Combining Qualitative Physics Ranking Tasks with Modeling Instruction and its Effects on Students' Conceptual Understanding of Basic Mechanics

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Action Research required for the Master of Natural Science Degree
with a concentration in Physics

July 2016
Acknowledgements

From start to finish this project was a tremendous learning opportunity for the three of us. Several individuals generously gave their time to offer invaluable advice and guidance and we would like to thank them for their support. We thank James Archambault for helping us understand the nature of research and narrow the focus of our investigation. We thank Dr. Robert Culbertson for heading up the MNS program and for his support. We thank Dr. Carl Covatto, and Dr. Eugene Judson for graciously agreeing to be a part of our committee. We thank Dr. Jane Jackson for her tireless work in spreading the word for modeling. We thank Dr. Margarita Pivovarova for taking the time to read and help us sort through our data. We thank Mark McConnell, and Jacob Dunklee for providing feedback and support. We thank Nicole Hoover for her editing skills.
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Abstract

The purpose of this study was to measure the impact on students’ conceptual understanding of mechanics by adding ranking tasks into the modeling curriculum. In the past, the investigators noticed that students’ successful completion of physics courses taught with the modeling method did not always increase students’ conceptual understanding of the content or their mathematical problem solving skills. The investigators believed that the addition of a conceptual component into the modeling learning cycle after the paradigm lab and before the introduction of quantitative problems would increase students’ conceptual understanding.

This study was conducted over the course of one regular school year. High school students served as the target population, and the sample for this study included 504 introductory physics students from Rancho Verde High School in Moreno Valley, California; Perry High School in Chandler, Arizona; and Greenwood High School in Greenwood, Arkansas. Of the sample population, 327 students in the control group received instruction from the standard modeling mechanics curriculum, and 177 students in the treatment group received both modeling instruction and ranking task collaborative exercises. Both groups were given the Force Concept Inventory (FCI) before and after treatment. Results indicated that the treatment group had statistically higher scores on the FCI compared to the control group. The methods utilized for implementing ranking task exercises and the implications of emphasizing conceptual understanding in physics instruction are discussed in the following sections.
Rationale

The investigators’ past teaching experience revealed that despite students’ exposure to conceptual models through modeling, many reverted to a mathematically based method of problem solving when responding to open-ended questions. In their haste to find the “right” formula to solve the problem, students often overlooked common sense solutions. Due to the conventional emphasis on algorithmic problem solving methods, many students enter physics courses thinking that their ability to manipulate formulas will automatically lead to success. Though mathematics is important to the study of physics, many other essential scientific skills are often overlooked. Examples include the ability to think critically, to analyze multiple factors, and to apply basic scientific models to novel situations. This paper proposed an emphasis on qualitative problem sets that require students to construct explanations, identify relevant fundamental principles, and make predictions. By focusing on increasing students’ conceptual understanding of physics before moving toward mathematical analysis, it was predicted that this approach would facilitate a deeper understanding of basic mechanics, and subsequently the mathematics behind them. The crucial nature of critical and analytical thinking in the scientific investigative process was validated by the emergence of the Next Generation of Science Standards (NGSS) in science educational policy. The lead states authoring NGSS designed three main facets: disciplinary core ideas, scientific and engineering practices, and crosscutting concepts. These components create a coherent scientific body of knowledge for students progressing from grade K-12. This study aimed to incorporate the paradigm shift to emphasizing conceptual understanding by adding ranking tasks to the high school physics modeling classroom.
A review of current research in physics education has showed that teacher centered dissemination of information and quantitative problem solving in physics have resulted in high deficiency rates in student understanding of Newtonian mechanics (Mualem, Eylon 2009). The majority of freshman college students in introductory physics courses have generated low pretest scores on the FCI, and continued to struggle with basic mechanics after passing the class (Hestenes 1985). Cognitive research has shown that a focus on formulaic rote memorization that is disconnected from underlying scientific principles have resulted in students becoming expert equation manipulators without any real idea of the conceptual underpinnings (McDermott 1993). Even in combination with small class instruction and explicit multistep problem solving strategies, students showed no overall conceptual gain when compared to the control group receiving traditional textbook instruction (Huffman 1997). This lack of conceptual understanding cannot be attributed to lack of practice. Researchers in South Korea have shown that senior high school students who have successfully completed one thousand traditional problems still retained many misconceptions of basic mechanics, and they ultimately concluded that there is no correlation between the number of problems solved and students’ conceptual understanding (Kim, Pak 2002).

On the other hand, some research has showed that a stronger non-mathematical foundation can improve mathematical problem solving later on (De Leone, Gire 2005). The investigators believe two essential questions that address these challenges in physics education are: “How are expert problem solvers different from novices?” and “How can these differences be feasibly addressed by educators?” To address the first question, a review of current research in cognitive science focused on skills needed for problem solving was conducted. The result revealed that novice learners could be taught conceptual analytical skills and become better problem solvers. For the second question, current physics education research regarding modeling and sense making tasks focused on dispelling students’ misconceptions of force have showed strong promise for developing conceptual understanding. The summary for these research questions is discussed below.
Cognitive Research: Strong conceptual understanding leads to better problem solving.

While many students are able to state Newton’s three laws verbatim, they generally lacked the ability to explain, generalize, and apply them to solve questions (Mualem, Eylon 2009). Much research has been done to explore the cognitive differences between novice and expert problem solvers. In his 1989 landmark study Hardiman found that expert problem solvers were able to use the deep structures (i.e., general principles and concepts) to solve similar problems 78% of the time by matching comparison problems with model problems. Novices, on the other hand, tended to rely on surface features (i.e., problem jargon, descriptor terms, equations, specific facts) to solve similar problems, using deep structures only 59% of the time; however, some novices were able to use deep structures to solve problems but only on topics that they understood better (Hardiman et al. 1989). This research demonstrated that the ability to categorize a problem by matching it with overarching principles can be used to make a distinction between expert and novice physics learners, and that novice students can be taught analytical skills to become better problem solvers. The authors found that novice students who tend to make more explanatory notes and attempt to justify their answers by going back to the general principles scored higher on assessments. “Novices who attempt to analyze mechanics problems using principles make more correct judgments concerning solution similarity, and are better problem solvers” (Hardiman et al. 1989). A 2009 study aimed at teaching ninth graders to describe Newton’s third law conceptually further cemented these observations. The researchers used a combination of conceptual framework and qualitative free-body diagrams with their treatment groups. They found that these junior high physical science students had higher posttest scores on the FCI than the control group comprised of twelfth graders in advanced physics classes (Mualem, Eylon 2009). Additionally, 60% of these students demonstrated that they were able to accurately describe and explain force interactions six months after instruction (Mualem, Eylon 2009). Hardiman et al. showed that the initial effort required to categorize a problem will be greater than the effort to memorize and manipulate equations (1989). However, he also observed that once a strong foundational background is achieved, the effort required to sort through applicable models is considerably less than the effort needed to try plugging numbers into multiple equations. To conclude, the findings detailed above showed that novice students are able to make gains in conceptual understanding and develop problem solving skills.
comparable to expert problems solvers if they are taught both qualitative and quantitative problem solving approaches. Next, two effective pedagogies for building students’ conceptual understanding of physics are discussed: the modeling method and ranking tasks.

**Modeling Instruction: Conceptual Models as basis for learning physics**

A scientific model is a representation of an observed phenomenon that works by simplifying a system to focus on key features in order to describe, explain, and predict scientific phenomena (Schwarz 2009). It consists of four parts: an object or an agent, a descriptor variable conveying a property of the object, equations that describe the object’s change over time, and “an interpretation relating the descriptive variables to properties of some objects that the model represents” (Hestenes 1987). Examples of scientific models are Bohr’s model of the atom, the particle model of matter, and the electric and gravitational fields models. All of these models compact abstract, often infinitely complex processes, into a manageable scenario by isolating variables of interest for manipulation and testing while keeping other variables constant. Therefore, it stands to reason that students in introductory physics should start their studies by learning the steps in model construction. From there students will learn to continually refine the model, and expand it to encompass more complicated systems after the initial constraints are reached. The success of using models in science education has been well documented beginning with Malcolm Wells in 1995. Wells’ modeling classes scored 19% higher in posttest scores on the FCI than his inquiry class, and 15% higher than a comparable teacher’s traditional lecture class (Wells et al. 1995). Wells’ posttest scores were also compared against algebra based and calculus based university level physics courses, and both scored significantly lower than Wells’ high school physics modeling courses (Wells et al. 1995).

A literature review of current cognitive research indicated the descriptive part of a scientific model is essential for understanding content. The presence or absence of the descriptive portion of the scientific model separates expert from novice problem solvers (Hardiman et al. 1989). For the expert, the model is intrinsically linked with its representative mathematical formula. That linkage becomes second nature with practice and is often taken for granted. The novice, on the other hand, is led to believe that the mathematical formula is the only way to describe and predict physical behavior, never truly connecting it to the underlying conceptual model (Hardiman et al. 1989). Researcher David Hestenes further pointed out that a coherent chain of conceptual models, which helped create basic theories of mechanics, is often
omitted in textbooks and physics instruction. He claimed that a lack of a coherent chain of scientific models and misleading everyday experience are why students cling to naive beliefs about motion despite successful completion of high school and college level physics classes (Hestenes 1987).

Scientists typically begin constructing models by making broad assumptions, refining and filtering out extraneous variables, designing experiments, collecting data, and finally constructing a general model that can be used to describe an observed phenomenon (Brewe 2008). Brewe listed the stages as: introduction and representation, coordination of representations, abstraction and generalization, and application and refinement of models in Table 1 below (2008). According to Brewe graphical and mathematical equations, the third stage in the sequence, are constructed only when the descriptive and conceptual foundation of the model have been completed in the Coordination of Representations of the second stage.

<table>
<thead>
<tr>
<th>Step</th>
<th>Instructional goal</th>
<th>Example student activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction and Representation</td>
<td>Phenomenology—initiates the need for a new model (accelerated motion is not explained by general constant velocity model.) Introduction of kinematic graphs as useful representation.</td>
<td>Experimentation involving students moving with constant acceleration in front of motion detectors.</td>
</tr>
<tr>
<td>Coordination of Representations</td>
<td>Relate kinematic graphs to other common representations (motion maps).</td>
<td>Experimentation and conceptual activities.</td>
</tr>
<tr>
<td>Application</td>
<td>Begin to apply knowledge and tools. Develop experience, heuristics, and ability to draw conclusions based on representations.</td>
<td>Develop kinematic equations from kinematic graphs by analyzing velocity versus time graphs. Problem solving emphasizing use of modeling tools.</td>
</tr>
<tr>
<td>Abstraction and Generalization</td>
<td>Identify characteristics of representations in situations involving constant acceleration.</td>
<td>Review of constant acceleration and guided discussion.</td>
</tr>
<tr>
<td>Continued Incremental Development</td>
<td>Relate constant acceleration model to dynamical models and apply to new situations.</td>
<td>Continually revisit constant acceleration model, coordinate with energy and forces, apply to electricity and magnetism.</td>
</tr>
</tbody>
</table>

Table 1 *Modeling Theory Applied: Modeling Instruction in Introductory Physics* (Brewe 2008).
This sequence was purposely designed to help students see that using math formulas without understanding the concepts is not an effective way to solve problems because they can do the calculations correctly and still get the wrong answer if the wrong concept was used. The investigators hypothesized that the second stage in modeling theory—Coordination of Representation—is the conceptual development stage that mathematically focused students are tempted to skip; instead they jump straight to the calculation of formulas in the third stage. By doing this, students inadvertently created a conceptual gap that can be difficult to overcome. To remedy this problem, a program of treatment was formed to emphasize qualitative, conceptual understanding of models by inserting ranking tasks into the modeling learning cycle after the paradigm lab discussion (Figure 1).

Figure 1 Proposed modification to the modeling learning cycle.

The typical modeling cycle in a high school physics classroom consists of identifying the variables, a paradigm lab, and a post lab whiteboard discussion (Jackson et al. 2008). Next, students are asked to use their model to complete related questions. Once the questions have been discussed and students have shared their ideas, they are asked to test their model in a lab
practicum and demonstrate their understanding by taking an end of unit exam (Jackson et al. 2008). These steps are described in Table 2 using the Constant Velocity unit.

Table 2 A typical modeling method learning cycle. This is the Constant Velocity Unit (Jackson et al. 2008)
Ranking tasks in physics: conceptual development exercises that can strengthen models

Ranking tasks (See Appendix C) are conceptual exercises or intellectual puzzles in which the solutions may not be immediately obvious (Hudgins et al. 2006). Ranking tasks require students to contemplate slightly altered, real world scenarios to decide what information is most important and rank them according to some criterion (Cox, Belloni, Christian 2005). Ranking tasks have been designed to address common student misconceptions found by physics education research to be present at all levels of physics learning from high school to college and beyond making the same ranking tasks appropriate for all grades from ninth grade to college (O’Kuma et al. 2000). Combined with modeling, these two approaches reinforce and promote sense making of many common scenarios to help students build models that they can apply to other similar situations. To this end, students were presented with ranking tasks with multiple representations of forces all in different scenarios in order to increase the flexibility and depth of their understanding (O’Kuma et al. 2000). These exercises force student to rely on a more qualitative and concept driven method of analysis rather than the “plug and chug” method of problem solving. Doing so may increase students’ chances of arriving at conceptually sound solutions, while enhancing their ability to explain the feasibility and validity of their response (Cox et al. 2005). In addition to ranking each scenario, students must provide a written reason for their ranking scheme, which can be a valuable diagnostic tool for educators to pinpoint misconceptions (O’Kuma et al. 2000). A typical format of ranking tasks is shown in Appendix C. Each task has carefully worded description of a scenario, diagrams with reference frames, a space for students to explain their reasoning, and a confidence ranking scale from one to five.

Ranking tasks also affords students the opportunity to defend their problem solving method and promote rich conceptual discussion with their peers (Maloney 1995). The discussion format discussed by Maloney mimicked the format set up in the paradigm lab of modeling instruction. Many researchers have found that lasting conceptual change requires students to explicitly describe their problem solving process, especially in discussion with peers who hold alternative ideas, or approached the problem using different models (Howe et al. 1995). Thus, it seems natural to insert ranking tasks after the paradigm lab to provide students with additional time to apply and discuss their models. By combining modeling and ranking tasks together into
a single pedagogy, the investigators predicted an additive effect in students’ conceptual understanding of mechanics that can be measured with the FCI.

**Method**

**Study Subjects**

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Group Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group 1</td>
<td>57</td>
<td>9th grade physics class (42 girls, 15 boys) concurrently taking algebra I or geometry.</td>
</tr>
<tr>
<td>Treatment Group 1</td>
<td>65</td>
<td>9th grade physics class (27 girls, 38 boys) concurrently taking algebra I or geometry.</td>
</tr>
<tr>
<td>Control Group 2</td>
<td>248</td>
<td>11th-12th grade first year physics students combined from 2 previous school years 2013-2014 and 2014-2015; all were concurrently taking pre-calculus or calculus class.</td>
</tr>
<tr>
<td>Treatment Group 2</td>
<td>82</td>
<td>11th-12th grade first year physics students; all were concurrently taking pre-calculus or calculus class.</td>
</tr>
<tr>
<td>Control Group 3</td>
<td>12</td>
<td>2014-15 Regular level juniors and seniors concurrently taking pre-calculus or algebra III</td>
</tr>
<tr>
<td>Treatment Group 3</td>
<td>13</td>
<td>2015-16 Regular level juniors and seniors concurrently taking pre-calculus or algebra III.</td>
</tr>
<tr>
<td>Control Group 3</td>
<td>13</td>
<td>2014-15 Honors level juniors and seniors concurrently taking pre-calculus or AP calculus.</td>
</tr>
<tr>
<td>Treatment Group 3</td>
<td>14</td>
<td>2015-16 Honors level juniors and seniors concurrently taking pre-calculus or AP calculus.</td>
</tr>
</tbody>
</table>

Table 3 Description of study participants sorted into numbered groups according to the investigators in charge. For example, control and treatment groups one were instructed by investigator 1 and so on.

**Investigator 1:**

Investigator one taught at Rancho Verde High School in Moreno Valley, California. Moreno Valley is a small suburban school located southeast of Riverside about 15 minutes from UC Riverside. Rancho Verde is a comprehensive high school with 3,276 students enrolled in grades 9-12. The general population of the school is 67% Hispanic, 21% African-American, 5%
White, 5% Asian, 0.8% Pacific Islander, and 0.2% Native American. This is a Title I school where approximately 60% of students qualify for the free or reduced lunch program. Investigator one worked with 145 ninth graders using the standard modeling curriculum. All of these students were also concurrently enrolled in either Algebra I or Geometry.

Investigator 2:
Investigator two taught at a Phoenix suburb high school near Gilbert, Arizona. The population were approximately thirty-four hundred with about 72% white, 5% African American, 1% Native American, 7% Asian, and 15% Hispanic. Approximately 16% of the students received free or reduced lunch. Investigator 2 worked with 330 eleventh and twelfth grade students taking regular physics and concurrently enrolled in pre-calculus or calculus.

Investigator 3:
Investigator three taught at Greenwood High School located in Greenwood, Arkansas; a small community located on the western border of Arkansas. It is a senior high school population composed of approximately 850 10-12 students. GHS is composed of 84.5% white, 3.9% Hispanic, 2.6% American Indian, 1.8% Asian and 0.1% African American. Twenty-eight percent of the students receive free or discounted lunch. Investigator three worked with approximately thirty-eight physics students in regular level and honors level physics. Honors physics is populated by 90% seniors while regular level physics is populated by mostly juniors. Both levels of physics are considered college preparatory.

Procedure for Treatment:
1. Pre-assessments of Student Abilities:
   Students were given pretests to measure their initial level of understanding in 3 areas: Scientific Thinking & Reasoning, Graphical Understanding & Analysis, and Mechanics. We used the Lawson Classroom Test of Scientific Reasoning (CTSR), the TUG-K, and the simplified FCI (SFCI) to measure skills in these areas, respectively. The SFCI was chosen because of the presence of students of limited English proficiency in the treatment and control groups. Preliminary research by Osborn Popp on the SFCI in 2008-09 and 2009-10 on 337 matched students from grades eleven and twelve indicates comparability between scores on the
FCI and SFCI. The simplified language of the SFCI does not provide an unfair advantage, but may be an appropriate accommodation for younger students and/or students with limited English proficiency (Popp, Jackson 2009). Thus in the following sections the acronym FCI means “simplified FCI”. These pretests were given at different days at the beginning of the year so to not overwhelm students all at once. The days and order in which these pretests were administered were left to the discretion of each investigator.

2. Study Permission and Data Security:

No students under the age of 18 were included in this study without their signature on the “Student Assent Form” found in Appendix A, as well as their parent's/guardian’s signature on the “Parent/Guardian Assent Form”. If the student is above 18 years old, their signature was still required. Students as well as parents were also notified that they can leave the study at any time if they have any reservations without negatively affecting the student’s grade. All students’ exams results were coded numerically. The graded exams and numerical key that links students’ names to their scores were kept in separately locked cabinets. Any electronic copies of the results were kept on the investigator's password protected computer account.

3. Unit 1: “Getting Ready”:

Each investigator conducted their own individual preparatory unit depending on the ability, and grade level of their students. Refer to Investigators’ Field Report section for additional information on a specific investigator’s approach.

4. Description of Treatment:

Treatment consisted of placing ranking task activities into the established modeling sequence of instruction. Each investigator had implemented the modeling curriculum in their classrooms previously. Pacing was at the discretion of each investigator depending on level of students and their readiness for learning physics. The treatment represented a reasonable modification to the modeling sequence and is described in more detail below:

a. Each unit began with the paradigm lab as usual in the modeling sequence.
b. Upon completion of the paradigm lab discussion, a ranking task activity relating to the paradigm lab concept was introduced. Table 4 lists the selected ranking tasks from Okuma’s book of *Ranking Task Exercises in Physics* that were chosen for each unit.
c. The ranking task activities began with each student completing the ranking individually. Each group prepared whiteboards once a group consensus was reached and a classroom
whiteboard discussion took place. During the whiteboard discussion each group explained their reasoning by focusing on a specific criterion, or by referring to observation or experimental evidence. Afterwards, the instructor showed either the listed video or performed a demo listed in table 4. Students were then asked to revise their prediction, if needed and describe their thought process on the provided paper.

d. Other ranking tasks were inserted at different places in the unit in order to address different misconceptions students may have as they arise, so sometimes there were more than 1 ranking tasks for each unit, and where the investigators decided to insert them were left to their discretion.
Table 4: List of modeling curriculum units and corresponding chosen ranking tasks (O'Kuma et al. 2000).

5. Post-treatment Assessments

All students were assessed using the simplified FCI (FCI) after unit 9. Investigator one and two also gave the Lawson Classroom Test of Science Reasoning (Lawson CTSR is available at http://modeling.asu.edu/modeling/LawsonCTSRintro.htm) and Test of Understanding Graphs in
Kinematics (TUG-K). The Lawson CTSR and TUG-K posttests occurred at different times for these investigators depending on the pacing, level of the students, and varied school schedules.

6. Data Analysis

During this study both qualitative and quantitative data was collected. The quantitative data came from the FCI pretest and posttest. The ranking tasks provided qualitative data for the investigators to measure change in students’ conceptual understanding not directly measurable by the FCI. The quantitative data was analyzed in the following ways:

a. FCI pretest scores for control and treatment groups were compared to determine if they came from the same population using an independent t-test.

b. Intragroup comparison: The average gains of the control group’s FCI scores before and after treatment were compared to determine if there were statistically significant gains. Similarly, the treatment group’s FCI scores before and after treatment were also compared.

c. Intergroup Comparison: FCI posttest from the treatment group was compared to the control group. This allowed the investigators to determine whether the treatment group’s gains were less than, equal to, or greater than the anticipated gain made by the control group that received modeling instruction alone.

d. The qualitative data was analyzed using the Hudgins rubric from *Effectiveness of Collaborative Ranking Tasks on Student Understanding of Key Astronomy Concepts* from Appendix B was used to assign students a score of 1-5 based on their ability to identify key variables or factors in each ranking exercises. Several corresponding FCI questions were chosen to analyze whether there was a relationship between the student’s written score on a ranking task and his/her ability to answer the corresponding FCI question correctly.
Results

Quantitative Data

All 504 study participants took the FCI, and the general statistics for the pretests are listed in Table 5. However, only control and treatment groups one and two took both the pre- and posttests for the TUG-K and Lawson CSTR. Therefore, the investigators decided it would be more appropriate to report only the FCI results in the general results section of this paper. The investigators who had obtained TUG-K and Lawson CSTR post treatment results reported them in their own field reports.

<table>
<thead>
<tr>
<th></th>
<th>Control Group</th>
<th>Treatment Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCI Pretest</td>
<td>N=327</td>
<td>N=177</td>
</tr>
<tr>
<td></td>
<td>M=7.92; SD=3.07</td>
<td>M=7.62; SD=3.34</td>
</tr>
</tbody>
</table>

Table 5 FCI pretest for treatment and control groups. M=Mean, SD=Standard Deviation.

First the investigators attempted to determine if students involved in this study came from the same population. The boxplot in Figure 2 shows the FCI pretest results for both groups. The box plot separated the scores into quartiles. The length of the bottom line to the bottom of the box represents the bottom 25% of the score distribution. The middle box is the interquartile range and represents the middle 50% of the distribution with the dark line being the mean, and the top of the box to the top line represents the top 25% of the distribution. The lines above and below the box are also called “whiskers”. The dots above the top whisker are outliers, and the numbers represent the subject number that received those scores. Even though there were many outliers from the treatment group in Figure 2, the box plot clearly indicates that both control and treatment groups had a similar interquartile range and standard deviations on the FCI pretest (Table 5).
A non-directional independent t-test was conducted to confirm whether students from both groups came from the same population; the result is shown in Table 6. At alpha = 0.05, there was no significant difference in the mean FCI pretest scores $t(502) = -1.01$, $p = 0.31$. Thus we could not reject the null hypothesis that there is no difference in the average FCI pretest scores between the two groups. Therefore, we concluded that the students of the control group who received modeling instruction ($M = 7.92$, $SD = 3.07$) and the students of the treatment group who received modeling and ranking tasks ($M = 7.61$, $SD = 3.34$) came from the same population. The 95% confidence interval of the difference between both groups ranged from -0.895 to 0.297, thus including 0 mean difference.

**FCI Posttest Data:**
All participants in the study (N=504) took the FCI posttest. The posttest scores were used to determine if there were any gains in conceptual understanding between our control and treatment groups. The boxplot in Figure 3 compared the FCI posttest scores for both groups, the treatment group had a higher mean FCI posttest score depicted by the central bold line. There were also more scores grouped around the median since the length of the middle box is longer than the control groups. The higher mean score indicated that ranking tasks had a greater impact on students’ conceptual understanding than modeling alone.

To verify the results of the boxplot, a directional independent samples t-test was conducted and shown in Table 8. At alpha = 0.05, there was a significant effect of conceptual understanding gains $t(326.48) = -3.32$, $p < 0.001$ thus the null hypothesis was rejected that
instructional intervention of adding ranking tasks had no effect on students’ conceptual understanding. A large t-score was expected. Since a larger t-score provides greater evidence against the null hypothesis the likelihood that these scores was a result of random chance is very low. A high t-score would mean that the treatment group’s FCI posttest scores were statistically higher than that of the control groups. The negative sign on t-score was the result of designating the control group first so when the treatment group’s score was subtracted from the control group’s the result was a negative t score. The treatment group that had ranking tasks added to the modeling cycle (M = 15.81, SD = 5.53) performed better on average on the FCI posttest than the control group (M = 14.17, SD = 4.92). The 95% confidence interval of the difference ranged from -2.63 to -0.67. The 95% confidence interval does not contain a 0 difference in average scores.

Next the investigators were interested in examining the pre- to post treatment gain of each group separately. Two directional paired sample t-tests were conducted on the control and treatment groups separately. A significant result was expected between pre- and posttest scores for both groups, but a larger difference was expected for the treatment group. A result of control group’s paired samples t-test is shown in Table 7, and the result of the treatment groups’ paired samples t-test is in Table 8. The treatment group did have a higher average FCI posttest score than the control group. The treatment group had a difference of 8.19 points from pre- to posttest, while the control group had an increase of 6.24 points. At alpha = 0.05 there was statistical evidence that ranking tasks did have an effect on students’ conceptual understanding, and the null hypothesis that the mean differences of both groups would be zero was rejected. We found that both groups showed significant increase in FCI scores, but the control group’s conceptual understanding (M = 6.24, SD = 4.39) as measured by percent means score gains was lower than the treatment groups’ (M = 8.19, SD = 5.07). There is 95% confidence the average increase in score for the control group was between 5.77 to 6.72 points, and between 7.44 to 8.94 for the treatment group.
Table 7 Control Group FCI Paired Samples T-test SPSS results

<table>
<thead>
<tr>
<th>Paire</th>
<th>Control group FCI posttest scores - Control group FCI pretest scores</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
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<tr>
<td>1</td>
<td></td>
<td>6.24465</td>
<td>4.39130</td>
<td>.24264</td>
<td>5.76992 - 6.72238</td>
<td>25.715</td>
<td>326</td>
<td>.000</td>
</tr>
</tbody>
</table>

Table 8 Treatment Group FCI Paired Samples T-test SPSS results

<table>
<thead>
<tr>
<th>Paire</th>
<th>Treatment group FCI posttest - Treatment group FCI pretest</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
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<tbody>
<tr>
<td>1</td>
<td></td>
<td>8.19209</td>
<td>5.06630</td>
<td>.38081</td>
<td>7.44056 - 8.94363</td>
<td>21.512</td>
<td>176</td>
<td>.000</td>
</tr>
</tbody>
</table>

Qualitative Data

Two ranking tasks were selected to see if there was a relationship between ranking task score and correctness on the corresponding FCI concept. Appendix D shows the matching of selected ranking tasks and their corresponding question on the FCI. Ranking task twenty-eight and FCI question twenty-five were chosen for comparison because both dealt with net force applied on various masses, which is related to Newton’s second law. Ranking task thirty-one and FCI question fifteen were matched because both addressed force pairs interaction of Newton’s third law. In all of these matched problems, careful attention was paid to ensure that similar scenarios and visual representations were used in order to minimize confusion and decrease visual bias. A single third-party grader was enlisted to try to ensure grading uniformity. For graded ranking task examples see Appendix E.

Figure 4 shows the second set of matched ranking task and FCI question comparison. The mean score for ranking task twenty-eight was plotted for students who responded correctly and incorrectly to FCI question fifteen. The sample size was 128 gradeable responses. For those answering FCI question twenty-five correctly the average ranking task score was 2.55 out of a
possible maximum score of five while the average ranking task score for those answering incorrectly was 1.63 out of five. There was a slight but not significant difference between ranking task scores and choosing the correct FCI answer.

Figure 4 Histogram analysis of ranking task 28 average score and FCI question 25
Figure 5 shows the second set of matched ranking task and FCI question comparison. The mean score for ranking task thirty-one was plotted for students who responded correctly and incorrectly to FCI question fifteen. There were 118 responses for ranking task thirty-one. For those answering FCI question fifteen correctly the average ranking task score was 1.96 out of five while the average ranking task score for those answering incorrectly was 1.71 out of five. There was a slight but not significant difference between ranking task scores and choosing the correct FCI answer.

Figure 5 Histogram analysis of ranking task 31 average score and FCI question 15
Conclusion

Recent cognitive and physics education research strongly indicate a relationship between students’ conceptual physics understanding and their ability to mathematically solve problems. With this implication in mind, an attempt was made to increase students’ conceptual understanding of Newtonian mechanics before any mathematical problem solving was introduced. The investigators expected favorable results using the FCI because it is a well vetted test of conceptual understanding. This expectation was realized in the results. The treatment group’s average posttest score on the FCI was significantly higher than those of the control groups. The average percent gain by the treatment group was also higher than the control group. The investigators are convinced that the addition of ranking tasks into the modeling curriculum helped deepened students’ conceptual understanding of Newtonian mechanics.

A relationship between ranking tasks score and correctness on corresponding FCI questions was expected as well. The fact that the data did not clearly indicate such relationship was a surprise. The investigators suspected this was due to students’ inability to express their understanding effectively in writing, and the rubric that was used penalized them for not explicitly mentioning certain variables/factors.

The investigators found that adding ranking tasks into the modeling cycle required a significant amount of instruction time. As a result of the treatment, there was little time for adding in the “extras” that all students enjoy, such as engineering projects. In implementing this treatment, while the investigators feel it is very valuable, there will be some inevitable sacrifice of time in other places. Careful consideration will have to be given to make sure the trade-off is most beneficial for the students.

This study has a number of notable limitations. After gathering the result, a lot of time was spent trying to match ranking tasks with specific FCI questions. In retrospect, it would have been more successful to complete the matching before treatment began. Also hampering the study was a lack of vetted ranking task grading rubrics. This resulted in contradictory results in the qualitative data. This study enjoyed a large sample size but any study can benefit from more data. It is thought that more data and better ranking task assessment tools would give even more significant results.
Investigator Field Reports

Investigator 1 Field Report

Investigator 1 taught at Rancho Verde High School in Moreno Valley, California. This school was also the year in which the school started the “Physics First” program for all 9th graders; all these students were also concurrently enrolled in either Algebra I or Geometry.

In order to maintain consistency in the control and treatment groups the standard Modeling in Mechanics Curriculum was used instead of a ninth grade physics Modeling Instruction curriculum even though the former was specifically designed for high school freshmen taking Physics as a first year science sequence. Furthermore, many of these students have also taken the appropriate mathematics placement tests provided by the school district in order to be enrolled in Algebra I or Geometry; since the standard Modeling in Mechanics Curriculum only required basic algebraic skills I felt confident that students were capable of handling the regular mechanics curriculum. The procedure for both the control and treatments groups were as follows.

Investigator 1 Methods

Control Group 1: Modeling only control protocol

1) For the “Getting Started” unit, I started the year with the vectors unit materials where students performed walking exercises, traced their steps and calculated their distance versus their displacement. This was an important prerequisite for discussing speed versus velocity as well as the 2D projectile model later on.

2) Following the original design of the Modeling Learning Cycle, students were shown a phenomenon (a car moving at constant speed, a ball rolling down an incline, a projectile launched at an angle, etc) for investigation in a paradigm lab.

3) Students conducted the paradigm lab, summarized results on whiteboard and had a class discussion on results eventually reaching a consensus for a verbal, visual, and eventually a graphical and mathematical models for the model being studied.

4) The Modeling Learning Cycle then continued as normal with additional practice worksheets, class discussions, ending with a cumulative exam.

5) While the treatment group was working on ranking tasks, the control group worked on engineering projects such as mousetrap cars for the motion unit,
projectile launchers for the projectile unit, balloon cars for the energy unit, and egg drop protection device for the impulse-momentum unit.

Treatment Group 1: Modeling Method + Ranking Tasks Protocol

1) Followed steps #1-3 from the Control Group Protocol.

2) After the Paradigm Lab, relevant ranking tasks were introduced. For each ranking tasks students worked on them independently, reconvened back into their groups, discussed the consensus, presented and discussed the results as a class. Afterwards, students revisited their initial predictions and either changed their answer and/or explained their choice by using experimental or observational evidence, and relevant vocabulary words as needed.

3) Next, I showed a relevant video and/or demo listed in Table 1 so students could see the model being played out. We then discussed why what happened, and students wrote a post video/demo explanation using experimental evidence from the lab and their knowledge from previous units.

4) From the class consensus, I gathered the relevant diagrams or representations that students used in their ranking tasks explanations and displayed it on the front whiteboard. We then discussed as a class why these representational tools were useful in fleshing out the details of that particular model.

5) For the most part, the rest of the modeling sequence were identical to the sequence described in step 3 of the control group protocol.

**Investigator 1 Results**

The control and treatment groups came from the same population.

Before measuring the difference caused by ranking tasks exercises, I was interested to see if the control and experiment students in my 9th grade physics class came from the same population. The essential statistics for the control and the treatment group is shown in Table 9 below. The mean and standard deviation for both groups were similar.
As shown by the box plot of FCI pretest scores in Figure 6, it was evident that both populations had similar, symmetrical, and overlapping range that’s indicative of the same sampling distribution. To confirm that they came from the same population, I ran a non-directional independent t-test at alpha=0.05 shown in Table 10. Based on the result, I failed to reject the null hypothesis that the difference between FCI pretest scores for the control group and the treatment population was equal to 0. There was not a significant difference between the control (M=8.05, SD=2.84) and the treatment group (M=7.02, SD=2.07); t(104.3)=−1.879, p=0.063. The randomly selected students in each group had been drawn from the same population.
The treatment group had higher gains than the control group in 2 out of 3 posttests (FCI, and Lawson CTSR).

The effects of Modeling instruction on physics education research has been widely proven by Hestenes and Wells; as evidenced by the gain in scores on the FCI by the modeling instruction group compared to the traditional lecture and demo format. Therefore, I was more interested in finding out if the ranking tasks would result in a measurable difference in students’ understanding of mechanics on top of the gains made by modeling by itself. To compare the effects of each pedagogy a box plot of FCI posttest scores in Figure 7 between the 2 groups showed a noticeable difference in the median and interquartile range. In the FCI posttest, a majority of students in the control scored a 16 out of 30 with the highest score being 22, while the students in the treatment group scored in the high teens with the highest score being 28 out of 30.

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<tbody>
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<tr>
<td>FCI pretest</td>
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Table 10: Investigator 1 FCI Pretest of Sample Population

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<td>Type of Protocol</td>
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<td>Experimental (Modeling w/ Ranking Tasks)</td>
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<td>Control (Modeling Only)</td>
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Table 11: Investigator 1 FCI posttest group statistics
The box plot for FCI posttest in Figure 7 showed that the treatment group had higher median and interquartile range than the control group. To determine if this gain was statistically significant, I ran a non-directional independent t-test at alpha=0.05 shown in Table 12. There was a significant difference between the treatment group’s FCI posttest scores (M=18.51, SD=3.84) and the control’s (M=15.84, SD=2.62); t(111.6)=4.33, p<0.001. Therefore, I reject the null hypothesis and concluded that adding ranking tasks to modeling did increase students’ conceptual understanding.
Lawson CTSR Results

Figure 8 shows the boxplot of Lawson CTSR posttest results. The Lawson CTSR gains made by the control (M=11.89 SD=3.49) was lower than the treatment group (M=13.4, SD=4.18). After conducting a non-directional independent t-test shown in Table 13, of the difference LCTSR posttest scores between the treatment and the control, a statistically significant difference was detected; t(118)=2.239, p=0.027. Thus I reject the null hypothesis that the mean LCTSR posttest for the control and treatment groups were equal to 0; instead I conclude that there is a statistically significant effect of LCTSR gains made by adding ranking tasks to whiteboard discussions.

Table 12: Investigator 1 FCI posttest Independent sample t-test SPSS results

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Table 13: Investigator 1 Lawson CTSR posttest independent t-test SPSS results

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Figure 8: Investigator 1 Lawson CTSR posttest boxplot
TUG-K Results

A glance at the TUG-K posttest distribution of the control and treatment groups in Figure 9 shows that both were similar in their sampling distribution between their medians, and interquartile range. Though the treatment group had a lot more outliers in the high range of TUG-K posttest scores than the control group.

Figure 9: Investigator 1 TUGK posttest results

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<td>TUG-K Posttest</td>
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<td>Equal variances not assumed</td>
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Table 14: Investigator 1 TUG-K posttest independent t test

A non-directional independent t-test, shown in Table 14, was conducted to compare the difference of means of the TUG-K posttest scores between the 2 groups. There was not a
significant difference in TUG-K posttest scores between the control (M=5.60, SD=2.26) and the treatment group (M=6.56, SD=3.02), t(115.742)=2.107, p=0.531. Thus I cannot reject the null hypothesis that the mean difference between the average TUG-K posttest scores between control and treatment groups were close or equal to 0. There was no significant difference between TUG-K posttest scores between both groups.

**Conclusion**

Since I was the only one of the investigators to have ninth graders as test subjects I was interested to see if ranking tasks would improve students’ understanding of basic mechanics. As shown by the results, the treatment group showed a significant difference in two out of three posttest scores compared to the control: the FCI and the Lawson CTSR. However, there was no clear association from the qualitative results. I was not able to show that there was a clear association between FCI posttest results and ranking tasks scores.

Referring back to my project journal, I noticed that the treatment students were able to progress from the traditional white boarding session advocated by Modeling alone to more sophisticated and meaningful conversation by using the ranking tasks to test their understanding of the new model or as a jumping point for further investigations. Due to the additional class discussion provided by the ranking tasks, I showed that my 9th graders had higher posttest score gains in the FCI and Lawson CTSR than the control group that had the traditional modeling curriculum.

As for the nonsignificant finding in the TUG-K posttest score between the control and treatment groups, I suspect this may be due to the small amount of ranking tasks specifically focused on kinematic graphing which the TUG-K test really dwelled into great detail. Also, the timing of the TUG-K posttest could have affected the score negatively since it was given near the end of the school year which was 8 months after we finished up with the kinematics unit, and while students were already flustered with multiple state-mandated tests. I believe the main reason that students showed gains in the FCI and Lawson CTSR and not the TUG-K was because the FCI and Lawson CTSR did not specifically focus on specific mathematically-focused concepts, unlike the TUG-K which required students to perform specific numerical calculations for slope and area on graphs.

In conclusion, the addition of ranking tasks did result in significant gains on students’ conceptual understanding of basic mechanical concepts. I found that students in the treatment
groups were more likely to resort to conceptual reasoning rather than number crunching method to solve problems than the control group. This effect was due to the additional class time that was given for them to work through the problems without the added stress of finding the “correct” answer dictated in a traditional physics class. Students in the treatment group were more likely to be active in class discussions because the stigma of giving the “wrong” answer was decreased due to the omission of numbers on many of the ranking tasks. Instead students had to rely on observational evidence and their understanding of the model in order to sort the scenario in a way that made sense. This was what Colleen Megowan referred to as “sense-making”. The result of this study will have a great impact on how I’ll structure my physics class in the future as I try to promote a more qualitative method of analysis rather than jumping to mathematical analysis right away.

**Investigator Two Field Report**

Investigator two has over fifteen years of experience teaching the modeling method to high school students. For the past three years, Investigator two has taught at a new school whose population is described above with mainly eleventh grade students. Having been very familiar with the modeling cycle, this new treatment, including ranking tasks to increase the conceptual understanding, was an undertaking that lasted through each of the Mechanics units, mid-July through mid-March. The additional class time required to implement the treatment was made possible by eliminating the semester projects, which each take approximately one complete week of class time per semester. The goal was to replace the culminating project with individual model inquires, which should produce statistically significant gains in the pre to post test, which included the Force Concept Inventory (FCI) given in July and March, as well as the Test of Understanding Graphs in Kinematics (TUG-K) given in July and October.

**Methods**

Investigator two used the Modeling Method of teaching Physics throughout her entire career (2001-present). Beginning with the demonstrations and paradigm labs to begin discussions with students as to what is happening in various circumstances such as a swinging pendulum or
objects rolling down inclined planes. In these pre-lab discussions, Socratic questioning techniques are used to encourage students to design their own investigation in order to determine the factors that affect the concept being studied. Once the data is collected and analyzed graphically, students partake in whiteboard round-table discussions or group presentations of their findings. These post-lab discussions are the foundation of their lab reports, which they produce either individually or as a group. Following the paradigm lab, students began the deployment activities, which include mathematical calculations of the mechanics concept. These worksheets and problems are presented using white-boards or round table discussions. The unit was then completed with a cumulative examination.

**Control Group: Modeling Methods in Physics, Only**

The control group consisted of the students that were in Core Physics classes, at the same school from 2013-2014 and 2014-2015. The FCI and TUG-K are typical evaluation tools that have been used over the past 15 years and were given in the first week of school as a pretest, then again as a post-test in October (TUG-K) and March (FCI). The population is similar to the population of the treatment group however; the total school population continues to grow since the opening of the school. Students followed the protocol discussed above and had an additional cumulative project for each semester. After the constant velocity and constant acceleration units, students build parachutes to specified parameters and compete against one another to determine the winner, the parachute that has the least acceleration. After the energy unit, students build a rubber-band car and compete for the fastest five-meter time. The project also includes a written component that requires the student to analyze their performance and discuss physics concepts that affected their projects.

**Treatment Group: Modeling Methods in Physics and Ranking Tasks**

The treatment group included 83 students who began and completed Core Physics classes in the 2015-2016 school year. There were many fewer students than the previous two years as there were only four Core classes in that year, whereas in the previous years there were five. The
protocol for the treatment followed the modeling method through the development phase of the model. Prior to the deployment activities, students were given ranking tasks to complete as homework. The following class meeting, students would discuss their rankings with one partner and write any changes in thought or rank on the back. Then students were grouped in fours. They discussed their ranking again and prepared a whiteboard for their collaborative ranking. All changes in thought or rank were to be chronicled on the back of the paper. All groups presented in a round table whiteboard discussion and again wrote any changes in their thinking on the back.

After discussion, ranking tasks were turned in for grading with the assigned rubric. Students were not given grades for ranking tasks but papers were divided into scoring groups of one through five. One being unstructured explanations and five being expert.

The modeling cycle continued, after the ranking tasks, with the deployment activities including computer modeling of data and problem solving worksheets in the curriculum. Each unit concluded with a cumulative test but there was no culminating project.

Results

In order to determine whether the treatment, including ranking tasks as part of the modeling cycle, would increase students’ conceptual understanding of Newtonian physics, a comparison of the Force Concept Inventory (FCI) pre and post-test scores was needed. Student scored from the prior two years, at the same school, with the modeling method only, were compared to the ones with whom ranking tasks were used. The results of the FCI appear somewhat disappointing, in that the mean did not increase, but instead decreased slightly, indicating that the treatment was not successful in raising scores. However, upon further interpretation of the data, the gains in FCI scores were in fact greater with the treatment than without. Supporting the hypothesis that including ranking tasks as part of the modeling cycle treatment is a way to increase gains. Students entering the class with an overall 6.61 mean pretest
score, from the treatment group compared to the 7.75 mean pretest score in the control group, showed greater gains in the post-test, although they total mean scores were slightly lower.
A non-directional independent samples T test was conducted to evaluate the hypothesis that adding ranking tasks into the modeling cycle would increases student’s conceptual understanding as measured by the FCI. At $\alpha = 0.05$, there was not a significant effect of conceptual understanding gains $t(328) = 3.005$, $p = 0.003$ thus the null hypothesis was rejected that students came from the same population. The students who had ranking tasks added to the modeling cycle ($M = 6.61$, $SD = 2.76$) did better on average on the FCI posttest than those who did not have ranking tasks added to the modeling cycle ($M = 7.75$, $SD = 3.06$). Since the 95% confidence interval of the difference ranged from 0.395 to 1.89, the mean scores cannot be used as a determination of the effectiveness of the treatment.
Figure 12 Posttest FCI data from control group.

Figure 13 Posttest FCI data from Treatment group.
The post-test scores show a slightly lower mean score but as compared to the 1.14 difference in pre scores, the post score is only 0.35 lower, indicating that although the mean is lower, the gain is higher. The treatment was intended to increase the gain, which it appears to have done when looking at the gains rather than the means. Since the null is rejected and the populations are not alike, the percentage change is used to determine the effect of the treatment instead of the overall mean scores.

By calculating the percent change rather than the mean scores, due to the fact students are arriving with lower pretest scores, it can be seen that the gains improved by 40%. The control group increased by 95% but the treatment increased their scores by 135%. Unfortunately, this does not speak well for science education. Pre and post-test scores have decreased each year. However, the data does show that although the scores are lower overall, there is a benefit in the treatment.
Figure 14 Pretest comparisons of the control and treatment groups.

Figure 15 Post-test comparisons of the control and treatment groups.
The independent samples t-test shows that the sample is in the norm and the null can be rejected due to the 95% confidence interval range of -0.74 and 0.48. The samples are from the same population and their means may be compared.
Figure 16 TUG-K results from the control group, shows a mean score of 9.51.

Figure 17 TUG-K results from the treatment group, shows a mean score of 10.53.

The TUG-K tests show a difference in mean of 9.51 to 10.53. This increase is approximately a five percent gain in post-test scores, with the treatment group. Although the ranking tasks were intended to increase conceptual understanding, they also seemed to have an effect in the quantitative areas as well. These tests were given immediately after the units involving graphing velocity and acceleration graphs, late September (treatment group) or early October (control group).

Conclusion

Although the scores did not increase the mean FCI score from the control group, it did increase overall gains of the participants. By entering with a lower pretest score, the post-test must show higher gains to improve. Our data shows that this does in fact happen. Using the ranking tasks as a part of the modeling cycle helps students recognize the important factors that
contribute to the changes in mathematical value prior to practicing the deployment activities in the modeling cycle. The TUG-K scores showed an unexpected gain due to the treatment, although an unexpectedly low overall score. The use of ranking tasks as part of the modeling cycle does have a statistically significant effect on students’ scores and I will continue to use them as part of my curriculum. If they are part of the class requirements, rather than an optional tool for collecting research data, the gains may prove to be even higher than detected through this research project.

In the future, students will be required to maintain a notebook of their ranking tasks. They will be given the ranking tasks as bell work after paradigm labs are introduced. Each similar task will be evaluated and the physics concepts that support the ranking will be discussed in an essay with each model. The completed notebook will be assessed for the students who wish to achieve an A in the class.

**Investigator 3 Field Report**

Investigator 3 taught in Greenwood, Arkansas and is the only physics teacher at Greenwood High School. Last year was Investigator three’s twenty-second year of teaching, sixteenth at Greenwood, and nineteenth year teaching physics. There were one section of honors physics and one section of regular level physics. The combined total of students in the treatment group was thirty-eight with twenty-seven of those students in regular level physics.

At Greenwood High School physics is an elective. Regular level physics is often taken as a junior after biology but can be taken as a junior or senior after having successfully completed algebra 1 and 2.

Greenwood offers seven fifty minute classes daily so both of my physics classes met every day. Honors physics was comprised of all seniors except one and had a higher level math background all except the junior having taken pre-calculus and were concurrently enrolled in AP calculus. The regular level class was much more mathematically diverse. All of these students
had successfully completed algebra 1 and 2 and some had gone on to be concurrently enrolled in college algebra/trig or pre-calculus. Despite the fact that they had all successfully completed the math requirements for physics their mathematical abilities widely varied. This is a typical problem in my physics classes and the impetus for this treatment.

As a control I used data from 2014-15 regular level and honors physics classes that I taught using the Modeling curriculum alone.

**Methods**

The pretests for the FCI was given the first week of classes in August 2015. The posttests were given the last full week of school before finals in May of 2016. I feel that I had developed sufficient rapport with my students that even though these tests in no way impacted their grade, I feel the majority gave their best effort. I point to the general increase in posttest scores as evidence for this statement.

Generally, the concept to be studied would be introduced via paradigm lab. After the lab and some discussion, a ranking task would be introduced. Each student would be asked to complete the task individually first. Then they would convene into groups of two to three to discuss their ideas and come to a group consensus on the appropriate model for ranking the scenario. Once a consensus was reached, each group was asked to whiteboard their ideas. Whiteboards were then shared in “board meeting” style and a class came together to decide on the appropriate ranking of the items. Afterwards I asked each student whose ideas changed as a result of the discussion to write how and why their model changed.

**Results**

Since the FCI is designed to assess student understanding of force in Newtonian physics, I was interested in comparing the control and treatment group’s posttest scores to evaluate whether there was evidence that the treatment group had higher FCI posttest scores.

I had to first establish that my samples represented samples pulled from the same population. To accomplish this, I conducted an independent t-test (Table 1). To prove that my

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<td>FCI Pretest Scores</td>
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Table 19 Investigator 3 FCI Pretest Independent Samples T-test SPSS results
samples were from the same population I was looking for a small t-score and a large significance (p). Using the significance level (alpha) of 0.05 that would give me a 95% confidence interval I found that my expectations were met and I failed to reject the null hypothesis that the mean difference of my groups would be zero. The t-test indicated that there was no significant difference in the means of the control with a sample size n = 22 (M = 9.91, SD = 4.41) and treatment groups with a sample size n = 30 (M = 4.48, SD = 4.48). The 95% confidence interval of the difference ranged from -3.87 to 1.15. That confidence interval contains a 0 mean difference validating the null hypothesis allowing me to state that both of my samples were drawn from the same population. Once I was able to show that both my control and treatment groups are from the same population I could attribute any differences in their posttest scores to the treatment.

Next, I looked at histograms to get an idea if the data was skewed positively or negatively (Figure 1). I was interested in seeing if there the treatment group had a greater frequency of higher FCI scores as that would suggest better conceptual understanding. I found that the treatment group did have a higher frequency of correct answers on the FCI posttest.
Figure 18 Investigator 3 FCI Posttest Histogram
After looking at the histograms, I was interested in determining whether there was statistical evidence that the treatment group’s posttest scores were significantly higher than those of the control group. To that end, I conducted a directional independent samples t-test to evaluate that hypothesis. With the results of the t-test I expected to see a large negative t-score and a confidence interval that did not include zero. Table 2 shows the SPSS output results at alpha = 0.05 and there was no significant effect on conceptual understanding measured by the FCI, the scores for the control group FCI posttest scores (M = 17.05, SD = 7.13) and the treatment group FCI posttest scores (M = 17.30, SD = 7.78). With a t-score of -0.12, and a confidence interval that included zero I could not reject the null hypothesis that the difference in mean scores would be zero. There were no significant differences between the FCI posttest scores of the control and treatment groups.

The last statistic that I was interested in looking at was any differences in the FCI score gains between pretest and posttest. More than ten years’ experience with the modeling curriculum has led me to believe that there would be significant gains with the modeling curriculum alone. I was interested in testing whether there was a significant increase in FCI posttest scores with the addition of ranking tasks. I looked at a boxplot graph of the control and treatment groups FCI pre- and posttest scores (Figure 2). I found that the mean scores or standard deviations for both pretest and posttest were very comparable. I could conclude that there were no significant gains from pretest to posttest with the use of ranking tasks. However, I did find that there was a more even distribution of scores around the mean and the range was larger.

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<th>Equal variances not assumed</th>
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<td>.122</td>
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Table 20 Investigator 3 FCI Posttest Independent T-test SPSS Results
Conclusion:

Figure 19 Investigator 3 FCI Pre- and Posttest Score Comparison
While there is no statistical evidence that inserting ranking tasks into the modeling cycle had an impact on the conceptual understanding within my treatment group, I feel that the finding may be affected by the small number of participants in my samples.

Looking back over my notes from the treatment, one thing I noted was the productive discussions my students had. I rarely had to re-direct students because they stayed on task. In my experience this is unusual and I found it initially encouraging. However, after testing I learned that regardless of the fact that they were on-task and having what appeared to be meaningful conversations about the topic of study, their performance on conceptual test questions did not always corroborate that their meaningful conversations meant an actual deeper conceptual understanding or more thoughtful use of a model. The statistics agree with my assessment. Both levels in the control and treatment groups indicated that there is a statistical difference between pre- and posttest results. Since they were both taught using the Modeling Method and the Modeling curriculum I attribute their gains to the modeling learning cycle and the modeling pedagogy. For my treatment groups there was no statistical evidence that placing the ranking tasks into the learning cycle increased my students conceptual understanding of the Newtonian idea of force as tested by the FCI. Despite this lack of statistical evidence, I do have anecdotal evidence from conversations and observations that ranking tasks do help. Every student that I talked to about ranking tasks told me that ranking tasks were frustrating and hard but that they thought that working through the ranking tasks had helped them grasp the concepts in a more meaningful way. In a conversation with one of my honors level student after the ranking task activity on constant velocity I was told, “It (the ranking task) helped me deepen my understanding and make connections between the math I already understood and the concept”. This young man seemed to think the ranking tasks useful for helping him apply the mathematics he was learning in his math class.

“This time I know I can argue my position”, and “these (ranking tasks) make me take what I thought I knew and realize I didn’t really know it”, were just two comments I heard as I circulated around the room during a class period. I plan on tweaking the treatment and I will continue to use them because end-of-year conversations with students were invariably positive and all students that I spoke to about ranking tasks specifically had the opinion that the ranking tasks helped them more fully understand the concepts. The method will definitely have to be
modified because of the amount of time it takes to implement. I am going to have to give consideration of how I will continue to use ranking tasks in my classroom. My treatment group did not get the benefit of all of the projects that the control group did. They were assigned one project instead of the usual two. I believe my students benefitted from ranking tasks but I believe they also benefit from engineering projects. I do plan on keeping ranking tasks in my curriculum. I will just have to seriously consider how to streamline the process.

**Implications for Further Research**

After seeing positive results from ranking task exercises, the investigators are interested in exploring other exercises inspired by Physics Education Research (PER) to see how they would affect student’s conceptual understanding. As conceptual understanding becomes more emphasized under NGSS, there is a need to develop additional rubrics for educators to assess students’ narrative responses to ranking tasks and other written exercises specifically in science, that will help students express their understanding of Newtonian Physics more succinctly and effectively. Finally, seeing how collaborative discourse was a big part in helping students complete the ranking tasks, the investigators would be interested in seeing if there are rubrics for scientific discourse, especially those that match the whiteboard meeting style of modeling instruction. Since the implementation of ranking tasks into the modeling curriculum required a significant amount of instruction time, there is some question whether the gains seen between the FCI pre- and posttest could be attributed to a greater time addressing topics specifically related to questions on the FCI and the expense of collaborative engineering projects. It would be interesting to see research into the benefits of engineering projects versus more single topic related activities. Finally, though ranking tasks have been developed over 10 years ago, there has been a surprising lack of discussion in PER literature on how they can be implemented in the classroom. Perhaps a more detailed plan for classroom implementation is needed before more teachers will be open to using them.
Works Cited


Howe, C., Tomie, A, Greer, K & Mackenzie, M Peer collaboration and conceptual growth in physics; task influences on children's understanding of heating and cooling. Cognition and Instruction 1995, 13(4)

Hudgins, David W., Prather, Edward E, Grayson, Diane, J., Smits, Dereck P. Effectiveness of Collaborative Ranking Tasks on Student Understanding of Key Astronomy Concepts. Astronomy Education review Vol 5 April 2006-November 2007


Mason, Lucia and Scirica, Fabio. Prediction of students' argumentation skills about controversial topics by epistemological understanding, Learning and Instruction Volume 16, Issue 5, October 2006, Pages 492–509


Appendices

Appendix A

Parent Consent/Parental Permission Form

Dear Parent/Guardian of __________________________:

I, Karen Preston, am a graduate student under the direction of Professor Culbertson in the Department/Division/College of Physics at Arizona State University. I am conducting a research study to study if qualitative examples of physics problems without a heavy emphasis on math will increase students’ conceptual understanding of physics. The purpose of this form is to provide you with information that will help you decide if you will give consent for you and your child to participate in this research.

I, Karen Preston, am inviting you and your child's (Child Name:________________________) participation in this study, which will involve student discussions and presentations using ranking tasks in class. Ranking tasks are physics problems without numbers or formulas. The study will last till the end of the 2015-2016 school year. You and your child's participation in this study are voluntary. You and your child may decline participation at any time. You may also withdraw yourself or your child from the study at any time; there will be no grade penalty. Likewise, if your child chooses not to participate or to withdraw from the study at any time, there will be no penalty.

Although there may be no direct benefit to you or your child, the possible benefit of you and your child's participation is being able to solve and understand physics problems without having to memorize formulas. There are no foreseeable risks or discomforts to you and your child’s participation. The information obtained in this study has a probability (minimal) of the student’s
identity being exposed. Therefore, THE FOLLOWING steps will be taken to protect the student’s confidentiality:

- Responses will be confidential; **NO NAMES** will be shown on their work.
- Submitted work used in the study will be kept for one year and then shredded.
- The data will only be used in a research project for a Masters of Natural Science Degree. Statistical analysis will be completed to determine the effectiveness the treatment and the gains on these various assessment instruments.
- Student may volunteer for video interviews which will be conducted either immediately before school, at lunch, or immediately after school during typical tutoring times. The videos will only show the whiteboard of students working on problems. The data will only be viewed by teachers involved in the study. Refer to a separate consent form for videotaping.
- The results of this study may be used in reports, presentations, or publications but your child’s name will **NOT** be used.

If you have any questions concerning the research study or your child's participation in this study, please call me at (479) 996-4141.

Sincerely,

By signing below, you are giving consent for you and your child ________________ (Child’s name) to participate in the above study.

________________________  __________________________
Signature                                Printed Name                                Date

If you have any questions about you or your child's rights as a subject/participant in this research, or if you feel you or your child have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the Office of Research Integrity and Assurance, at (480) 965-6788.

Formulario de Permiso de Consentimiento de Padres / Padres

Estimado padre / tutor de ________________________________:
Yo, el nombre del investigador, (_________________) Soy un estudiante de posgrado bajo la dirección del profesor Culbertson en el Departamento / División / Facultad de Física de la Universidad Estatal de Arizona. Estoy realizando un estudio de investigación para estudiar si ejemplos cualitativos de problemas de física sin un fuerte énfasis en matemáticas aumentará la comprensión conceptual de los estudiantes de la física. El propósito de este formulario es para ofrecerle información que le ayudará a decidir si va a dar su consentimiento para que usted y su niño a participar en esta investigación.

Yo, el nombre del investigador, (_________________) usted y estoy invitando a su hijo de (Nombre del niño: _________________________) La participación en este estudio, lo que implicará discusiones y presentaciones de los estudiantes utilizando las tareas de clasificación en la clase. Clasificación tareas son problemas de física sin números o fórmulas. El estudio durará hasta el final del año escolar 2015-2016. Usted y la participación de su hijo en este estudio es voluntaria. Usted y su niño puede rechazar la participación en cualquier momento. También puede retirar usted mismo o su hijo del estudio en cualquier momento; no habrá pena de grado. Del mismo modo, si su hijo decide no participar o retirarse del estudio en cualquier momento, no habrá sanción.

Aunque puede que no haya un beneficio directo para usted o su hijo, el posible beneficio de ustedes y la participación de su hijo está siendo capaz de resolver problemas y comprender la física sin tener que memorizar fórmulas sin saber por qué lo están utilizando. No hay riesgos previsibles o molestias para usted y la participación de su hijo. La información obtenida en este estudio podría causar problemas para usted o su hijo si otros aprendieron de él. Por lo tanto, se tomarán los siguientes pasos para protegerse de cualquier daño:

● Las respuestas serán confidenciales; no hay nombres se mostrarán en su trabajo.
● Trabajo presentado utilizada en el estudio se mantendrá por un año y luego rallado.
● Los datos serán utilizados en un proyecto de investigación para una Maestría en Ciencias Naturales Grado. El análisis estadístico se completará para determinar la efectividad del tratamiento y las ganancias en estos diversos instrumentos de evaluación.
● El estudiante puede ser voluntario para las entrevistas de vídeo que se llevarán a cabo ya sea inmediatamente antes de la escuela, durante el almuerzo, o inmediatamente después de la escuela en tiempos típicos de tutoría. Los videos sólo mostrará la pizarra de los estudiantes que trabajan en problemas. Los datos sólo estará al alcance de los profesores que participan en el estudio.
● Los resultados de este estudio pueden ser utilizados en informes, presentaciones o publicaciones, pero no se utilizarán su nombre y el nombre de su hijo.

Si tiene alguna pregunta relacionada con el estudio de investigación o la participación de su hijo en este estudio, por favor llame al ( ) ___ - ____.
Atentamente,
_______________________________ Firma del Maestro

Al firmar a continuación, usted está dando su consentimiento para que usted y su niño 
_____________________ _________________ (nombre del niño) a participar en el estudio anterior.

_______________________________ ____________________________
Firma Fecha Nombre Impreso

Si usted tiene alguna pregunta acerca de usted o de los derechos de su hijo como sujeto /
participante en esta investigación, o si usted siente que usted o su hijo ha sido colocado en
situación de riesgo, puede ponerse en contacto con el Presidente del Sujetos Humanos Junta de
Revisión Institucional, a través de la Oficina de Integridad de la Investigación y Aseguramiento,
al (480) 965  6.788.
Appendix

<table>
<thead>
<tr>
<th>Level of Student Understanding</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 5: Expert</td>
<td>Complex and accurate, student demonstrates a grasp of all relative concepts. Includes naming of critical variables and correctly describing how essential variables and rules affect the outcome of the phenomena. A robust general process described with correct scientific language.</td>
</tr>
<tr>
<td>Level 4: Functional</td>
<td>Yielding correct solution, but a briefer (but generally correct) description of major variables and interactions. Somewhat short of demonstrating a robust general process.</td>
</tr>
<tr>
<td>Level 3: Near functional</td>
<td>Student description identifies two or more relevant variables and relationships of relevant concepts but omits describing at least one essential element of knowledge. Description sometimes shows some minor confusion in language or terms but often still results in correct solution. However, the student description suggests a limited conceptual understanding that does not have the depth or flexibility to deal with small changes in the format or presentation of the problem.</td>
</tr>
<tr>
<td>Level 2: Subfunctional</td>
<td>Student explanation correctly identifies at least one relevant variable, but only portions of the component concepts are demonstrated. Important interrelationships of variables are not suggested by student narrative, and the student’s description may include significant misapplication of language, contradictions, or simplifications of logic.</td>
</tr>
<tr>
<td>Level 1: Unstructured/alternative</td>
<td>Student may identify one relevant variable, but he or she does not describe or appear to recognize any of the component concepts. Or, the student describes an alternative model not based on science studies.</td>
</tr>
</tbody>
</table>

The rubric was tested for reliability and repeatability in terms of the consistency of scoring student level of understanding. Three experienced astronomy instructors used the rubric to each independently score pairs of Post-Traditional Instruction and Post-Ranking Task narrative responses from a sample of 15 students. T tests showed that there was no statistical difference in scoring student responses among the instructors. This test demonstrated the interrater reliability of the scoring process using the rubric. Ultimately one author (Hudgens) scored all Post-Traditional Instruction and Post-Ranking Task student responses (approximately 180) for a quantitative measure of level of understanding.

In summary, the level-of-understanding rubric provided an independent numeric score for comparison with the multiple-choice test results. In addition, this qualitative analysis provided a window into student conceptual change resulting from the ranking-task treatments, as discussed in the Results section.

Appendix C
Appendix D

Ropes Pulling Boxes—Acceleration

The figures below show boxes that are being pulled by ropes along frictionless surfaces, accelerating toward the left. All of the boxes are identical. The pulling force applied to the leftmost rope is the same in each figure. As you can see, some of the boxes are pulled by ropes attached to the box in front of them.

Rank the masses from greatest to least on the basis of the acceleration of the masses.

Greatest: 1.  2.  3.  4.  5.  6.  Least

Or, all of the accelerations will be the same (but not zero).

Or, the acceleration will be zero for all of these blocks.

Please carefully explain your reasoning.
Moving Car and Boat Trailer—Force Difference

In the six figures below, all the boat trailers and cars are identical but the boat trailers have different loads.

Rank from greatest to least on the basis of the difference between the strength (magnitude) of the force the car exerts on the boat trailer, and the strength of the force the boat trailer exerts on the car.

A
\[ m = 1000 \text{ kg}, \quad v_f = 20 \text{ m/s} \]

B
\[ m = 2000 \text{ kg}, \quad v_f = 20 \text{ m/s} \]

C
\[ m = 1000 \text{ kg}, \quad v_f = 40 \text{ m/s} \]

D
\[ m = 4000 \text{ kg}, \quad v_f = 10 \text{ m/s} \]

E
\[ m = 2000 \text{ kg}, \quad v_f = 10 \text{ m/s} \]

F
\[ m = 1000 \text{ kg}, \quad v_f = 10 \text{ m/s} \]

Greatest 1 2 3 4 5 6 Least

Or, the differences between the two forces are the same in each situation.

Please carefully explain your reasoning.
Appendix E

Ropes Pulling Boxes—Acceleration

The figures below show boxes that are being pulled by ropes along frictionless surfaces, accelerating toward the left. All of the boxes are identical. The pulling force applied to the leftmost rope is the same in each figure. As you can see, some of the boxes are pulled by ropes attached to the box in front of them.

Rank the masses from greatest to least on the basis of the acceleration of the masses.

Greatest

Or, all of the accelerations will be the same (but not zero).

Or, the acceleration will be zero for all of these blocks.

Please carefully explain your reasoning.

The a is the same in all so the Fnet is greater the more the more it increase.

How sure were you of your ranking? (circle one)

1 2 3 4 5 6

Basiclly Guessed

Sure

Very Sure

28 S. Louna
Ranking Task Recceives in Physics: Student Edition
Motion Diagrams—Displacement

Flash strobe photographs were taken every second of a set of spheres moving from left to right. The diagram below shows the location of each sphere when each photograph was taken. The total time intervals shown vary among the spheres. All the displacements are in meters. Rank these spheres on the basis of the greatest displacement over the first 3 seconds. Give the highest rank to the one(s) with the greatest displacement, and give the lowest rank to the one(s) indicating the least displacement. If two motion diagrams indicate the same displacement for the 3-second interval, give them the same rank.

A

B

C

D

E

F

Greatest 1 F 2 D E 3 A 4 B 5 C Least

F D E A B C

Or, none of these motion diagrams indicate any displacement at all.

Or, the displacement is the same for all of these.

Please carefully explain your reasoning.

DISCOVER WHAT IS THE DISTANCE, USING A STRAIGHT LINE, BETWEEN TWO POINTS

How sure were you of your ranking? (circle one)

<table>
<thead>
<tr>
<th>Basically Guessed</th>
<th>Sure</th>
<th>Very Sure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

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Physics Ranking Tasks 12 Mechanics
Motion Diagrams—Displacement

Flash strobe photographs were taken every second of a set of spheres moving from left to right. The diagram below shows the location of each sphere when each photograph was taken. The total time intervals shown vary among the spheres. All the displacements are in meters. Rank these spheres on the basis of the greatest displacement over the first 3 seconds. Give the highest rank to the one(s) with the greatest displacement, and give the lowest rank to the one(s) indicating the least displacement. If two motion diagrams indicate the same displacement for the 3-second interval, give them the same rank.

A

B

C

D

E

F

Greatest 1 F 2 D 3 E 4 A 5 B 6 C Least

Or, none of these motion diagrams indicate any displacement at all. __________

Or, the displacement is the same for all of these. __________

Please carefully explain your reasoning.

[Diagram of the motion diagrams with arrows indicating displacements]

How sure were you of your ranking? (circle one)

<table>
<thead>
<tr>
<th>Basically Guessed</th>
<th>Sure</th>
<th>Very Sure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

11 K. W. Nicholson, C. Hieggelke, D. Maloney

Physics Ranking Tasks 12  Mechanics
Moving Car and Boat Trailer—Force Difference

In the six figures below, all the boat trailers and cars are identical but the boat trailers have different loads.

Rank from greatest to least on the basis of the difference between the strength (magnitude) of the force the car exerts on the boat trailer, and the strength of the force the boat trailer exerts on the car.

Greatest 1 CD 2 B 3 AE 4 5 6 F Least

Or, the differences between the two forces are the same in each situation.

Please carefully explain your reasoning.

CD are paired because they are the same thing, just two opposite variables.
B and F are different from each other even though the variables are slightly the same. AE are paired because they are the thing, just two opposite variables.

How sure were you of your ranking? (circle one)

Basic 1 2 3 4 5 6 Sure

Very Sure 7 8 9 10

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 Ranking Task Exercises in Physics: Student Edition 31