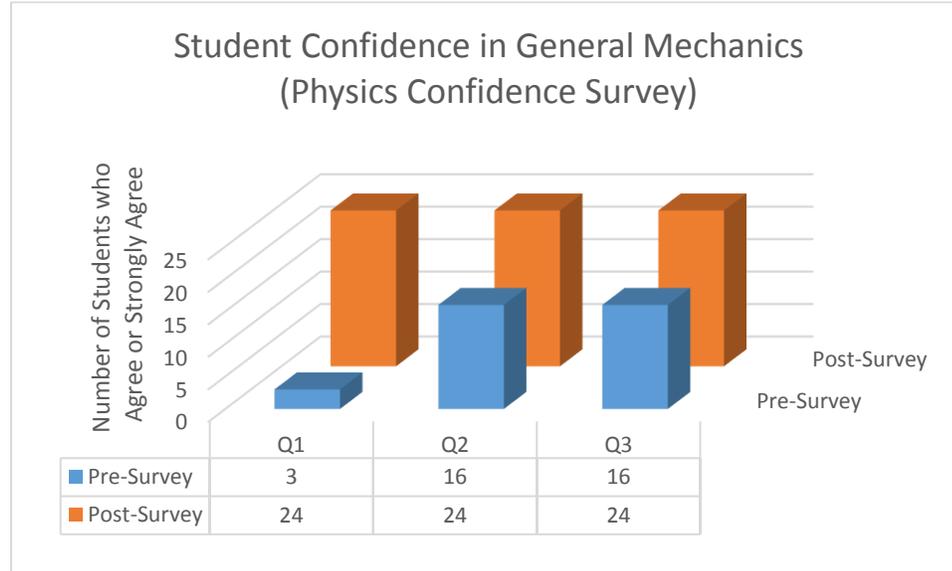


Figure 1. Student confidence in general mechanics concepts from the physics confidence survey, ($N=29$).

The next set of questions were designed to measure student confidence in problem solving (largely mathematical) in physics course. Question four asks students if they feel confident in using mathematics as a tool in problem solving. On the pre-survey 19 students said they either agreed or strongly agreed (66%), which grew to 24 students (83%) on the post-survey. Question six asks students if they feel they understand how the mathematical framework of motion (kinematic equations and Newton's Laws) are related to the conceptual structure of motion, of which 10 students (34%) either agreed or strongly agreed on the pre-survey, which grew to 24 students (83%) on the post-survey. Question 7 asks students whether they feel, when solving a physics problem, all they are doing is plugging numbers into equations and hoping for the best (attempting to measure how confident they are in understanding the meaning behind the equations). On the pre-survey only 4 students (14%) either disagreed or strongly disagreed that this is what they would do, but the post-survey had this grow to 22 students (76%). The results of these

three questions show that students grew more confident in using mathematics in problem solving, and relating the equations to the actual concepts, as the course progressed. The results are depicted in Figure 2.

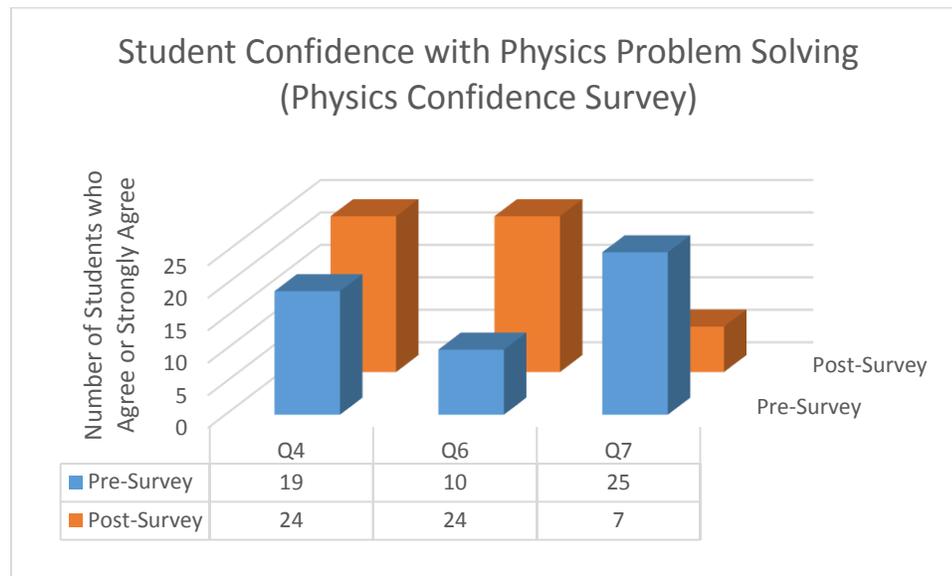


Figure 2. Student confidence in physics problem solving from the physics confidence survey, (N=29).

The final two questions on the survey were designed to measure students' comfort level with physics in general. Question five asks students whether or not they feel confident using their physics knowledge to analyze real world situations. This showed surprisingly little growth, from 10 students (34%) agreeing in the pre-survey, to 13 students (45%) agreeing in the post-survey. This tells me that students' still see physics as an abstraction, something that looks good on paper but is not applicable in the real world (a major issue that will need to be addressed in future). Finally, students were asked whether or not they agreed that they feel their current physics understanding has them prepared to go deeper into these topics in future courses. The pre-survey had five

students (17%) either agree or strongly agree, which grew to 24 students (83%) in the post-survey. I feel this last question is the most indicative of student confidence growth in the subject as a whole. The results are depicted in Figure 3.

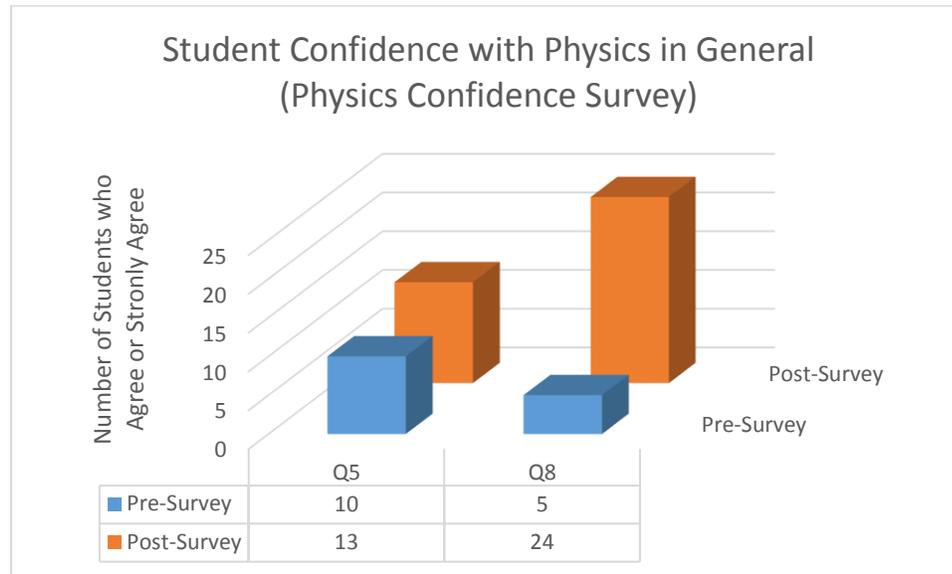


Figure 3. Student confidence in general physics concepts from the physics confidence survey, (N=29).

Student interviews gave insight into how student confidence grew as a result of the intervention. One student stated, “The lab made you think deeper about how the objects would actually move, or what forces you were dealing with, then any homework problem could. It helped me feel that I truly had a grasp of the subject.” Another student agreed that the intervention gave a confidence boost, “You had to actually know the material to do the lab, and so it made you think about it more deeply. This really helped me understand what was going on more.” There was one dissenting voice, but with a positive spin. “Discussing the lab design with your group, and they know what they are talking about, and you don’t, really just makes you feel dumb, and that is how it was for

me. At the same time, knowing that the lab was coming, and wanting to contribute did make me study before coming in, and by the third lab I felt like I was contributing, and grasping the concepts a bit more.” My observation is that, initially, the class was much divided in how confident they were with the content, as noticed in how hesitant they were to contribute with their lab groups. This is especially true for students who tend to be lower performing, or who have never dealt with the subject matter before. By the end of the intervention, this seemed to even out, with most students willing to openly discuss the lab designs, as well as concepts that go into it, with their lab group. This is what makes it such a great learning experience, as the students will gain a greater understanding based on asking questions to their group, as well as responding to the questions of their fellow classmates.

Understanding Data-Analysis

“When I handed students their data analysis pre-test, each group seemed very confused by what to do. As time went on they seemed to attempt to analyze using very basic methods (averaging, etc.), with only one group attempting to use a graphical approach, and no one even thinking to look for any statistical error in the data. This will require a lot of work,” quoted from my teaching journal from an observation of the students data analysis skills made during their pre-test on January 20, 2016. This sub-question is the one that I feel the intervention had the greatest impact on the students overall. Upon taking the post-test, all groups but one graphed the data, found the statistical error in each data point, and found a best fit line, a very significant improvement. The pre/post-test is available in Appendix D.

The survey was graded based on a 40 point scale, which is available in Appendix D based on how I would go about analyzing the given data set. As most groups did not even attempt to graph the data in the pre-test, the mean score was a 4.66 (SD=2.07). The mean score for the post test was a 26.38 (SD=4.66). The t-score was $t(14)=12.07$, $p<0.05$, and so the growth of the class as a whole was significant.

I made many observations about the growth of the students analysis skills throughout the process (see the observation guide in Appendix G), beginning with the initial observation made at the beginning of this section. After giving the pre-test, I gave students a crash course in why multiple measurements were made, how to graph data in Microsoft Excel, how to fit a regression line to the data, and how to account for standard error and add error bars. I made the following observation after their first lab presentations. “About half of the groups took their analysis much further. All but two groups used a graph, but four of them explained in their presentation how and why they chose the number of data points they did, analyzed the error in each point, and three groups added error bars to their graphs. Already a significant improvement, but the rest of the groups must realize why this is important. I made sure to press them in their presentation, in the hopes that they remember for the next lab (personal observation, January 27, 2016).” I continued to see and push for growth throughout the intervention. After the final lab I wrote the following observation, “All groups are finally graphing their data, accounting for error, etc. No group has taken it any further than regression lines and error bars (it never occurred to anyone that the slope value they found itself has

some error to account for) but I am going to take this as a victory (personal observation, February 24, 2016).”

Student interviews showed a general consensus on what students think about deeper levels of data analysis, which are summed up nicely by this quote. “I have never had to look at data and error this deeply before, and it was unexpected. Every past class really just had you calculate a percent error, or a percent difference, but no one had me try to determine the error in each point and then make sure a best fit line was consistent with the error. It was a hard thing to get used to, but a good learning experience to take with to future courses.” In honesty, no group seemed comfortable with their first presentation, but by the end many grown accustomed to the requirement, and spent some of their lab time discussing the concepts so they were prepared to present.

Confidence with Science Processes

To determine whether the intervention helped students gain confidence in science practices I used a pre and post-survey, as well as student interviews. The survey was a collection of ten questions (available in Appendix E) designed to measure student confidence in their understanding of the scientific method, experimental design and data analysis. The survey begins with a question on whether the student is confident in their understanding of the difference between a hypothesis and the scientific method. The pre and post survey results were identical for this question, with 27 students (93%) selecting agree or strongly agree. The sixth question takes this further, asking students the degree to which they understand the link between using past knowledge to formulate a hypothesis, and then using the hypothesis to design an experiment. The pre-survey had

18 students (62%) saying they agreed, which grew to 27 students (93%) in the post survey. I feel this shows growth in understanding the scientific process in general, as they claim an understanding of the difference between a hypothesis and a theory, but less so the link between them, experiment. The latter shows growth to a higher level of understanding beyond the abstract definition. The results of this portion of the survey are viewable in Figure 4.

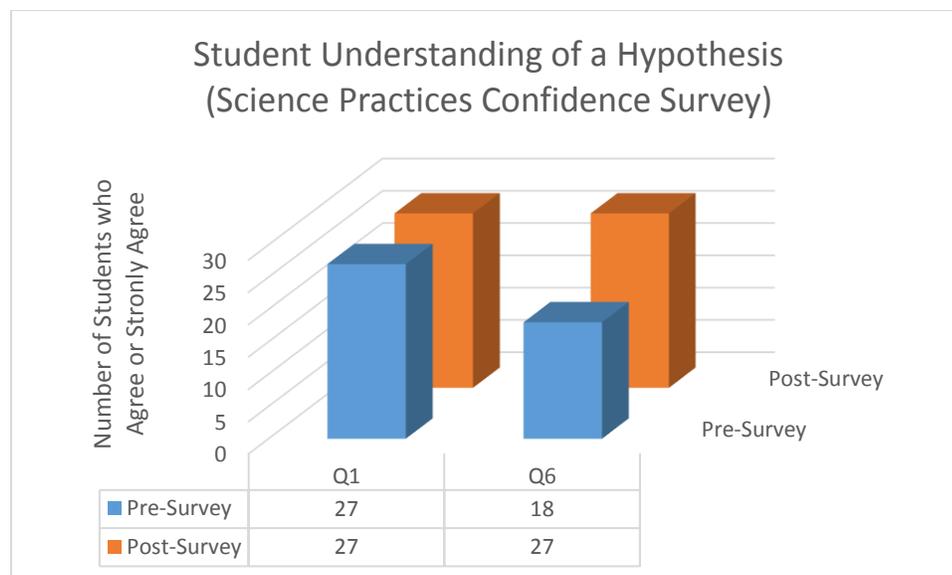


Figure 4. Student confidence in understanding the meaning of a hypothesis from the science practices confidence survey, (N=29).

For the second item of the survey I ask students whether they feel they understand the importance of accurate measurement, proper data analysis and analysis of error.

Again the pre and post surveys are similar with 27 students agreeing on the pre survey and 28 on the post survey. The survey then goes on to determine how well students feel they understand the actual process of measurement, data analysis and error analysis. The third question asks students if they are comfortable using statistics to quantitatively

evaluate measurement error, of which 15 students (52%) agreed on the pre-survey. This amount grew to 26 students (90%) on the post survey. Question four asks students if they feel confident using mathematics to quantitatively analyze data gathered in experiment. The pre-survey had 13 students (45%) showing agreement, which grew to 28 students (97%) showing agreement on the post-survey. The survey shows that students came into class with an understanding of the importance of proper analysis, but are leaving the intervention confident using the tools of data analysis. These results are depicted in Figure 5.

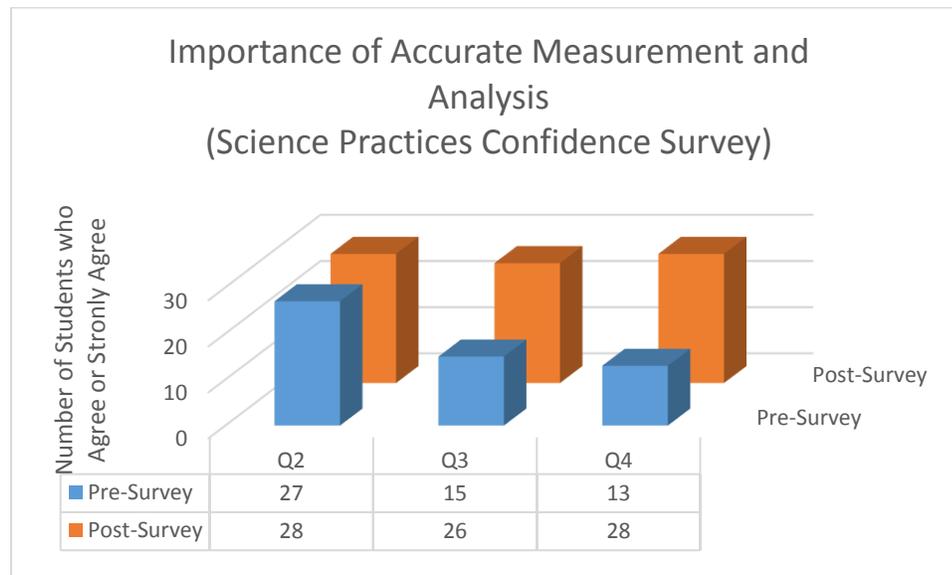


Figure 5. Student confidence in understanding the importance of accurate measurement, data analysis and analysis of experimental error, (N=29).

The final questions of the survey deal with student understanding of the importance of the scientific mindset itself. Question seven asks students if they understand the need for honesty in data collection and analysis, which showed similar results in both pre and post surveys (28 students showing agreement in the pre-survey, 29

in the post survey). Question eight asks students if they have an understanding of the need to draw conclusions from their collected data, and not from past beliefs or ideas, which had the same pre/post survey results as the previous question. Question nine asks students if they understand the need to properly communicate their conclusions drawn from experimental data. There was growth in this regard, moving from 22 students (76%) showing agreement in the pre-survey to 28 students (97%) showing agreement in the post survey. The final question asks students if they understand they believe they use scientific processes to analyze the world around them. Eighteen students (62%) showed agreement in the pre-survey, growing to 24 students (83%) in the post survey. This portion of the survey showed students came into the intervention knowing the importance of honesty in the scientific process, but leave the intervention feeling they are more equipped to communicate scientific observations and conclusions. The results from these four questions are depicted in Figure 6.

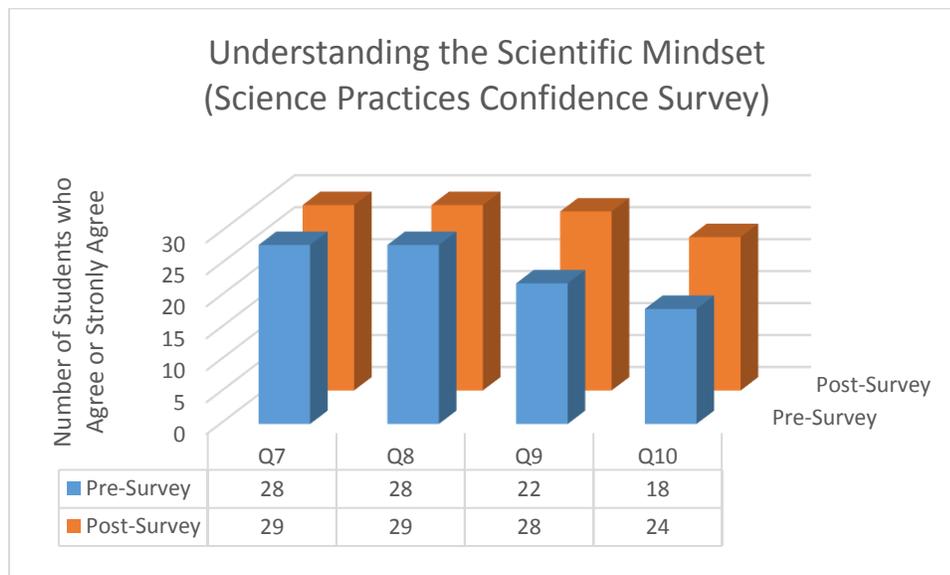


Figure 6. Student confidence in understanding the scientific mindset, (N=29).

Student interviews gave both negative and positive accounts of the effect of the intervention on their scientific processes and analysis confidence. One student stated, “I feel that you put a lot of pressure on us to analyze the data in just the right way, and then, whether we felt we understood what was going on, present our analysis to the class. It was often nerve wrecking, and definitely not a confidence booster.” Another student interpreted the intervention differently. “By making me and my group present our findings, and by questioning us, I feel you pushed us to learn to communicate our experiment and findings clearly. I feel better equipped to discuss the elements of this course with my classmates more clearly.”

INTERPRETATION AND CONCLUSION

I am very happy with the results of the intervention. According to the data, students grew in their understanding of physics conceptual understanding, their confidence in the subject matter, data analysis skills and their confidence in understanding the scientific process. On top of this there was a visible increase in classroom interest, student retention in the class is higher than average, and my personal enjoyment in the classroom, as well as enthusiasm for my job, is vastly increased.

Similar to the findings of Bowe (2003), my intervention showed that group and inquiry based learning in a physics classroom go hand in hand with increases in student understanding of course content. Though I did not see any conceptual understanding growth on the conceptual portion of my own exam, it is noted in the increase in the pre/post tests given before and after each lab, as well as the increase in normalized gains on the Force Concept Inventory. Student interviews showed a mixture of opinion on how useful

the intervention was for their conceptual understanding, but it was apparent to me that, once students began to get involved, they began to take an interest in the content, ask questions to their lab groups, and expand their own understanding.

Pre- and post-survey data showed that, after the intervention was completed, students' confidence in their understanding of concepts had grown. This includes the topics of mechanics and motion, problem solving and problem solving strategy, and physics as a science in general. While watching students present their lab results, it was obvious that as the intervention progressed students were more comfortable and confident discussing their designs, the ideas behind those designs, and their results and interpretations in scientific terms. This is seen as a natural part of problem based learning, as stated by Batdi (2014), in which by forcing students to think about the concepts for themselves to determine a course to the solution they will experience greater content retention, academic achievement and increases student motivation. This all leads to more confident and capable students.

Data analysis is the area where I feel the intervention had the greatest impact on students. When presented with data for the pre-test on data analysis, most lab groups did not have the slightest bit of a clue on where to begin working through a set of data to find a relationship, and wouldn't even fathom accounting for error within that relationship. At the end of the intervention a visible increase in general analysis skills (graphing, standard deviation and error, curve fitting) was very apparent. Finally, pre- and post-test data shows an increase in student confidence with science practices including formulation of a hypothesis, importance of accurate data reduction and analysis, the use of mathematics as

a tool of analysis, and the scientific mindset itself. This finding is similar to those of Szott (2014) when he introduced student inquiry into a physics lab environment. Similarly, when Sarasola (2015) made his students design labs to find solutions to their given problem to solve, he found increases in data analysis abilities as well as understanding of the methods of science.

There are many ways to further and improve upon this intervention. When it comes down to it, I do not know whether or not I feel it is designing their own labs in particular that bring about these positive changes, but the fact that I put the learning experience into the hands of the students themselves. They were given a goal of what to understand, a team of students to learn from and discuss the objective, and the necessary background knowledge for them to expand further. This is an idea that can apply to all areas of the classroom, not just the lab.

The next phase is to bring these ideas into my lecture, and the main tool I will use is white-boarding. I will limit my lecture to as little as possible, and put the focus on students discussing the ideas among themselves. Students will brainstorm ideas after viewing demos, perform mini-experiments to derive relationships before I show them an equation, and solve problems together with little to no examples from myself. Everything they come up with will be written on their whiteboard, and the students will present their ideas and have a class wide discussion on conceptual subject matter and problem solving techniques. Labs will be a little more guided but still largely open investigation, and in between each lab investigation students will discuss their results and the class to come up with a consensus. The classroom as a whole, lecture and lab, will become an interactive

learning experience, and I expect the results I have found in the intervention will continue to grow.

VALUE

The intervention had many positive outcomes, both for my students (present and future) and to myself. I think the best thing that has come out of it is that it pulled me out of my comfort zone and made me realize the value in breaking away from traditional classroom management techniques. After the intervention, I was inspired to go a step further, and began having the students problem solve in groups using giant white boards, I continued having students use lab time for personal discovery (though I give them a setup and a goal), and I've begun to have students present a lot more often (in a less formal way). It seems to me that the more involved you make the students, the more independent you make the students, the more the students take charge of their own education. During the intervention I saw an increase in classroom interaction, an increase in content understanding and an increase in students' confidence in themselves. As I progress beyond this I have seen an increase in retention, an increase in attendance, and an overall more enjoyable classroom for by the students and myself. There is a lot of value in moving away from traditional techniques and trying something new.

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APPENDICES

APPENDIX A
FREE FALL LAB WRITE UP AND PRE/POST TESTS

Free Fall

Scenario

As a young physicist/engineer, you have been taught that the acceleration due to gravity near the surface of the Earth is 9.8 m/s^2 , a fact that is taken without question. Recently, it has come up under debate whether or not this value is accurate. As so much depends on our understanding of how objects fall, you have been chosen to help determine the accuracy of this value.

Your task is design and implement an experiment to determine:

- a. The magnitude of the free fall acceleration (g) near the Earth's surface
- b. Whether or not the free fall acceleration is dependent on mass
- c. Whether or not the free fall acceleration is dependent on surface area

You are free to design a single experiment that tests all three, or conduct three separate experiments. Use any tools/instruments you want to work out your design, but be prepared to explain and defend the value of your design. You may not communicate with other lab groups or take their ideas (your design must be solely your lab team's creation). You may not look up lab designs online.

Upon completion of data collection, build a short slideshow presentation about your lab design and results. When all groups are finished each will present to their classmates.

APPENDIX B
PROJECTILE MOTION LAB WRITE UP AND PRE/POST TESTS

Projectile Motion

Scenario

An amusement park investment group wants to build a terrifying new ride in which thrill seekers are launched out of a spring loaded cannon to land safely on a giant air mattress. The job has been assigned to your engineering firm, and your boss has tasked you with determining whether or not the ride would be safe (assuming if someone lands on the air mattress they will be just fine).

Your task is design and implement an experiment to determine:

- d. The initial velocity of a scale model of the spring loaded canon.
- e. If the projectile fired in your scale launcher represents the 2.50 m diameter spherical ball amusement park customers would be placed in before being launched, what is the minimum sized landing mattress that would need to be purchased to make the launcher safe.
- f. The amusement park owners want an additional test performed. They wish to know whether it is easy to predict where the ball would land if the launcher were placed at a new height (some thrill seekers may wish to be launched from higher up). When you know the size of mattress and initial velocity of the launcher, call your boss (instructor) to change the height of the launcher, and prove that you can predict where to put the mattress (target) so that the projectile ball lands on it when fired from the new height. (In this instance, you cannot launch the ball until your mattress target is secured to the location).

You are free to design a single experiment that tests all three, or conduct three separate experiments. Use any tools/instruments you want to work out your design, but be prepared to explain and defend the value of your design. You may not communicate with other lab groups or take their ideas (your design must be solely your lab team's creation). You may not look up lab designs online.

Upon completion of data collection, build a short slideshow presentation about your lab design and results. When all groups are finished each will present to their classmates.

Free Fall: Post-Lab Concept Tracker

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Two students, Tom and Janet, stand on a cliff 30.0 m above the surface of the Moon (remember, there would be no wind resistance on the Moon) to perform a physics experiment. Each one has a ball, which are identical to each other. Tom throws his with a velocity of 25 m/s at an angle of 45.0° , while Janet throws hers vertically upward with a velocity of 20 m/s.

1. Whose ball reaches a higher point, Tom or Janet? Explain your reasoning.
2. At the highest point of the flight, which ball has the greater vertical velocity? Explain your reasoning.
3. At the highest point of the flight, which ball has the greater horizontal velocity? Explain your reasoning.
4. At the moment Tom's ball falls past the top of the cliff, Janet throws another ball straight downward with an initial speed of 25 m/s. Which ball hits the ground first? Explain your reasoning.

APPENDIX C

FRictional Forces Lab Write Up and Pre/Post Tests

Frictional Forces

Scenario

Frictional forces are forces that oppose the motion of an object as a result of the rubbing together of two surfaces. At an elementary level, these come in two varieties: static friction and kinetic friction. Static friction is the frictional force that must be overcome to put an object into motion, whereas kinetic friction is the frictional force that must be overcome to keep an object in motion.

You work for a startup company that wishes to be the world leader in designing systems where you want to control the strength of the frictional force (slides, for an example). They hired you and your team to discover the ins and outs of the frictional force. Design an experiment to determine:

- a. The coefficient of static friction between wood and glass, wood and sand paper, and wood and wood.
- b. The coefficient of kinetic friction between wood and glass, wood and sand paper, and wood and wood.
- c. The minimum force required to start a 250g cart with a sandpaper bottom moving across a sandpaper surface.
- d. The minimum force required to keep a 250g cart with a sandpaper bottom moving across a sandpaper surface at a constant speed.

You are free to design a single experiment that tests all three, or conduct three separate experiments. Use any tools/instruments you want to work out your design, but be prepared to explain and defend the value of your design. You may not communicate with other lab groups or take their ideas (your design must be solely your lab team's creation). You may not look up lab designs online.

Upon completion of data collection, build a short slideshow presentation about your lab design and results. When all groups are finished each will present to their classmates.

Frictional Forces: Pre-Lab Concept Tracker

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

1. If an object is already in motion, would the minimum applied force required to keep it moving at a constant speed be greater than, less than or equal to the force due to friction? Explain.
2. Generally speaking, does it require a greater force to get an object to start moving, or to get an object to stay in constant motion? Explain.
3. How is the weight of an object related to the force due to friction? Explain.
4. Will a surface you perceive to be rougher always have a greater frictional force than a surface you perceive to be smoother? Explain.

Frictional Forces: Post-Lab Concept Tracker

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

1. If an object is already in motion, would the minimum applied force required to keep it moving at a constant speed be greater than, less than or equal to the force due to friction? Explain.
2. Generally speaking, does it require a greater force to get an object to start moving, or to get an object to stay in constant motion? Explain.
3. How is the weight of an object related to the force due to friction? Explain.
4. Will a surface you perceive to be rougher always have a greater frictional force than a surface you perceive to be smoother? Explain.

APPENDIX D
DATA ANALYSIS PRE/POST TEST AND SCORING RUBRIC

Data Analysis: Pre-Test

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

You and your group run an experiment where the independent variable (the variable you have control over) is x , and the dependent variable (the one that you measure based on x) is y . These are related by the equation $y=mx$. Your group decides on a value for x , performs the experiment three times (gathering three values for y). You then vary x and repeat the process. This happens a total of six times. The results are below.

X	y
0.50	2.2
0.50	2.0
0.50	1.8
x	y
2.0	8.4
2.0	7.7
2.0	7.9

x	y
1.0	4.2
1.0	3.9
1.0	3.9
x	y
2.5	11
2.5	9.5
2.5	9.5

x	y
1.5	6.0
1.5	5.9
1.5	6.1
x	y
3.0	12
3.0	11
3.0	13

Using any methods you feel appropriate, analyze this data set to draw a conclusion for the value of "m".

Data Analysis: Post-Test

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

You and your group run an experiment where the independent variable (the variable you have control over) is x , and the dependent variable (the one that you measure based on x) is y . These are related by the equation $y=mx$. Your group decides on a value for x , performs the experiment three times (gathering three values for y). You then vary x and repeat the process. This happens a total of six times. The results are below.

X	y
0.50	2.2
0.50	2.0
0.50	1.8
x	y
2.0	8.4
2.0	7.7
2.0	7.9

x	y
1.0	4.2
1.0	3.9
1.0	3.9
x	y
2.5	11
2.5	9.5
2.5	9.5

x	y
1.5	6.0
1.5	5.9
1.5	6.1
x	y
3.0	12
3.0	11
3.0	13

Using any methods you feel appropriate, analyze this data set to draw a conclusion for the value of "m".

Data Analysis: Rating Scheme

Each criteria below is rated on a 0-5 system, 5 being a strong demonstration of understanding and execution, 0 being absolutely no understanding and execution.

<u>Criteria</u>	<u>Score</u>
Students used averages to determine the average obtained value for y for each given x.	
Students properly graphed the data to see a visual representation of their relationship.	
Students applied a best fit trendline to the data to obtain a quantitative representation of the relationship.	
Students obtained a value for “m” from the slope of the graph.	
Students made use of regression to determine how well the trendline fits the data.	
Students performed error analysis on each point of the data.	
Students used error bars to show the inherent error at each point on their graph.	
Students determined the potential error in their value for “m”.	

APPENDIX E
PHYSICS CONFIDENCE SURVEY

Physics Content: Confidence Survey

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

For each of the following statements, reflect personally and decide whether you strongly agree, agree, disagree or strongly disagree with the statement as it pertains to yourself.

1. I have a good understanding of what it means to break a vector into independent vector components.

Strongly Agree Agree Disagree Strong Disagree

2. I understand forces that act in the horizontal direction do not influence the acceleration in the vertical direction.

Strongly Agree Agree Disagree Strong Disagree

3. I understand that the term constant velocity does not imply no forces, but balanced forces.

Strongly Agree Agree Disagree Strong Disagree

4. I feel confident in using mathematics as a tool to quantitatively work through physics problems.

Strongly Agree Agree Disagree Strong Disagree

5. I believe that my understanding of the physics concepts of force and motion are strong enough to analyze complex real world situations.

Strongly Agree Agree Disagree Strong Disagree

6. I understand how the mathematical framework of motion is related to the concept of motion and forces.

Strongly Agree Agree Disagree Strong Disagree

7. When solving physics problems I simply plug numbers into equations and hope for the best.

Strongly Agree Agree Disagree Strong Disagree

8. I believe that I have a strong enough understanding of physics principles at the level of my current course and am prepared to enter future courses which go deeper into these concepts.

Strongly Agree Agree Disagree Strong Disagree

Science Practices Confidence Survey

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

For each of the following statements, reflect personally and decide whether you strongly agree, agree, disagree or strongly disagree with the statement as it pertains to yourself.

1. I have a good understanding of the difference between a hypothesis and a theory.

Strongly Agree Agree Disagree Strong Disagree

2. I understand the importance of accurate measurement, proper data analysis and the analysis of error.

Strongly Agree Agree Disagree Strong Disagree

3. I feel confident in using statistics as a tool to quantitatively perform error analysis of a set of experimental data.

Strongly Agree Agree Disagree Strong Disagree

4. I feel confident in using mathematics as a tool to quantitatively analyze data gathered in an experiment.

Strongly Agree Agree Disagree Strong Disagree

5. I understand the difference between a set of data that should be graphed for analysis and a set of data that requires a less visual analysis.

Strongly Agree Agree Disagree Strong Disagree

6. I understand the process of using past knowledge to build a hypothesis, and using the hypothesis to design the experiment.

Strongly Agree Agree Disagree Strong Disagree

7. I understand that the scientific process requires that participants be honest with data collection and analysis to draw proper conclusions about the universe.

Strongly Agree Agree Disagree Strong Disagree

8. I understand the importance of drawing conclusions from the data that is collected, and not from personal beliefs or past understanding.

Strongly Agree Agree Disagree Strong Disagree

9. I believe it is important to properly communicate the conclusions drawn from my data.

Strongly Agree Agree Disagree Strong Disagree

10. I believe that I understand the scientific process and analyze the world using scientific practices and scientific tools.

Strongly Agree Agree Disagree Strong Disagree

APPENDIX F
STUDENT INTERVIEW QUESTIONNAIRE

Student Interviews

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

1. Do you feel that the labs you have worked on are helpful in solidifying concepts discussed in lecture?
2. Do you feel that the labs have given you a strong understanding of the overall scientific process?
3. Do you feel the labs have helped you to gain a stronger understanding of the methods of data analysis?
4. Have the labs helped you to think more clearly when working on physics problems?
5. Do you feel the labs help you perform better on quizzes and exams?

APPENDIX G
PERSONAL OBSERVATIONS OF LAB GROUPS GUIDE

Personal Observations of Lab Groups Guide

1. What behaviors do you observe in the interactions between teammates? Do they work together to stay on task? Do they assign roles? Etc.

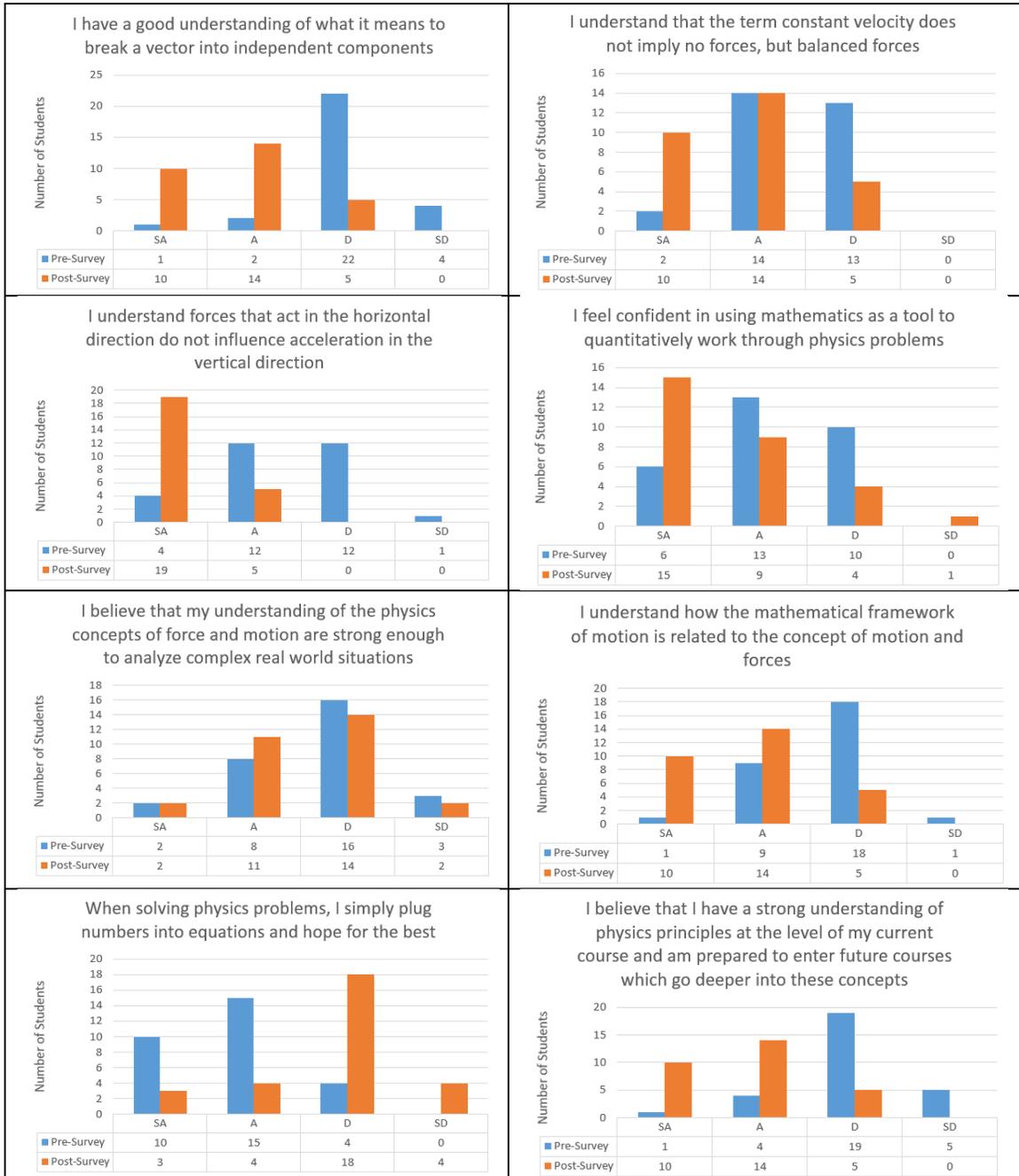
2. What kind of questions are being asked by students? Do the questions show a higher level of thinking about the subject, or just an attempt to act as a means to an end?

3. How well structured are the experiments in terms of what they are attempting to measure? Do you witness growth in the design structure for groups throughout the intervention?

4. Do students grow in their ability to both ask and answer scientific questions throughout the intervention (this could be questions asked by myself or by a classmate during their presentations)? Do students grow in their ability to communicate scientific principles to their peers?

APPENDIX H
SURVEY RESULTS

Conceptual Understanding Survey Data



Science Practices Survey Data

