Developing Lesson Plans to Increase Physics Understanding and Literacy in High School and Low Level College Courses: Final Report

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April 25, 2022

1 Abstract

The goal of this project was to create two physics lesson plans that, according to current educational theory, significantly contribute to the physics understanding and literacy of participating students. Furthermore, this project evaluated the effectiveness of these lesson plans, in both quantitative testing of student understanding of topics, as well as the qualitative data regarding student response to the lesson and the viability of the lesson plans within a classroom setting. The educational theory being utilized within these lesson plans states that physics students benefit greatly from learning topics such that their physics learning style is geared towards developing a mental model of physics concepts and equations. Teaching topics in this fashion allows and encourages students to create and maintain connections between physical concepts and equations, making recalling previous topics and learning new topics easier for students. After evaluation, it was found that the lesson plans which utilized this education theory were both viable for use within the classroom, and improved student understanding of each topic to a statistically significant extent.

2 Introduction

This project relies on physics to provide the concepts that need to be expanded upon within a classroom setting. Furthermore, this project hopes to produce lessons that follow current theory regarding teaching physics in a meaningful way. Current theory proposes that physics education tends to focus on ability to solve physics problems over understanding relevance and make connections to other areas of physics (Suzanne, 2021, pg 2). This trend does not lend itself to optimal learning, and can hamper future learning, as "[i]nstruction in college physics courses leans heavily on Quantitative Literacy, the interconnected skills, attitudes, and habits of mind that together support the sophisticated use of familiar mathematics for sense-making." (Suzanne, 2021, pg 1). Applying these new educational theories to how we teach physics concepts will lead to a lesson plan geared toward increasing understanding of concepts in physics. These lesson plans and how they were created will be discussed in the Methods section. For now, we will discuss the educational theory utilized in creating lesson plans, as well as the physics concepts that lesson plans were created for.

3 Theory

3.1 Educational Theory

Current education research seeks to find the best teaching methods in order to ensure students' understanding of how to use information, as well as students' understanding of the relevance of information in physics. General methods have been organized into the RBIS (Research-Based Instructional Strategies). The RBIS lists education strategies, such as peer instruction and interactive demonstrations, to be studied/evaluated (Henderson, 2009, pg. 1). A majority of research lies in determining which of these strategies most effectively helps students understand the concepts, both in general and for specific subjects within physics. This Capstone aims to utilize this type if research in order to produce lesson plans for the following topics: Kinematics/Equations of Motion and Coulomb's Law.

First, I would like to address research on which RBIS methods are typically best for teaching physics in general. As of now, the optimal methods for teaching physics concepts as well as ensuring understanding of significance are: peer instruction, ranking tasks, and interactive lecture demonstrations (Henderson, 2009, pg. 4).

Peer instruction has students verbalize their understanding of a concept, and has their classmates critique or add onto their response. This method is great for checking for understanding, as well as helping to expand each student's understanding. Additionally, this method is optimal for subjects like fundamental laws (such as Coulomb's Law), as it allows discussion of understanding to each individual student, allowing for contribution on the part of the teacher/professor. While this method can also be applied to kinematics and the equations of motion, these concepts are results of applying fundamental laws, and therefore have more reliance on values within a situation. This type of concept benefits far more from activities that utilize ranking tasks.

The ranking tasks teaching method involves students ranking physical situations based on specific physical quantities. This method is best utilized in order to allow students to explore quantitative relationships within concepts of physics. This is especially good for subjects like kinematics and the equations of motion, as results from these types of lessons are easily interpreted into physical context. Interpretation is typically required for students to increase their understanding, and is therefore indispensable when using this teaching tool.

Interactive lecture demonstrations involves three stages: students predicting what will happen in a physical scenario, students experiencing the physical scenario within the classroom, and students reflecting on their expectations and what they actually experienced. This method differs from a lab in that it does not expect quantitative date gathering. Typically the professor will provide the demonstration after receiving feedback on the students' expectations, as well as any disagreements between expectations and the result, and then ask for explanations regarding the results.

These three RBISs were utilized at varying levels within the lesson plans in order to create engaging lessons that benefit the understanding of student; however, these RBISs only answered the question of how the students can apply their knowledge to increase understanding. It was still necessary to organize these RBISs behind educational theory of how lesson plans should lead students to organize information such they can easily interpret/understand the physical events described within the lessons. The theory being applied through the lesson plans states that students benefit from "instructional strategies intended to facilitate mental model-building both in individuals and among groups of learners"(Gobert, 2000). Generally, ease in interpretation of physical events comes from students building their own mental connections between physical concepts and equations as a result of lessons they participate in. Additional research was necessary on what mental modelling should be encouraged through the structure of the lesson plans.

The research of Bashirah Ibrahim and N. Sanjay Rebello suggests that lesson plans should allow students to apply propositional mental representations, which are physics concepts that are represented as equations and mental connections, made relevant through context provided by physical situations (Rebello, 2013, pg. 3). Two of the best methods to encourage propositional mental representations is through direct use of multiple concepts within a lesson, so that students will be encouraged to make propositional connections between the concepts, and forge a stronger understanding of both as a result. Non-propositional representations will still allow the student to establish understanding of a topic, but frequently leads to an incomplete understanding of topics as a whole, especially within topics such as physics and mathematics. The students will understand how equations may apply to specific scenarios, but not be able to extend that knowledge to unexpected areas. The inability to expand previous knowledge due to a lack of mental connections can be detrimental to how a students learns in the future.

Within the lesson plans, the students were given opportunities to apply propositional thinking in order to draw conclusions and relevant connections between their natural understanding of concepts, the concepts each lesson aims to increase student understanding in, and for future concepts that a student might apply their new understanding to. Specifically, within the Kinematics/Equations of motion lesson plan students will be encouraged to form propositional connections between Kinematics and Equations of Motion, two topics within the same field (Mechanics) that host differences between each other that require an understanding of both to understand. For the Coulomb's Law/Newton's Law of Universal Gravitation lesson plan, students will be encouraged to form propositional connections between different topics (Mechanics/Classical Forces and Electrostatics) to attain a higher understanding of both topics.

3.2 Physics Concepts

3.2.1 Kinematics and Equations of Motion

The first subjects in physics that a lesson plan was created for were kinematic equations and equations of motion. Kinematic equations represent the 1-Dimensional motion of point masses in terms of displacement, velocity, acceleration, and time. These equations assume that acceleration is constant. If the desired motion is in the x-direction, the kinematic equations are:

$$\begin{aligned}
\Delta v &= at \\
\Delta x &= v_i t + \frac{1}{2}at^2 \\
\Delta x &= v_f t - \frac{1}{2}at^2 \\
\Delta x &= \frac{v_f + v_i}{2}t \\
v_f^2 &= v_i^2 + 2a\Delta x
\end{aligned}$$

Where v is velocity, Δv is the change in velocity, v_i is initial velocity, v_f is final velocity, Δx is the change in position, a is acceleration, and t is time.

The derivation and accuracy of these equations comes from the equations of motion, a differential equation describing the acceleration of the point mass. The relationship between acceleration, velocity, position, and time is described as:

$$m\ddot{x} - b\dot{x} + kx = 0$$

$$ma - bv + kx = 0$$

This relationship does not assume constant acceleration; however, this assumption is made when applied to the kinematic equations. My lesson plan was designed to allow students to explore these two concepts' relationship with each other, increasing understanding of motion in both kinematics and equations of motion.

3.2.2 Coulomb's Law and Newton's Law of Universal Gravitation

The second subjects a lesson plan will be designed around is electricity, specifically Coulomb's Law for two particles, as well as Newton's Universal Law of Gravitation. A lesson plan was designed that equates these two forces to encourage understanding of both Newton's 3rd law within electrostatics as well as reinforce base physics knowledge at higher levels.

Coulomb's law states that, for two charges q_1 and q_2, the force of one charge on another is:

$$F_{21} = k\frac{q_1 q_2}{r_{21}^2}\hat{r_{21}}$$
$$F_{12} = k\frac{q_1 q_2}{r_{12}^2}\hat{r_{12}}$$
$$k = 8.987551787 \times 10^9$$

This formula describes the electrical force between two charged particles with charges q_1 and q_2, at a distance of r from each other.

This equation has a similar structure to Newton's Law of Universal Gravitation, which has the form:

$$F_g = G\frac{m_1 m_2}{r^2}$$
$$G = \text{Gravitational Constant} = 6.673 \times 10^{-11}\,\frac{Nm^2}{kg^2}$$

Newton's Law of Universal Gravitation describes the gravitational force (in Newtons) between two objects of masses m_1 and m_2, at a distance of r from each other.

4 Methods

The teaching methods for each topic are described within the lesson plans as well as the data collection for each are described within each subsection below.

4.1 Lesson Plan: Kinematics and Equations of Motion

4.1.1 General Timetable

Time Period	Section and General Information	Necessary Materials
0 - 15 Minutes	Section 1: Variables Students will participate in a quick review of the general relationship between position, velocity and acceleration using the algebraic definitions.	Lesson Slideshow
15 - 50 Minutes	Section 2: Kinematics Students will participate in an introduction/review of the four kinematics equations typically utilized in a PHYS 151 or 201 course.	INTRODUCTION_TO_KINEMATICS Lesson Slideshow
50 - 90 Minutes	Section 3: Equations of Motion Students will participate in an open discussion on the transition between algebra to calculus when calculating values in motion, and the derivation of kinematics from calculus.	Lesson Slideshow

This lesson plan aims to utilize each participant's natural ranking skills to show their expectations of the relationship between kinematics and equations of motion. The goal is to develop their expectations regarding both kinematics and physical concepts as a whle toward the understanding that models are developed for specific scenarios in which they remain accurate. From this understanding, participants will be more prepared to make additional connections between physical concepts in the future, better developing their propositional mental model of information in physics.

Note: Shorter class periods should divide these sections if necessary. Optimally, Sections 1 and 2 should be kept together, while Section 3 is taught next class period. Students are encouraged to take self-guided noted throughout the lesson (pencil and paper).

4.1.2 Variables

This section of the class should be performed with both the students and instructor utilizing the provided slideshow.

Part One: Discussion [5 minutes]

This subsection should be utilized as a warm-up, where the instructor asks participating students about their initial understanding of position, velocity, and acceleration. Encourage students to take notes on the discussion, and write down any questions they have initially.

Possible Questions to Ask

- How would you describe the position of something compared to the position of something else (where neither are yourself)?
- How accurately could you measure velocity/acceleration by eye?
- What do you need to know to accurately describe the velocity of an object?

Part Two: Introduction [10 minutes]

This subsection will utilize the lesson slideshow worksheet to guide the students through an explanation of the algebraic relationship between position, velocity and acceleration.

This subsection begins with the question: **What is required for something to change?** This is an intentionally odd question to give, to continue students' consideration of contributing variables. The desired answer is time. This will lead into the introduction of the Δ symbol, which represents the change in the variable at two time stamps.

At this time, turn the students' attention to the worksheet, where they will now begin the fill in the blank section, where:

$$x_i = \text{initial position},\ x_f = \text{final position}$$

$$\Delta x = x_f - x_i = \text{change in position}$$

$$v_i = \text{initial velocity},\ v_f = \text{final velocity}$$

$$\Delta v = v_f - v_i = \text{change in velocity}$$

$$a = \text{acceleration}$$

$$t_i = \text{initial time},\ t_f = \text{final time}$$

$$\Delta t = t_f - t_i = \text{change in time}$$

Lastly, the students will be introduced to the algebraic relationship between position, velocity, and acceleration. Make sure to identify these relationships through their definitive terms, not their letters.

$v = \frac{\Delta x}{\Delta t}$

$a = \frac{\Delta v}{\Delta t}$

4.1.3 Kinematics

This section will utilize the INTRODUCTION_TO_KINEMATICS worksheet to provide students with the necessary kinematic formulas to solve the provided physical events.

Introducing Kinematic Equations [15 minutes]

This subsection begins with asking the students why they believe that the change in acceleration was not included in our variables.

The answer to this question is that we assume that the value for acceleration is assumed constant when using kinematics. The relevance of this assumption will be further discussed in Section 3.

At this point, it will be explained that kinematics are used to describe motion in one dimension and find values for the variables assuming constant velocity. The kinematic equations to be used are:

$$v_f = v_i + a\Delta t \tag{1}$$

$$\Delta x = \frac{v_f + v_i}{2}\Delta t \tag{2}$$

$$\Delta x = v_i \Delta t + \frac{1}{2}a\Delta t^2 \tag{3}$$

$$v_f^2 = v_i^2 + 2a\Delta x \tag{4}$$

At this point, it is necessary to state that, if the initial time is set to zero, then the change of time is set to the final time, making the calculations involving time easier to perform.

Each equation should be reviewed for what variables it includes, and the process of finding missing variables explained:

1. Equation 1 excludes position
2. Equation 2 excludes acceleration
3. Equation 3 excludes final velocity
4. Equation 4 excludes time

Utilizing Kinematic Equations [30 minutes]

The remainder of this section is dedicated to solving the problems provided on INTRODUCTION_TO_KINEMATICS. For each question, the following questions should be asked in order:

1. What variables do we know the value of?

2. What variables are missing?

3. What kinematic equation should we use for this problem?

This section is focused on establishing the importance of the equations for simple motion, so that the next section can be discussed understanding what kinematics are used for.

4.1.4 Equations of Motion

This section will utilize the INTRODUCTION_TO_MOTION worksheet to provide a place to organize notes on the conversation on equations of motion.

Introducing Equations of Motion [10 minutes]

At this point, a majority of questions regarding exceptions to the kinematic equations would be addressed: equations of motion are far more accurate to describe motion; however, the drawback is that finding and using equations of motion is far more difficult.

The default form of an equation of motion is:

$$m\ddot{x} - b\dot{x} + kx = 0 \tag{5}$$

$$ma - bv + kx = 0 \tag{6}$$

where b and k are constants dependant on the physical event. Be sure to explain that the "dots" represent when a variable has gone through a time derivative.

The goal of this section is not to derive this, but to put the degrees of accuracy in physics into perspective.

Finding Kinematics in Equations of Motion [30 minutes]

This last section is dedicated to how the assumption of constant acceleration allows an equation of motion to agree with kinematics. This process should be done in full in front of the students.

The students will be asked the question: **Do you believe that kinematics are incorrect in comparison to equations of motion?**

If we assume that the acceleration is constant at zero:

$$-bv + kx = 0$$
$$kx = bv$$

This relationship and assumption tells us two things:

1. Initial velocity is equal to final velocity

2. Position and velocity are related by two constants

This relationship can be applied to each kinematic equation, which will result in all true statements. For each respective kinematic equation:

$$v_f = v_i$$
$$\Delta x = v\Delta t$$
$$\Delta x = v\Delta t$$
$$v_f = v_i$$

If acceleration is not zero, but is a constant, the resulting relationship is:

$$\frac{b}{m}v - \frac{k}{m}x = a$$
$$Av - Bx = a$$

This relationship establishes that, regardless of time, both position and velocity are subject to being a function of time related to acceleration that cannot change, which can be seen as true in the kinematic equations, especially equations (1) and (3):

$$\Delta v = a\Delta t$$
$$\Delta x = v_i\Delta t + \frac{1}{2}a\Delta t^2$$

The purpose of this exercise is to show that the power of kinematics does not come from ignoring characteristics of your system, but rather making assumptions about the system, and making the same assumptions in a "more accurate" equation of motion yields support in the accuracy of kinematics.

The summary of this lesson is that creating models to portray motion according to assumptions is widely used in every level of physics, and applies even to kinematics. The goal of this lesson is to begin to have students develop a mindset of establishing models that are seen as accurate under their assumptions, instead of inaccurate under their assumptions.

4.2 Lesson Plan: Coulomb's Law and Newton's Law of Universal Gravitation

4.2.1 General Timetable

Time Period	Section and General Information	Necessary Materials
0 - 20 Minutes	Section 1: Gravity Students will participate in a discussion on their understanding of gravity, as well as build towards what they should expect in an equation for force between two objects	Whiteboard and Markers
20 - 40 Minutes	Section 2: Constructing a Formula Students will use their previous knowledge, as seen in the previous section, to discuss electric analogs and construct Coulomb's Law.	Whiteboard and Markers
40 - 50 Minutes	Section 3: Using Coulomb's Law Students will be guided through the use of Coulomb's Law through an example.	COULOMBS_LAW_EXAMPLE

This lesson plan aims to utilize an interactive lecture demonstration of similarities between Coulomb's Law and Newton's Law of Gravitation to develop a propositional mental connection between the two concepts, and increase the participants' understanding of both.

Note: This lesson is designed for a single class period. If necessary, the example section can be utilized as the first activity the next class period. It is necessary to teach Sections 1 & 2 together.

4.2.2 Gravity

This lesson will be utilizing each student's understanding of gravity to find the reasoning behind the legitimacy of Newton's Law of Universal Gravitation. This law states that the gravitational force between two objects, F_g, can be calculated through the equation:

$$F_g = G\frac{m_1 m_2}{r^2}$$

$$G = \text{Gravitational Constant} = 6.673 \times 10^{-11}\frac{Nm^2}{kg^2}$$

$$m_1 = \text{Mass of object 1, } m_2 = \text{Mass of object 2}$$

$$r = \text{Distance between the two masses}$$

The reasoning behind this equation will be found through a series of questions.

The first question to ask the students is: **Is there a minimum amount of gravitational force?** The students may need to be led by asking "If something is an infinite distance away, will there be any force?" The answer is no, so there is no minimum amount of force. What this implies is that the force, if it can be explained through an equation, would be found to be a single multiplication term.

The next question to ask the students is: **As something gets further away from the earth (i.e. in space), does the gravity pulling the object to Earth get stronger or weaker?** As this value gets weaker, it is reasonable to set that the distance between objects r is in the denominator of the equation for gravitational force.

Lastly, the students should be introduced to the information that, more massive planets have higher gravity, and that gravity is a mutual force (Forces between two objects balance, meaning that the force vector cannot be separable, and both masses should be involved). With this information, the students should be asked: **Do both masses contribute to the force of gravity? In what way?** The conclusions drawn should be that both masses contribute, and they have a direct, inseparable relationship to the force of gravity.

Combining these three conversations will result in the formation of the relationship that:

$$F_g \propto \frac{m_1 m_2}{r^2}$$

At this point, students may ask if this is the correct equation, to which the answer is no. However, this point is where in class derivation becomes unavailable, so the students should be introduced to the Universal Gravitation Constant, which requires physical observations and trial/error in order to derive:

$$G = \text{Gravitational Constant} = 6.673 \times 10^{-11}\frac{Nm^2}{kg^2}$$

With this addition, the Law of Universal Gravitation is complete for the class, with an understanding of how each relevant value contributes to the system.

4.2.3 Coulomb's Law

In this section, each element of Newton's Law of Universal Gravitation will be discussed even further, in a way that connects them to their electric analogues, allowing students to arrive at Coulomb's Law for Force Between Two Charges:

$$F_e = \frac{kq_1q_2}{r^2}$$

$$F_e = \text{Electric Force}$$

$$k = \text{Coulomb Constant} = 8.987551787 \times 10^9 \frac{Nm^2}{C^2}$$

$$q_1 = \text{Magnitude of Charge 1},\ q_2 = \text{Magnitude of Charge 2}$$

$$r = \text{Distance between the two charges}$$

This section should begin with a graphical comparison of a gravity system and an electrical system with only two objects. This can be drawn on a white board, or simply shown with your hands. The message is, these systems, without unnecessary details, look identical. The similarities they share lead us to seeking an analogue for the new system.

The first value to explore is the distance between the the masses. From our visual comparison between the two systems, it is clear to see that the systems may have a similar relationship for this distance. At this point, it is reasonable to assume that the distance has a similar, inverse relationship to the force.

The second value to explore are the masses of the involved objects. They will be linked to the magnitude of the involved charges. An analogy of mass in a gravitational system will be used here. The students should be asked: **Without mentioning other values, how does mass contribute to the system. In other words, what does increasing either mass do to the system?**

The students may contribute a large variety of answers, and are expected to. At this stage, it is necessary to herd answers toward that "mass is a characteristic within the relevant objects in the system that allows those objects to interact with the rest of the system". From this guided discovery, students will be ready to learn that the analogue of mass in an electrical system is charge (q). Where mass denotes an object's action within a gravitational field, charge denotes an object's action within an electric field.

From these two "created" analogues, a proportion can be set up in a similar fashion as we made for gravitation:

$$F_e \propto \frac{q_1q_2}{r^2}$$

At this point, it is reasonable to expect that the resolution to this equation will be another constant, which is correct. This constant is:

$$k = \text{Coulomb Constant} = 8.987551787 \times 10^9 \frac{Nm^2}{C^2}$$

4.2.4 Using Coulomb's Law

The remainder of the class will be dedicated to solving one problem involving Coulomb's Law. This problem is provided on the worksheet COULOMBS_LAW_EXAMPLE.

4.3 Data Collection

The legitimacy of the lesson plans were evaluated through feedback from classes given utilizing the lesson plans. Lessons regarding each topic were given to students that have the required prerequisite knowledge to participate in the lesson. The lesson plan needed provide all necessary aspects of the lesson, as well as be capable of being utilized within the class period, and its ability to do so was logged to be discussed in the data section.

To test that the lesson plan increases understanding within the topic, students filled out a survey at the beginning and end of the class period. The survey asked the students to answer computational questions involving the topic, and asked about the relevance of the material, as explored within the lesson. The survey did not ask the student about their understanding of the topic, as that type of survey frequently results in biases and inaccuracies. These surveys were evaluated against predetermined criteria to determine the effectiveness of the lesson plan in increasing understanding of the topic.

The survey data was used to evaluate the qualitative improvement in understanding that students experience from participating in the class period. The pretest scores were compared to the post test scores using a one tailed paired t-test, to find if the difference in the average score before and after the lesson was statistically significant enough to support the effectiveness of the lesson plans.

5 Data

5.1 Survey Data

Analysis of the entry and exit surveys revealed a significant difference between their mean values at the $p = 0.05$ significance level. This evaluation was reached through performing a one-tailed paired t-test. It is necessary to describe both data sets before interpreting the final t-value and draw conclusions about the significance of the lesson plans in the increase of understanding that the students experienced.

5.1.1 Pretest Data

The pretest data was taken from 20 students before they participated in the relevant lesson plans. Each student would participate in each course, and provide 2 pretest and 2 post test scores. For the kinematics portion of the data, 14 participants had been exposed to kinematics in the past through high school or college courses, while 6 of the participants had never utilized kinematics. No participants had been exposed to the equations of motion prior to the lesson plan. For the Coulomb's Law section of the data, 14 of 20 participants had been exposed to Newton's Law of Universal Gravitation, and 4 of 20 participants had been exposed to Coulomb's Law for two point charges. This distribution of prior knowledge is acceptable for this investigation, as all students were at a level of experience in physics that this investigation desired to study (low level course knowledge).

In the data tables in Appendix C and E, the data is prepared to present both the actual value of the pretest scores, as well as their contributing values (Difference from the mean value and the square of that difference). Each score is compared to the mean value of the pretest scores: 4.62 points.

Participants	Degrees of Freedom	Mean	Sum of Squares	Variance
40	39	4.62	505.38	12.96

5.1.2 Post Test Data

The same students who took the pretest then participated in each lesson plan, with the instructor utilizing the lessons as described in the methods section. After the class period, the participants would complete the post-test to evaluate the effectiveness of the lesson in improving the understanding the participants had of the various physics topics. In the data tables in Appendix D and F, the data has been organized in a similar fashion to the pretest data, so that it can be utilized as the second treatment in the one tailed t-test for two independent means.

Participants	Degrees of Freedom	Mean	Sum of Squares	Variance
40	39	17.95	273.9	7.02

5.2 Quantitative Results

The results of the pretest and post test, when processed through the t-test, revealed that the lesson plans have a statistically significant affect on the change in score between the pretest and post test. The final t-value was calculated to be 18.85316. This far exceeds the minimum t-value at this investigation's degrees of freedom (39) and significance level (p= 0.05), which is 1.694. These results demand that the hull hypothesis of this t-test be rejected, and supports that the effectiveness of the lesson plans are statistically significant.

Significance Level	Participants	Degrees of Freedom	Variance	Minimum t-value	Actual t-value
$p = 0.05$	40	78	9.99	1.694	18.85316

5.3 Qualitative Data

While the quantitative data supports the legitimacy of the lessons, it is also necessary to evaluate the lessons based on the individual class periods. Specifically, how well the lesson plans could be used to guide the class period, and how the students reacted to and participated in the lesson.

The lesson plans were organized in a way that efficiently separated the stages of the lesson plan into sections. Each section would require some reflection or conversation for the students to go through. While this provided opportunities for students to participate in the ranking and peer instruction RBISs, this did not guarantee that students desired to discuss the material. For example, in the Kinematics/Equations of Motion Lesson Plan, the participants are asked "Do you believe that kinematics are incorrect in comparison to equations of motion?" This is an attempt to begin a ranking task, where students are asked to organize information the form of a ranked list (a list of two in this case). This question was, by far, the component of the lesson that students were the least receptive to due to its nature of being open-ended, where students will frequently prefer to only answer if they feel that they are correct. While this section was salvaged before moving on, it would frequently feel like a break in the flow of the class, due to a lack of participation. It is suspected that this is due to students not being accustomed to this form of feedback within the classroom. Instead of these alternative RBISs, students are accustomed to only participating through answering quantitative questions, or asking quantitative questions regarding concepts or equations. The most common feedback I received from students was that they felt unprepared to participate in the questions, not due to the content, but due to the new form of questions and conversations that went on during the class.

Additionally, the lesson plans would benefit from strategies to increase student participation, such as activities solely geared towards student engagement, as well as getting participants more comfortable with the material.

Other than the hiccups in using RBISs with students, the feedback received on the lesson plans from participants was overwhelmingly positive. The participants evaluated themselves as far more proficient in using the material. Additionally, participants unanimously evaluated their understanding as having improved from their previous understanding, especially those who had taken a course relevant to the material prior to participating in a lesson period.

6 Discussion & Conclusion

The results of the one-tailed t-test leads to the conclusion that the lesson plans, as a treatment, had a positive effect on the participants' understanding of the topics. Furthermore, the wide gap between the minimum t-value (1.694) and the actual t-value (18.85316) alludes to a strong relationship between the treatment and the change in scores. The general consensus that I received from interviewed professors was that teaching these concepts, especially kinematics, rarely yields a large increase in understanding after only one lesson. The participating students in this study, however, immediately saw a large increase in understanding, including students who had and had not seen the content in any capacity before. These results exceeded expectations of success. This great success in test scores speaks to the effectiveness of the lesson plans in introduction and explanation of the concepts and application of the concepts.

After utilizing the lesson plans, it is clear that that the utilized RBISs (peer instruction, ranking tasks, interactive lecture demonstration) and leading towards a propositional mental model are viable within a classroom. Furthermore, the methods employed were received by the participants in a way that they could develop their understanding. Past this conclusion, we cannot determine the best methods without testing alternative RBISs, or determine if propositional mental modeling improves understanding without testing non-propositional (analog) mental modeling for the same lessons/concepts.

As discussed in the qualitative data section, the participants all self evaluated to have a better understanding of the concepts involved in each lesson plan. While this evaluation is very susceptible to personal bias, it is also necessary to evaluate what that entails in general. A common piece of feedback received from participants who had seen the material before was that they had no memory of discussion of connections to other topics or an explanation of how equations are derived past the equations being given to them. The fact that the lesson plan felt different enough from their original instruction to mention supports the relevance of including propositional mental modeling in consideration for the creation of lesson plans.

Overall, this project was successful in its application of propositional mental modeling and RBISs in order to create lesson plans that are viable within a class setting. For future investigations, it would be necessary to test if other areas of inquiry in physics can have the same or different RBISs applied to lesson plans. Additionally, it would be necessary to test if these lessons, without the encouragement of developing propositional mental models, would reap the same amount of success in increasing student understanding of the concepts.

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8 Appendix A: INTRODUCTION TO KINEMATICS

Introduction to Kinematics

Name:	Session #:	Date:

1: Write down the four kinematic equations:

2: An airplane accelerates down a runway at $3.20 \frac{m}{s^2}$ for 32.8 seconds until is finally lifts off the ground. Determine the distance traveled before takeoff.

9 Appendix B: Raw Data - Kinematics Lesson (Pretest)

Pretest Scores: Kinematics Lesson

Pretest Score	Mean Diff	Mean Diff Squared
0	-4.62	21.39
2	-2.62	6.89
3	-1.62	2.64
8	3.38	11.39
8	3.38	11.39
15	10.38	107.64
8	4.38	19.14
3	-1.62	2.64
5	0.38	0.14
1	-3.62	13.14
2	-2.62	6.89
9	4.38	19.14
6	1.38	1.89
9	4.38	19.14
7	2.38	5.64
9	4.38	19.14
2	-2.62	6.89
9	4.38	19.14
1	-3.62	14.14
3	-1.62	2.64

10 Appendix C: Raw Data - Kinematics Lesson (Post Test)

Post Test Scores: Kinematics Lesson

Post Test Score	Mean Diff	Mean Diff Squared
14	-3.95	15.60
16	-1.95	3.80
18	0.05	0.0025
21	3.05	9.30
21	3.05	9.30
19	1.05	1.10
19	1.05	1.10
17	-0.95	0.90
14	-3.95	15.60
13	-4.95	24.50
19	1.05	1.10
20	2.05	4.20
17	-0.95	0.90
13	-4.95	24.50
15	-2.95	8.70
17	-0.95	0.90
13	-4.95	24.50
20	2.05	4.20
19	1.05	1.10
19	1.05	1.10

11 Appendix D: Raw Data - Coulomb's Law Lesson (Pretest)

Pretest Scores: Coulomb's Law Lesson

Pretest Score	Mean Diff	Mean Diff Squared
8	3.38	11.39
3	-1.62	2.64
1	-3.62	13.14
9	4.38	19.14
3	-1.62	2.64
2	-2.62	6.89
2	-2.62	6.89
5	0.38	0.14
4	-0.62	0.39
0	-4.62	0.39
4	-0.62	0.39
7	2.38	5.64
8	3.38	11.39
4	-0.62	0.39
3	-1.62	2.64
9	4.38	19.14
0	-4.62	21.39
0	-4.62	21.39
0	-4.62	21.39
2	-2.62	6.89

12 Appendix E: Raw Data - Coulomb's Law Lesson (Post Test)

Post Test Scores: Coulomb's Law Lesson

Pretest Score	Mean Diff	Mean Diff Squared
19	1.05	1.10
22	4.05	16.40
15	-2.95	8.70
22	4.05	16.40
17	-0.95	0.90
16	-1.95	3.80
20	2.05	4.20
20	2.05	4.20
15	-2.95	8.70
22	4.05	16.40
20	2.05	4.20
21	3.05	9.30
19	1.05	1.10
22	4.05	16.40
18	0.05	0.0025
19	1.05	1.10
17	-0.95	0.90
16	-1.95	3.80
18	0.05	0.0025
16	-1.95	3.80