

ENERGY AND WORK INSTRUCTIONAL STRATEGIES IN GENERAL PHYSICS

by

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I would like to thank my wife Jayme for her support during my completion of this research project.

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TABLE OF CONTENTS

1. INTRODUCTION AND BACKGROUND	1
2. CONCEPTUAL FRAMEWORK	5
3. METHODOLOGY	10
4. DATA AND ANALYSIS	16
5. INTERPRETATION AND CONCLUSION	30
6. VALUE	33
REFERENCES CITED	37
APPENDICES	41
APPENDIX A – Institutional Review Board Exemption	42
APPENDIX B – Free Response Questions	44
APPENDIX C – Student Survey	48
APPENDIX D – Student Interview Questions	51

LIST OF TABLES

1. Data Triangulation Matrix	15
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LIST OF FIGURES

1. Example LOL Diagram.....	3
2. Example System Diagram and Energy Bar Graph	12
3. Example Energy and Work Lab Scenario.....	14
4. Average Pre- and Post-Instruction Multiple Choice Assessment Scores	18
5. Normalized Gain on the Pre- and Post-Instruction Multiple Choice Assessment	19
6. Distribution of Pre- and Post-Instruction Multiple Choice Assessment Scores	19
7. Distribution of Traditional Free Response Assessment Scores	20
8. Distribution of Lab Interpretive Free Response Assessment Scores	21
9. Survey Responses: Problem Solving with an Energy and Work Approach	24
10. Survey Responses: Preference for Teacher-Led and Student-Led Investigations	25
11. Survey Responses: Preference for Teacher-Led and Student-Led Activities.....	26
12. Survey Responses: Identifying Energy Changes	27

ABSTRACT

Introductory physics students have demonstrated unsatisfactory learning gains after traditional energy instruction. Energy instruction was adapted to include pictorial system diagrams, energy bar graphs, and interactive physical modeling. Learning gains of students who received adapted instruction was compared to students who received traditional instruction. Students who participated in the adapted instruction showed slightly greater gains in interpretation of lab data compared to those students who received traditional instruction. There was no significant difference in gains noticed on traditional assessments of work and energy concepts. No significant differences in preference for student-led interactive physical modeling over traditional instruction was found.

INTRODUCTION AND BACKGROUND

Project Background

Teaching Experience and Classroom Portrait

I enjoy teaching General Physics and AP Physics 2 at Arrowhead High School near Hartland, Wisconsin. I have taught at Arrowhead High School for four years. I previously taught science and engineering at another public school for five years. Arrowhead High School is in a suburban setting. Approximately 2,300 students in grades 9 – 12 attend the school. The 157-acre campus includes two instructional buildings referred to as “South and North Campus” as well as exceptional athletic facilities. Freshman and sophomore courses are taught at South Campus, while junior and senior courses are taught at North Campus.

The class schedule is somewhat atypical in that regular class periods are short. Classes are taught in 40 minute periods, 10 periods daily. Students from smaller public and private K-8 schools in nine small communities feed into the high school. The surrounding communities are part of the “Lake Country Area”, named for the multitude of lakes that encompass Arrowhead’s campus. The community is largely affluent, with six percent of the school population qualifying for free and reduced lunch. About 72% of graduates attend four-year post-secondary institutions, and an additional 20% attend two-year institutions.

Students take General Physics as an elective introductory course in grades 10, 11, or 12. The course focuses on mechanics. During first semester, students learn about motion and forces. Connections between motion and Newton’s First and Second Laws are emphasized. Approximately one-half of motion and forces instructional time is

devoted to student-led lab and interactive explorations. Students study energy and work at the beginning of the second semester.

Problem Description

The instructional approach to energy and work has focused less on student-led interactive explorations. It skews towards a traditional lecture and problem solving approach, especially in comparison to force and motion instruction. I have found student performance on energy and work assessments to be unsatisfactory.

When initially solving energy and work problems, students often revert to a force and motion approach. This is perhaps due to familiarity with force and motion approaches, or general confusion regarding energy approaches. Students often incorrectly attempt to apply one-dimensional kinematic equations and Newton's Second Law to solve problems that present complex two-dimensional motion. When problems include springs, some students confuse elastic energy and elastic force. Appropriate selection of an energy and work approach to analyze a problem is an essential outcome of the course.

Students are explicitly taught how to draw and interpret free body diagrams and motion graphs early in instruction. Free body diagrams and motion graphs become essential tools adeptly utilized by students to analyze mechanics scenarios. Energy bar graphs and system diagrams are introduced as an analog to free body diagrams and motion graphs. The two are combined into a single analysis tool sometimes referred to as an "LOL diagram", named for the outline the blank diagrams produce (Scherr, et. al., 2014). An example is shown in Figure 1. These diagrams are limited in their ability to communicate energy transfer between objects (Scherr, Close, McKagan, and Vokos,

2012). Precursors to these diagrams have been published by Van Heuvelen (1991) and Van Heuvelen and D'Alessandris (1998).

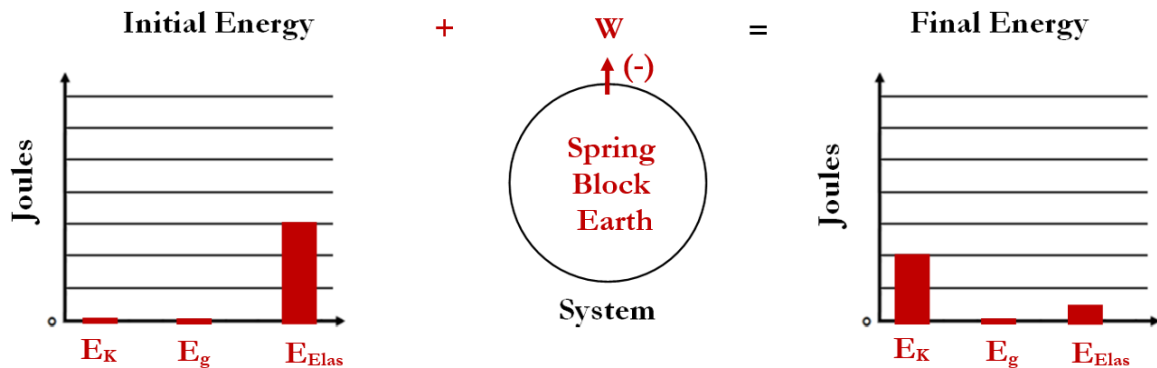


Figure 1. An example of an LOL diagram used in energy analyses.

LOL diagrams encourage students to deliberately consider the stores of energy present in the initial and final states of the system. Energy stores in the system include familiar forms of energy such as kinetic energy, gravitational potential energy, or elastic potential energy. Students also analyze energy transfer in or out of the system due to work done by external forces. The completed diagram is used to write a mathematical model for energy and work. Students have expressed difficulty in completing these diagrams, even after explicit direct instruction and peer instruction sessions. Students often have trouble identifying appropriate initial and final states of the system. In addition, students initially struggle to determine which types of energy are present in each state, and how each type has changed between the initial and final state. Many students will complete the LOL diagram but fail to use it to write the mathematical energy and work model. Students often revert to the generic energy and work model presented on their reference equation list. This path frequently leads to errors in the calculation of net external work. It is apparent that the LOL diagram method has value but requires refinement.

Compared to test items which assess force and motion concepts, I have found that students consistently earn unsatisfactory scores on items which assess energy and work concepts. Interactive explorations are lacking in the energy and work instructional model. Students initially (and often incorrectly) grasp onto force and motion approaches when an energy and work approach is more appropriate to analyze a scenario. The LOL diagram approach requires further refinement to serve as an analysis aid for students.

Purpose

The primary goal of this project is to develop, implement, and assess the effectiveness of interactive student explorations. This project will also evaluate the effectiveness of a refined energy diagramming approach. The deliberate selection of an appropriate model (force and motion or energy and work) to analyze a scenario is an essential student outcome.

Research Questions

- 1) Will incorporation of student-led energy and work physical modeling activities improve students' ability to identify energy changes in a system?
- 2) Will interactive physical modeling strategies improve students' appropriate selection of an energy and work approach or force and motion approach to solve a problem?
- 3) Does the incorporation of scaffolded approaches to energy and work instruction, such as pictorial system diagrams and energy bar graphs, improve students' abilities to identify the energy changes in a system?

CONCEPTUAL FRAMEWORK

The energy model is one of the most powerful tools to analyze the mechanics of natural phenomena. However, students often struggle to analyze simple mechanics problems using energy concepts. This review begins by presenting evidence and causes of student confusion related to energy. Next, selected misconceptions related to energy are examined. To conclude, the basis for two instructional strategies to aid development of energy concepts are presented. The first, energy bar graphs and system diagrams, scaffold student development of energy transformation and conservation. The second, interactive explorations, have been found to produce significantly greater learning gains compared to traditional physics instruction.

Student Difficulties in Understanding and Applying Energy Principles

Students frequently struggle to develop conceptual understandings of basic energy concepts. Singh and Rosengrant (2003) developed a research-based test that assessed momentum and energy concepts. The assessment was administered to thousands of introductory physics students. Student comprehension of energy concepts was found to be incomplete. In addition, students struggled to apply energy concepts to physical scenarios (Singh & Rosengrant, 2003). Student background knowledge about energy is muddled by everyday language and a variety of inconsistent energy perspectives presented in different disciplines (Quinn, 2014). Jewett (2008b) explained how use of casual language during instructional activities can lead to unintended student misconceptions. For example, the terms *heat* and *energy transfer* are often used inappropriately to describe energy transformations (Jewett, 2008b). Students are often reticent to analyze problems and phenomena using energy concepts (Swackhamer, 2008).

Perhaps this is due to their fragmented background knowledge and poor understanding of energy.

Duit (1981) found that students often associate the terms force and energy together, implying confusion about the differences between these terms. Herrmann-Abell and DeBoer (2014) reported test results that indicate student confusion between the force of gravity and gravitational potential energy. A longitudinal study performed by Summers & Kruger (1993) indicated confusion between potential energy and energy an object could possess at a future time. Misconceptions may be introduced by associating potential energy with the position of an object, instead of the configuration of a system of objects in a field (Jewett, 2008b).

Misconceptions about work done by an external force may originate from the rapid firing of skeletal muscles required to hold an object overhead (Feynman, et. al., 1966). The feeling of doing work is conveyed, however no work is done by forces in a static equilibrium scenario. Students also confuse the displacement of the center of mass of an object with the displacement that individual forces act through (Jewett, 2008a).

Students often confuse energy transformations involving internal energy as a loss or dissipation of energy (Swackhamer, 2008). Kesidou and Duit (1993) found that students had substantial deficits in differentiating between heat, internal energy, and temperature after four years of biweekly physics instruction. Jewett (2008b) cautions against casual use of the term heat in place of internal energy. Liu and McKeough (2005) examined student responses to energy items selected from the Third International Mathematics and Science Study database. Using Rasch modeling, they determined the

relative difficulty of the four basic energy concepts identified by Duit (1981; 2014). In order from most to least, items which assess energy conservation were the most difficult, followed by energy degradation items, energy transfer items, and types of energy items (Liu & McKeough, 2005).

Student misconceptions about energy may be the result of differing perspectives of the nature of energy. Feynman described energy as an abstract mathematical construct (Feynman, Leighton, & Sands, 1966). Feynman further remarked that energy has no physical analog, and that physicists of his time were unsure of the exact nature of energy (Feynman, et. al., 1966). Millar (2014) reports that “50 years on, this remains the case” (p. 190). Quinn notes that students often perceive energy as a thing, but physicists would describe it as a quantity which can be ascribed to things (2014). Duit (2014) identified the inclusion of substance-like qualities of energy in some energy curricula. Perception of energy as substance-like can lead to greater understanding of energy conservation (Duit, 2014). Swackhamer (2008) argues that energy is akin to a conserved substance that flows between systems.

Energy Diagrams as Instructional Scaffolding

Energy bar graphs and energy flow diagrams ascribe substance-like qualities to energy (Scherr, et. al., 2012). Energy bar graphs present energy as stacks of types of energy (Scherr, et. al., 2012). In bookkeeping fashion, a reduction in one stack must accompany an increase in another stack or a transfer of stacks (a *flow*) out of the system (Scherr, et. al., 2014). Feynman compares energy conservation to tracking the mass of toy blocks in a child’s house (Feynman, et. al., 1966). Seeley, Vokos, and Minstrell (2014)

encourage in-service teachers to manipulate cubes that represent arbitrary quantities of energy between white boarded system diagrams. Hertting (2016) describes the use of stacking blocks and wooden dowels as to physically model energy changes and energy bar graphs.

Duit (2014) and Quinn (2014) both advocate for an energy accounting-like approach when analyzing physical scenarios in terms of energy. An energy decrease must accompany an increase in another type of energy or an energy transfer to another system (Duit, 2014; Quinn, 2014). Several texts have counseled the use of diagrams to develop this concept. Swackhamer (2008) advocates for the use of energy flow diagrams to demonstrate energy transfers between systems. Boohan and Ogborn (1996a, 1996b) advocate for use of simple pictures accompanied with coded energy transformation and transfer diagrams to scaffold introductory energy instruction. Papadouris and Constantinou (2011) propose the use of simple pictures of stores of energy and energy transfer processes to track energy changes. The resulting diagrams may serve as a bridge to writing quantitative energy conservation equations (Papadouris & Constantinou, 2011).

Horner, Jeng, and Lindell (2007) compared correct responses on energy items on a final exam between three classes. One class drew horizontal energy bars to track energy changes in a system at an initial, mid-point, and final state. Instruction in this class was paired with physical manipulatives. One class drew vertical energy bar graphs to track types of energy present in a system in its initial and final states. A third class was taught using traditional methods. Students in the traditional group performed better on the

selected exam items, but students in the bar charts group showed better conceptual gains in correct application of conservation of energy (Horner, et. al., 2007).

Van Heuvelen and Zou (2001) analyzed the effect of pictorial system diagrams and energy bar graphs in introductory undergraduate physics courses. Students in the treatment group completed a four step conceptual approach to analyze energy scenarios: 1) verbal description, 2) diagramming, 3) physical modeling, and 4) mathematical modeling. Ninety-two percent of surveyed students found the technique helpful (Van Heuvelen & Zou, 2001). Van Heuvelen and Zou (2001) compared student explanations of the change in kinetic energy of two pucks acted on by the same force through the same displacement. Sixty percent of treatment group correctly explained results of this scenario, compared to twenty percent of non-treatment group (Van Heuvelen and Zou, 2001).

Interactive Engagement Methods to Improve Student Outcomes After Energy Instruction

Freedman (1996) observed that traditional instruction can lead to improved computational skills in energy problem-solving. However, traditional instruction often results in poor ability to explain or interpret physical scenarios in terms of energy concepts (Freedman, 1996). Quinn (2014) asserts that the concept of energy was derived through interactive exploration, not definition, and learners should actively engage in energy explorations to achieve comprehension. Multiple studies have reported unacceptable learning gains after traditional physics instruction. Duit (1981) found that a majority of students were unable to predict and explain simple physical phenomena using energy concepts after traditional energy instruction. Laws, Sokoloff, and Thornton

(1999), found significant improvement in physics learning gains when comparing traditional instruction to active learning kinematics activities. Hake (1998) performed a longitudinal study comparing normalized learning gains on standard physics concept assessments. Hake (1998) found that the average normalized gain scores of interactive engagement courses were twice that of traditional courses. Hake (1998) concluded that problem solving skills improve when concepts are emphasized.

Conclusion

Students hold misconceptions derived from informal use of energy vocabulary and disjointed perspectives presented in different contexts. Energy is an abstract mathematical construct with substance-like qualities, but no physical analog. Perhaps unfamiliarity with the nuances of this duality contributes to persistent student misconceptions. Accomplished physics educators advocate modeling mechanics scenarios as systems which have stores of energy. Emphasis on energy conservation during internal transformations and external transfers between systems is recommended. Pictorial system diagrams and energy bar charts diagrams have been demonstrated to improve student comprehension of these concepts. Interactive engagement methods have been shown to produce significantly greater learning gains than traditional instruction. The goal of this classroom research project is to compare student learning outcomes after these two interventions to outcomes after traditional energy instruction.

METHODOLOGY

This classroom research project investigated the effectiveness of energy and work instructional strategies in a high school introductory physics course. This section begins

by describing the participants and student demographics. Next, the interventions the treatment group will receive are discussed. This section concludes by describing data collection strategies to compare the effectiveness of the interventions to traditional instruction. The research methodology for this project received an exemption by Montana State University's Institutional Review Board, and compliance for working with human subjects was maintained (Appendix A).

Participants

This study spanned approximately five weeks beginning in late January of 2018. Approximately one hundred students in the second semester of an introductory physics course participated in this study. Students were in grades 10 – 12. This group was split into 4 sections of approximately 26 students each. Two of these sections contained sophomores. One of the sections with sophomores and one other section were taught using the instructional approach from the 2016-2017 school year (the non-treatment group). The remaining sections were taught using the approaches described in the following (the treatment group).

Intervention

The instructional approach of Van Heuvelen and Zou (2001) heavily influenced my classroom research project. Students in the treatment group completed pictorial system diagrams and energy bar graphs while modeling scenarios with manipulatives. Pictorial system representations were lacking in the energy instruction employed during the 2016-2017 school year. In addition, the organization of “LOL” diagrams (Figure 1) required improvement. The completed diagram shown in Figure 2 is organizationally and

conceptually improved. The analysis required to complete Figure 2 is consistent with the energy accounting approach advocated by Duit (2014) and Quinn (2014). The pictorial representation and scaffolded development of the mathematical energy conservation model are consistent with the recommendations of Papadouris and Constantinou (2011).

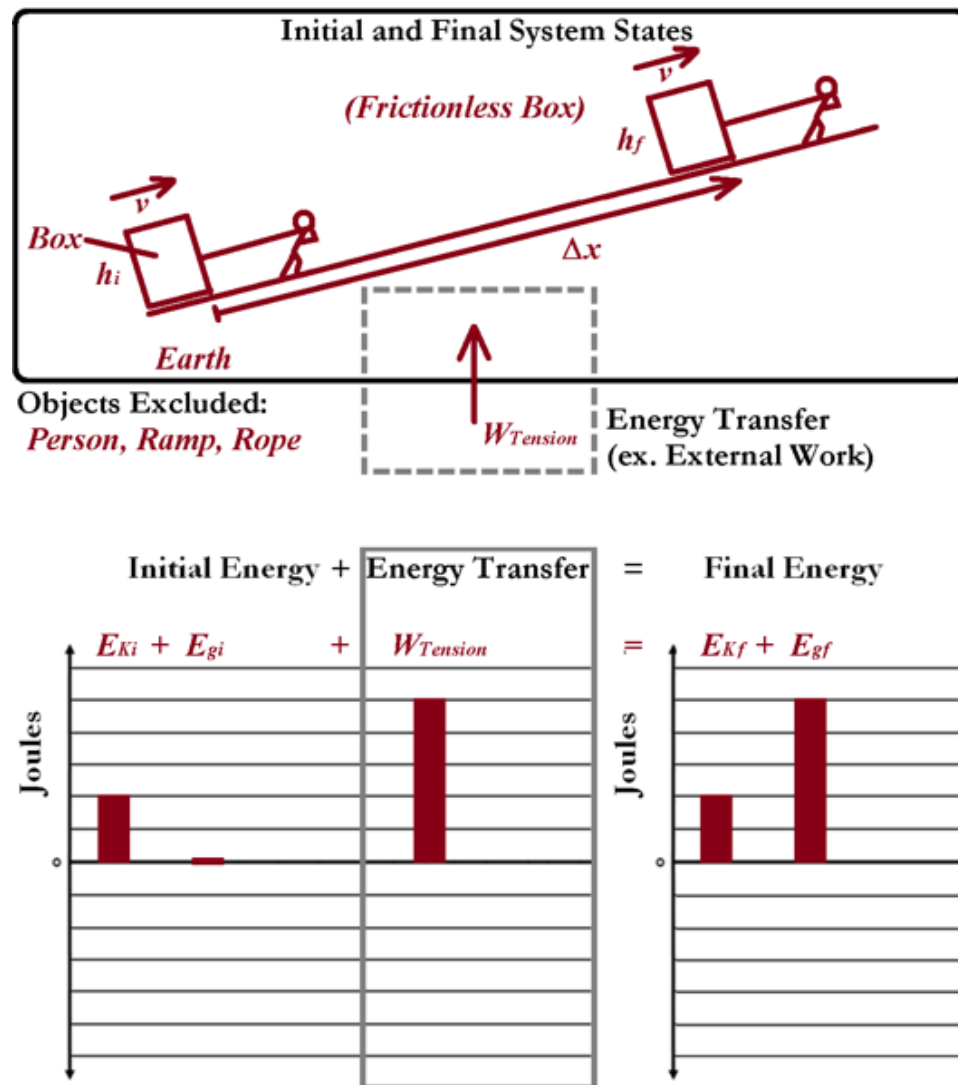


Figure 2. An original example of a pictorial system diagram and energy bar graph used as scaffolding to perform energy analyses.

Next I will present a summary of the progression of instructional activities administered to the treatment group. Students began by drawing system diagrams that matched scenario descriptions. Students then completed the bar graphs. As new types of energy were discussed, more terms were added to the bar graphs. The bar graphs guided students in writing a mathematical energy conservation model. Van Heuvelen and Zou (2001) had students use physical manipulatives while simultaneously completing system diagrams and energy bar graphs. I did the same. Students utilized their completed pictorial system diagrams and energy bar charts to predicted changes in motion and energy of a moving system. The *Vernier Dynamics Cart and Track System with Motion Encoder* was used to collect data to verify their predictions. Students analyzed and made predictions about several different scenarios involving different types of work and different energy transformations. These scenarios involved investigating the motion of the *Vernier Dynamics Cart on the Track System* after it was pushed by hand or pulled using a modified Atwoods machine setup. Later, the ramp was inclined to include changes in gravitational potential energy. Figure 3 depicts an example of one of the six different scenarios students analyzed. Students collected data using Vernier Logger Pro. Data analysis involved calculations of energy in the initial and final states of the system as well as mechanical work done on the system. Students identified energy transformations within a system as well as energy transfers due to mechanical work, then determined the accuracy of their predictions by writing and solving the energy conservation mathematical model.

Scenario: An IR Motion Encoder Cart, with friction pad, is pulled as shown. When the metal weight hits the floor, the cart slides to a stop.

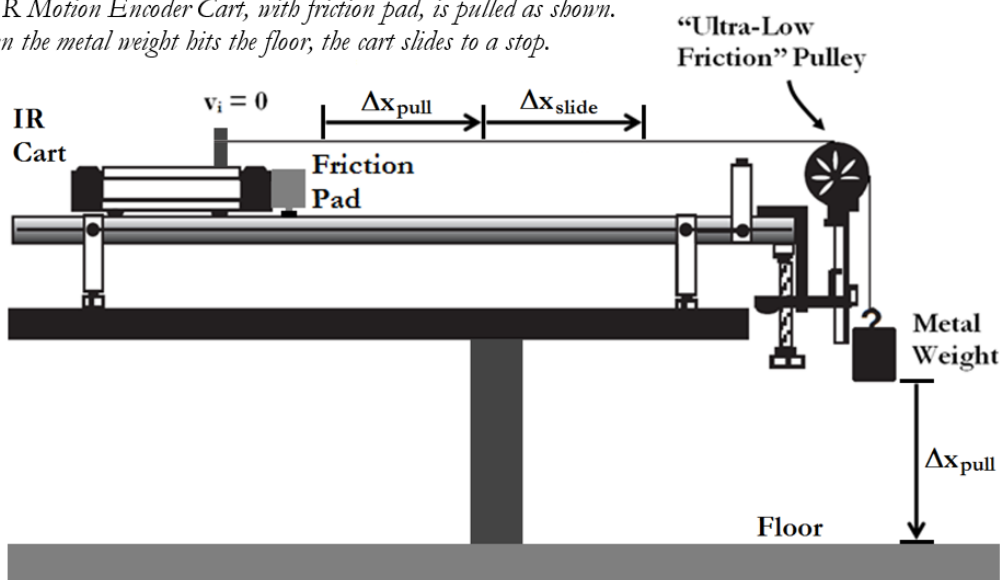


Figure 3. An example scenario analyzed by the General Physics students who received modified instruction. In this scenario, students were asked to predict the final position of the cart when given a starting position.

Data Collection

I administered a research-based energy and work assessment before and after instruction. Assessment items from the Energy Concept Assessment and Energy and Momentum Conceptual Survey were selected (Ding, et. al., 2007; Rosengrant & Singh, 2001). Hake (2001) demonstrated the use of normalized gain in conjunction with these types of assessments. I used Hake's normalized gain to measure learning gains.

In addition to the formal pre-treatment and post-treatment assessment, I triangulated results by conducting student interviews and administering a disposition survey composed primarily of Likert items. The interviewee population was comprised of students from the treatment and non-treatment groups. Observation notes and examples of student work were included as evidence in my determination of the effectiveness of the treatment. To assess students' ability to interpret and apply lab data using an energy and

work approach, two free response questions were administered. The first free response question was a traditional word problem. The second free response question was a lab interpretive question. This action research project began at the beginning of the second semester. Many students switch sections and teachers at the semester change over. As such, assessment data from prior units is not available for comparison. The methodology for this project has been approved by the MSU Institutional Review Board.

Table 1 *Triangulation Matrix*

TRIANGULATION MATRIX			
Focus Question: Will energy and work instruction focused on interactive student activities lead to better student understanding of energy and work compared to traditional instruction?			
Sub questions	Data Source		
Sub question 1: Will incorporation of student-led energy and work physical modeling activities improve students' ability to identify energy changes in a system?	Pre-Test	Examples of Student Work	Post-Test
Sub question 2: Will interactive physical modeling strategies improve students' appropriate selection of an energy and work approach or force and motion approach to solve a problem?	Pre-Test, Post-Test	Survey	Interviews
Sub question 3: Does the incorporation of scaffolded approaches to energy and work instruction, such as pictorial system diagrams and energy bar graphs, improve students' abilities to identify the energy changes in a system?	Pre-Test	Classroom Observation Notes	Post-Test

DATA AND ANALYSIS

The test results presented in the following is reported in four cohorts, representing each of the four sections of General Physics that participated in this study. “6th Hour” and “10th Hour” received the modified instruction and have been identified as the “Treatment Group”. “8th Hour” and “9th Hour” received traditional instruction and have been identified as the “Non-Treatment Group”. The four sections vary based on year in high school. I have taught 24 sections of General Physics at Arrowhead High School, 10 of which contained sophomores. I have observed consistently higher assessment scores in sections of General Physics which contain higher sophomore enrollment. Sophomores who enroll in General Physics are frequently on an accelerated academic track. The 10th Hour class is comprised of 25 students, 12 of which are sophomores. The 6th Hour and 8th Hour classes have no sophomores enrolled and are comprised of thirty students each. The 9th Hour class has 1 sophomore enrolled and is comprised of 24 students. My first research question asked if student-led energy lab activities influenced students’ ability to identify energy changes in a system. The data presented in the following suggests that variance in the cohort was more important than the modified instruction.

The pre-test and post-test multiple choice assessment focused on the relationship between choice of system, work, and energy changes. The assessment was comprised of fourteen research-validated multiple choice test items. The average pre-test score was 21.6% ($N = 103$). I observed no correlation between performance on prior course assessments and pre-test scores. The average score on the post-test was 42.7% ($N = 103$). The average pre-test and post-test multiple choice scores are shown in Figure 4. The

Treatment Group had slightly higher averages on the post-test (43.7% and 45.8%) than the Non-Treatment Group (41.2% and 42.0%). However, the Non-Treatment Group had slightly lower averages (20.0% and 20.8%) on the multiple choice pre-test than the Treatment Group (24.6% and 21.1%). Although all sections showed improved scores, the low post-test scores might indicate that the rigor of the assessment was not appropriate for an introductory physics course. This is likely the result of the limited selection of research-validated multiple-choice questions which assess energy concepts. The pre- and post-test items focused on identifying work and energy changes based on careful choice of the system. For example, several questions asked students to account for work done by the gravitational force when the earth is excluded from the system. Students often identify potential energy changes without considering which objects are in the system. Item analysis showed that students scored poorly on these questions.

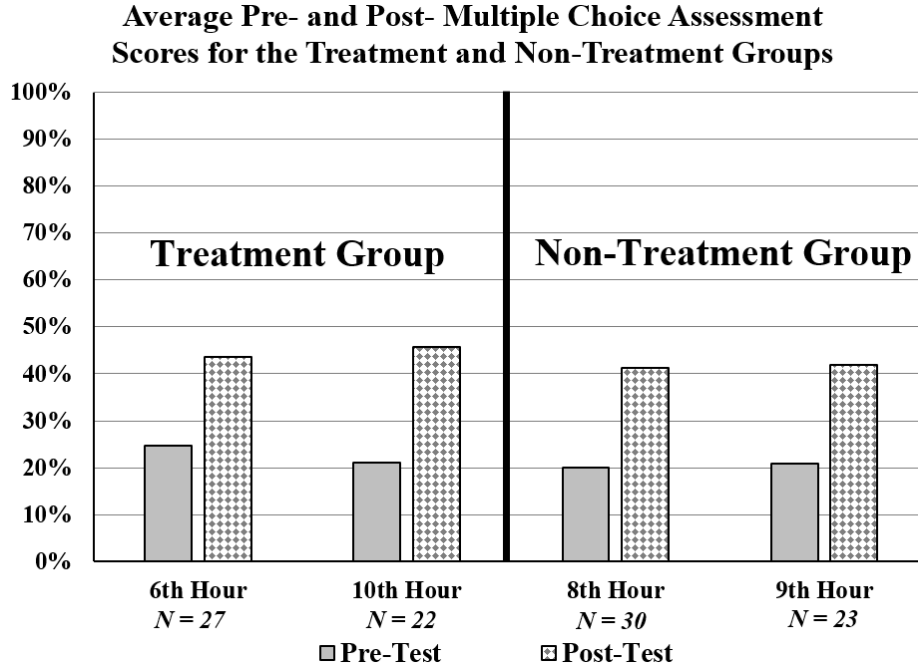


Figure 4. Average Pre- and Post-Multiple Choice assessment scores for the four cohorts.

Normalized gain was used to further interpret the multiple choice scores. The average normalized gain is summarized in Figure 5. The average normalized gain was highest for 10th Hour (0.313), lowest for 6th Hour (0.252), with 8th Hour and 9th Hour scores falling between these two (0.265 and 0.267 respectively). The normalized gain scores suggest that the differences in the post-test scores could be due to differences in cohort. The distribution of the post-test scores is summarized with box plots in Figure 6. The median post-test scores are very similar in the Treatment Group and Non-Treatment Group. The distribution of post-test scores is similar in three of the cohorts, where the median lies closer to the first quartile. The 8th Hour scores were distributed closer to the median than the other cohorts.

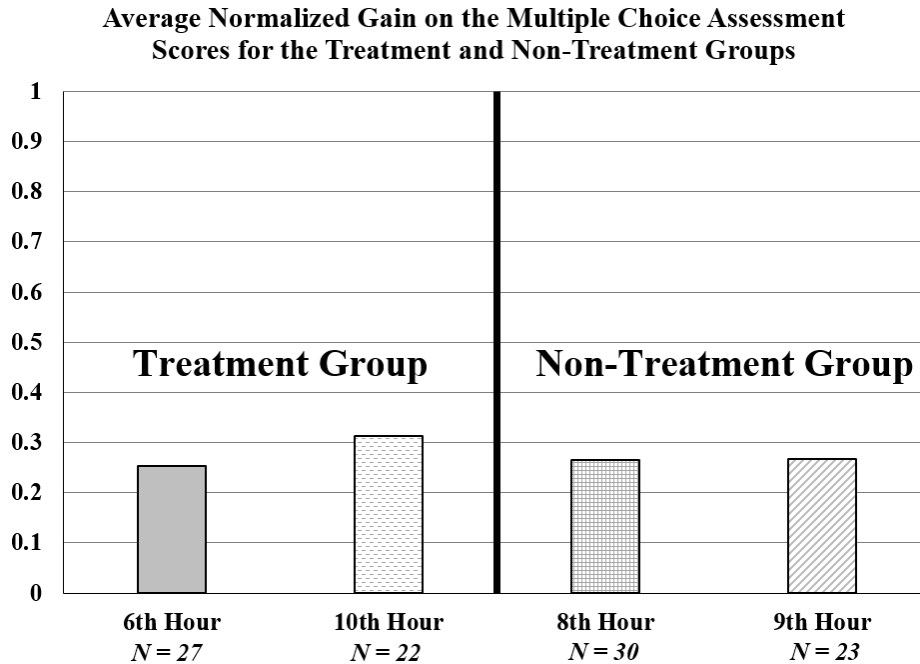


Figure 5. Average normalized gain shown on the Pre- and Post-Multiple Choice assessment scores for the four cohorts.

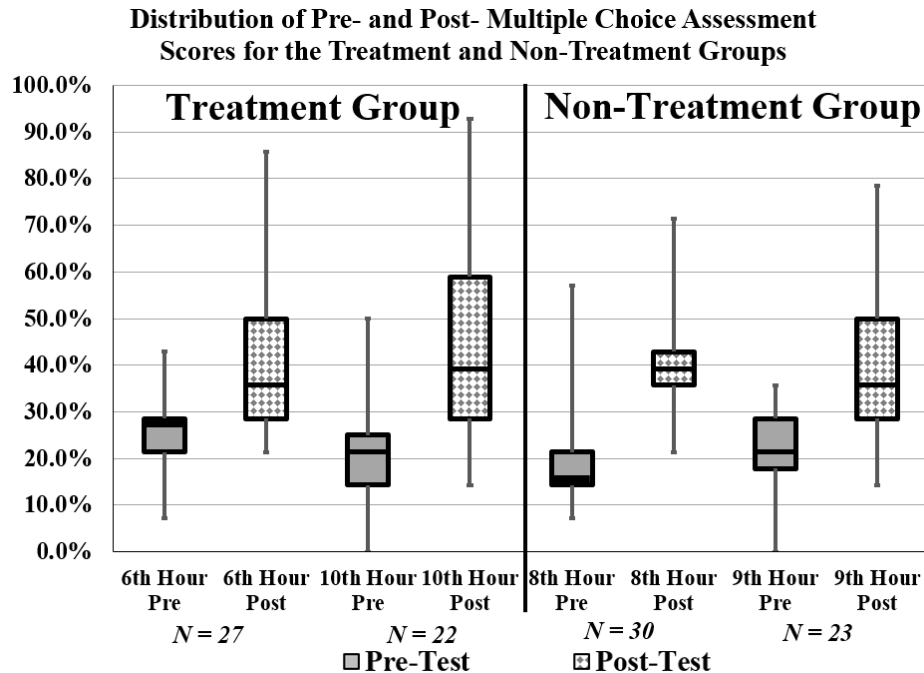


Figure 6. Distribution of Pre- and Post-Multiple Choice assessment scores for the four cohorts.

My second research question asked if student-led lab activities influenced students' appropriate selection of an energy approach to solve a problem. The pre- and post-test did not assess students' ability to interpret data collected in a lab setting and apply it using an energy approach. In addition, it did not assess students' mastery of solving problems using an energy approach. These learning outcomes were assessed on two multi-part free response questions. The free response questions can be found in Appendix B. The first free response question was a traditional word problem, and the second free response question was a lab interpretive question. Figure 7 shows the distribution of scores on the traditional free response question. The median scores for the Treatment Group (91.7% and 95.8%) and the Non-Treatment Group (95.8% and 94.8%) were very similar. Differences in these scores are likely the result of random chance or differences in cohort.

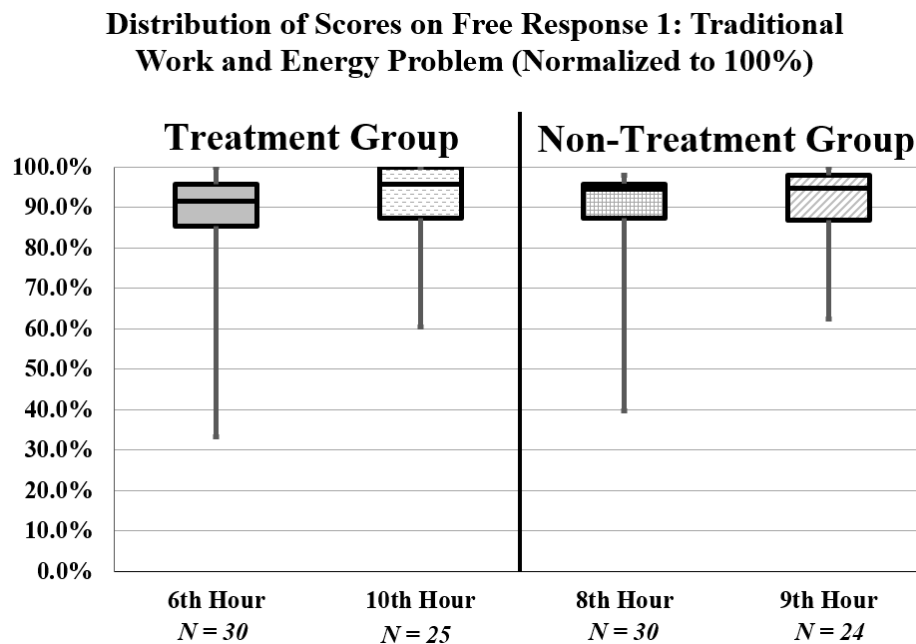


Figure 7. Distribution of the traditional word problem free response assessment scores for the four cohorts.

Figure 8 shows the distribution of scores on the lab interpretive free response question. The median scores for the Treatment Group (81.6% for both cohorts) were both higher and closer to the 3rd Quartile than the Non-Treatment Group (73.7% and 71.1%). In addition, the third quartile was higher for the Treatment Group (94.1% and 94.7%) than the Non-Treatment Group (89.5% and 84.9%).

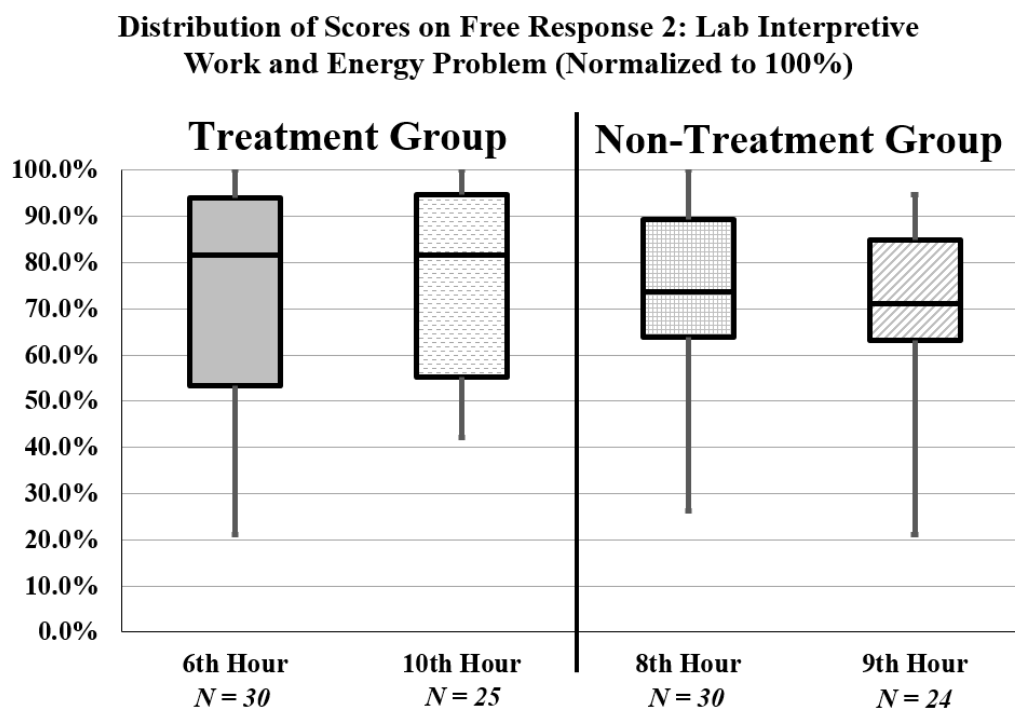


Figure 8. Distribution of the lab interpretive free response assessment scores for the four cohorts.

Based on the distribution of scores and the difference in medians, it appears unlikely that these differences are due to variances in cohort. Students who participated in the modified instruction appear to have better mastery of interpreting lab data and applying it to solve problems using an energy approach. Students in the Non-Treatment Group observed the teacher demonstrate the lab activities and interpreted data provided by the teacher. Concerning data interpretation and application to energy concepts, these

results suggest that this traditional approach may be less effective than the modified instructional approach. These results suggest that students in the Treatment Group were better able to identify energy changes and solve problems posed in a lab interpretive context. However, these results also suggest that the Treatment group performed no better than the Non-Treatment Group when answering traditional word problems.

The improved lab interpretive performance of the Treatment Group was observed during peer discussions. I observed rich peer discussions about the meaning of the data collected in terms of the energy present in the initial and final states of the system, as well as the work done between those states. When the Non-Treatment Group analyzed the teacher data, I did not observe those discussions with the same frequency. In addition, the Treatment Group submitted lab analyses which were more accurate and thorough on average than the Non-Treatment group. However, I observed very similar performance in both groups during traditional problem solving assignments and class activities. In addition, a traditional fifteen question multiple choice quiz was administered to the Treatment Group and Non-Treatment Group. The 6th Hour and 10th Hour cohorts had average scores of 76.9% ($N = 30$) and 80.8% ($N = 25$). The 8th Hour and 9th Hour cohorts had average scores of 74.2% ($N = 30$) and 74.5% ($N = 24$). Although the Treatment Group scored better on this assessment, it is likely that this difference is due to random chance and variances in cohort. My classroom observations support the conclusion that modified instruction improved student performance on lab interpretive questions. However, the modified instruction was not observed to have the aforementioned impacts when students were assessed in traditional contexts.

The disposition survey found in *Appendix C* was administered to students upon the completion of instruction. The survey questions can be summarized as assessing the following categories: choosing and energy and work approach, performing interactive investigations, and identifying work and energy changes. The survey questions were primarily Likert items with a four-point scale, ranging from 1 (Strongly Disagree) to 4 (Strongly Agree). The survey consisted of 10 questions, 9 of which were Likert items. Ninety-seven students completed the survey. These questions targeted student disposition concerning details of my three research questions.

Survey results pertinent to my second research question, which addresses appropriately choosing and applying an energy approach, are shown in Figure 9. The responses indicate that student disposition towards applying an energy approach was likely not significantly different for the Treatment Group and the Non-Treatment Group. The first survey item shown in *Figure 9* asked students about their confidence in appropriately selecting an energy approach. The proportion of students who agreed or strongly agreed was slightly higher in the Non-Treatment Group (85%, $N = 52$) than the Treatment Group (80%, $N = 45$). It is interesting that these differences are the opposite of the difference observed on assessment scores. Students may have interpreted this question as confidence in solving traditional word problems. The Non-Treatment Group spent more instructional time solving traditional word problems than the Treatment Group. My third research question asked if energy bar charts and system diagrams improve students' ability to identify energy changes. The second survey item shown in *Figure 9* is pertinent to this research question. The proportion of students who agreed or

strongly agreed was identical in the Non-Treatment Group (77%, $N = 52$) and the Treatment Group (77%, $N = 45$). The responses from this survey item indicate that students find bar charting helpful. But there is likely not a significant difference between completing LOL diagrams versus the energy bar charts proposed by Van Heuvelen and Zou (2001).

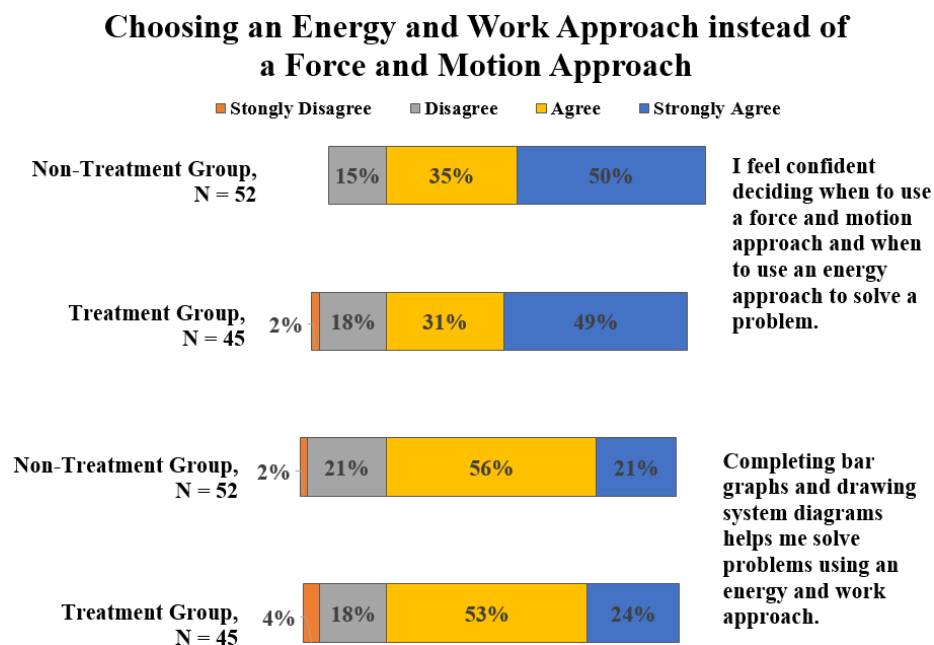


Figure 9. Survey responses for questions which measure student disposition related to using an energy and work approach to solve a problem.

Another survey item pertaining to my second research question (choosing and applying an energy and work approach) asked students about their preference for conducting student-led investigations versus analyzing teacher-led investigations. A summary of responses for this question is shown in Figure 10. The results of this question are inconclusive. These results have been disaggregated by cohort, since the difference between the two cohorts in both the Treatment Group and Non-Treatment Group was significant. Among the Treatment Group, the proportion of students who preferred

student-led investigations was 24% in 6th Hour ($N = 25$) compared to 65% in 10th Hour ($N = 20$). These differences could be attributed to the difference in composition of the cohorts. It is possible that a group with a higher proportion of accelerated students were more comfortable during the student-led investigations. Among the Non-Treatment Group, the proportion of students who preferred analyzing teacher-led investigations was 57% in 8th Hour ($N = 30$) compared to 86% in 9th Hour ($N = 22$). Since the Non-Treatment group did not conduct the student-led investigations, this question effectively assesses their preference for traditional instruction techniques. This difference may be attributable to random chance.

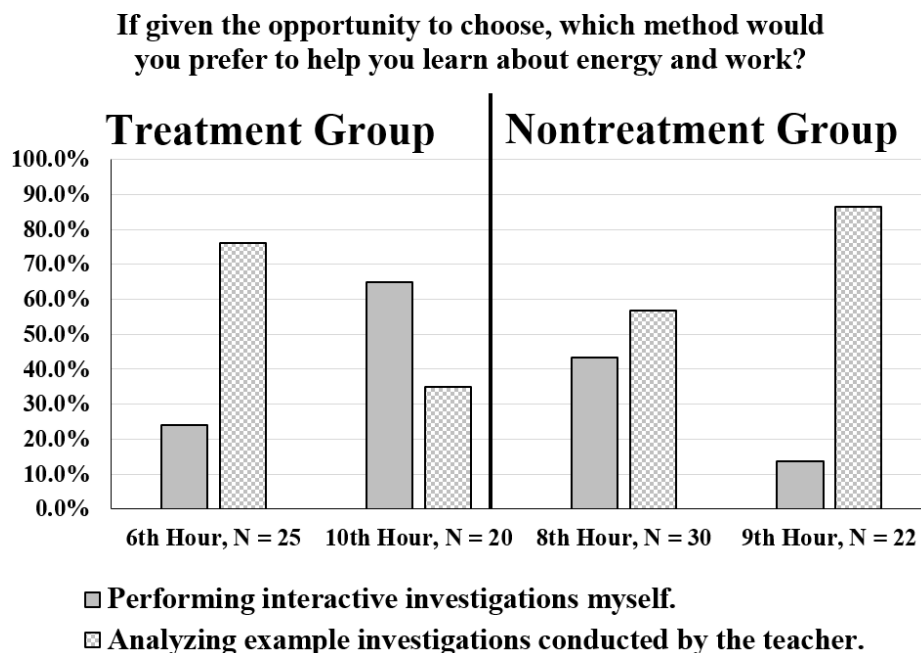


Figure 10. Survey responses which measure student preference for student-led energy and work investigations compared to teacher-led “demonstration” investigations.

The survey items presented in *Figure 11* summarize student learning preferences pertinent to my first research question, which addressed the effectiveness of student-led lab activities. These results indicate no conclusive student preference for teacher-led

activities or student-led activities. The first three items addressed student preference for teacher-led activities. For these three items, students in all cohorts indicated a majority preference for observing teacher-led activities. However, the fourth item shown in Figure 11 addressed student preference for conducting student-led investigations. Both the Treatment and Non-Treatment groups indicated preference for conducting student-led investigations. These results may indicate that students are most comfortable with a balanced approach between traditional instruction and the modified instruction.

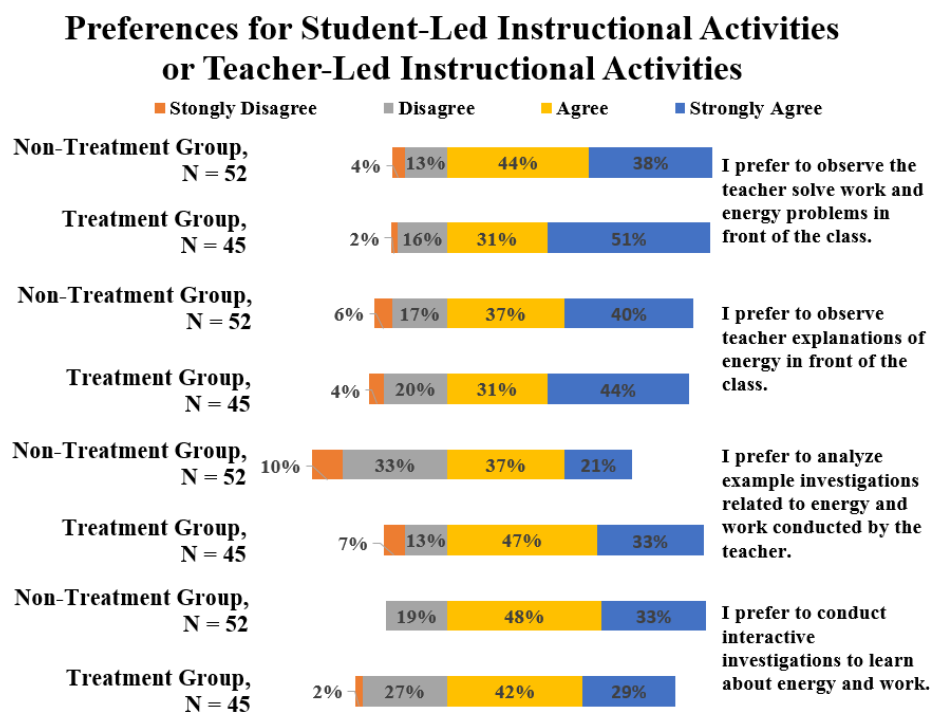


Figure 11. Survey responses which measure student preference for student-led energy and work instructional activities compared to teacher-led instructional activities.

The survey items presented in Figure 12 are pertinent to my third research question, which addressed the effectiveness of energy bar charts in helping students identify energy changes. These results indicate a slightly greater preference for the Non-Treatment Group, which completed the LOL diagrams. The proportion of students who

agreed or strongly agreed that completing bar charts was helpful was very high in the Non-Treatment Group (92%, $N = 52$). The majority of the Treatment Group also found the energy bar charts helpful, although the majority was not as large (77%, $N = 45$). The proportion of students who agreed that they could identify energy changes in a system was identical in both Treatment and Non-Treatment groups (73%). The responses from these survey items suggest that energy bar charting is a worthwhile activity for introductory physics students.

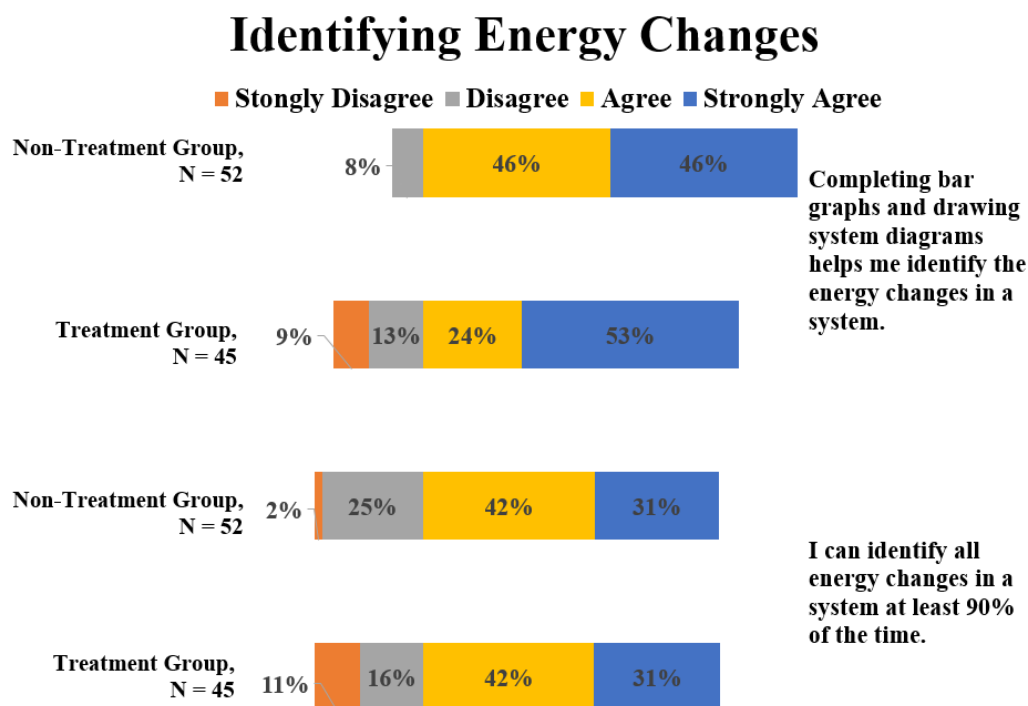


Figure 12. Survey responses which measure student confidence in identifying energy changes and student disposition towards the scaffolded approaches used to identify energy changes.

Student interviews were conducted after the post-test. Interview questions can be found in Appendix D. Interviewees were selected from both the Treatment Group and Non-Treatment Group. In regards to the first research question (addressing student-led investigations and identifying energy changes), a 10th Hour student was asked how the

energy and work investigations might be improved. This student indicated that “The setup is good because of the introductory discussion, followed by lab work, and ending in the debrief.” This student also thought that “The independence is good, but you need to ensure that everyone has reached an understanding of the activity upon conclusion.”

A 6th Hour student asked the same question indicated that “In my opinion, the concepts presented in the labs we did were explained as best as possible.” This student thought that “It’s easier for me to make connections and come to new understandings when I perform the investigations myself. I felt it stimulated me to learn the material actively.” A 9th

Hour student was asked about how the teacher-led energy and work investigations might be changed. This student thought that “...More student questions and class discussion would be helpful. Sample calculations or notes would be helpful.” This same student remarked that “I would prefer if the teacher conducts the investigation and I analyze the data. I think there is too much potential for confusion if students did the investigations themselves.” When asked about how they determine the types of energy present in the initial and final states of a system, interviewees reported similar mental processes.

Interviewees reported that they connect motion variables such as velocity and height to kinetic energy and potential energy.

Interviewees were also asked questions concerning the second research question (investigating participation in energy investigations and ability to appropriately select an energy approach). One question asked interviewees about their confidence in appropriately selecting an energy and work approach versus a force and motion approach. A 6th Hour student remarked that “It has changed from really having no idea of how to

apply work and energy to feeling quite confident in using it. The lab activities improved my confidence incrementally.” A 9th Hour student felt that “Doing problems helped me build confidence in my ability to apply a work and energy approach.” Interviewees were also asked how they might decide to use a force and motion approach or an energy and work approach when solving a problem. A 6th Hour student indicated that they would look for the givens in the problem for guidance, but was unsure how those givens might translate to a choice of one approach over the other. Another 6th Hour student and a 10th Hour student both indicated that they would assess the problem’s emphasis on displacement-based changes (as opposed to time-based changes). A 9th Hour student felt that the givens would help them select the approach, with emphasis on forces suggesting a force and motion approach is more appropriate. Another 9th Hour student felt that more descriptive word problems suggest that a work and energy approach is more appropriate.

Concerning the third research question (using system diagrams and energy bar charts to identify energy changes), interviewees were asked how the bar charts were helpful and how they might be improved. An interviewee from 6th Hour and an interviewee from 9th Hour reported that the bar charts helped identify the initial and final energy states of the system. Another 6th Hour student and a 10th hour student felt that the energy bar charts helped them methodically develop the mathematical conservation of energy model. The 6th Hour student remarked “They helped me develop the mathematical model necessary. I had the most difficulty setting up the bar charts properly, for example, failing to identify a type of work involved. If I got the bar charts correct, they really helped show the relationship between work and energy changes.” Interviewees in both

the Treatment Group and Non-Treatment Group felt that the energy bar charts were good how they are. One interviewee suggested that "...it's about making sure the students understand particular work and energy components prior to creating the bar charts. Familiarity with applicable situations for each type of work/energy is required to fill in the bar charts."

INTERPRETATION AND CONCLUSION

This classroom research project compared the effectiveness of two different instructional methods in improving students' understanding of energy and work concepts. An instructional method similar to that employed by Van Heuvelen and Zou (2001) was compared to a traditional teacher-led approach. The modified instruction was distinguished by a focus on student-led energy and work explorations involving physical manipulatives. Both methods employed energy bar charts to analyze energy changes in a system, although the format of the energy bar charts differed between LOL Diagrams (see Figure 1) and bar charts similar to those presented by Van Heuvelen and Zou (2001).

My first research question asked if students' ability to identify energy changes differed when they conducted energy investigations involving physical modeling. Concerning this question, the results from a pre- and post-test, disposition survey, and student interviews suggested that variance in cohort was likely more important than instructional method. Of note, all cohorts showed similar improvement and/or scores on the pre- and post-test. Student disposition surveys indicated a preference for teacher-led energy investigations in three out of four cohorts. Furthermore, student disposition surveys suggested no significant difference in student confidence in appropriately

selecting an energy approach. Student interviewees from the Treatment Group and Non-Treatment Group communicated similar mental processes to identify energy changes in a system.

Duit (1981) reported that traditional instruction yielded unacceptable gains in students' ability to explain physical phenomena using energy concepts. The results of the lab interpretive free response, which suggested slightly better mastery obtained by the treatment group, would appear to be congruent with Duit's findings (1981). Quinn (2014) advocated for interactive investigations to learn about energy. Laws, Sokoloff, and Thornton (1999), reported significantly better learning gains when comparing an active learning approach to traditional instruction. Hake's (1998) longitudinal study found significantly improved normalized learning gains for students enrolled in interactive engagement courses versus traditional courses. Other than the slightly better performance on the lab interpretive free response, the assessment results and survey data of the Treatment Group and Non-Treatment were not in agreement with these findings.

My second research question asked whether students were more likely to appropriately select an energy approach to solve problems when they participate in energy investigations involving physical modeling. Concerning this question, the traditional free response assessment, disposition survey, observation notes, and student interviews suggested that variance in cohort was likely more important than instructional method. Of note, all cohorts earned similar scores on the traditional free response assessments. Freedman (1996) noted that traditional instruction can lead to an improvement in computational problem solving. The results of the traditional free

response assessment appear to be congruent with this assertion. In all cohorts, the majority of students surveyed indicated confidence in selecting and applying energy approaches to solve problems. Student interviewees in both the Treatment Group and Non-Treatment Group reported that the instructional activities increased their confidence in correctly applying an energy approach. I observed that the frequency of students errantly selecting a force and motion approach instead of an energy approach was likely due to variance in cohorts. However, I did note that students were better able to select and apply an appropriate energy approach in the context of a lab interpretive assessment.

My third research question asked whether the use of pictorial system diagrams and energy bar charts improve students' abilities to identify energy changes in a system. Similar to Van Heuvelen and Zou (2001), a large majority of students in the Treatment Group found system diagrams and energy bar charts helpful. Both the Treatment Group and Non-Treatment Group reported that the energy bar charts were helpful. These findings are similar to those of Horner, Jeng, Lindell (2007), who reported better conceptual gains when students drew energy bar charts. However, disposition surveys, student interviews, and observation notes suggested that there was no benefit to the pictorial system diagrams accompanied with bar charts versus energy bar charts alone (LOL diagrams). Papadouris and Constantinou (2011) advocated for the use of pictorial diagrams to aid in the development of the mathematical conservation of energy model. However, a larger majority of students surveyed in the Non-Treatment Group felt that the energy bar charts were helpful in identifying energy changes. My classroom observations were that the pictorial diagrams likely did not help students identify the initial and final

system states better than energy bar charts alone. Student interviewees from the Treatment Group and the Non-Treatment Group both indicated that the diagramming and bar charting activities they completed were appropriate and helpful.

VALUE

Student engagement is a vital component of instruction. In this classroom research project, the scope and sequence of the modified instruction was nearly identical to that of the traditional instruction. However, I observed that students in the Treatment Group were more likely to be on-task and engaged in instructional activities than the Non-Treatment Group. The results of this project suggest that when students conduct interactive energy investigations, they likely demonstrate better learning gains in lab interpretive contexts. No sacrifices on traditional assessment performance were evident in the Treatment Group. In light of this, the gains of the Treatment Group may be viewed with greater significance. Students in the Treatment Group spent far less time practicing word problems with the teacher, yet were able to achieve the same learning gains on traditional assessments as students who participated in traditional instruction. In addition, students planned and conducted energy investigations with the teacher as a guide. These investigations allowed students to observe data collection live as energy changes occurred, and the motions investigated were easy to repeat. The graphs collected during motion were a powerful visual aid to learn about energy changes. The lab activities and visual aids served as an effective instructional tool during student-student discussions and teacher-student discussions. I observed students pointing to locations of the Vernier IR Encoder Carts and identifying energy changes. More peer discussions

were observed when students completed the interactive investigations compared to traditional problem-solving activities. In addition, more opportunities arose to address individual student misconceptions and difficulties than during traditional instruction. The added mastery of lab interpretive skills, as well as more frequent formative assessment opportunities, may hold merit for some teachers.

Students who completed the interactive investigations also indicated more apprehension on disposition surveys and during my class observations. Several students communicated that they found the activities both helpful and a welcome change of pace, but they would have been more comfortable if they were more familiar with energy concepts. During this study, it was apparent that deliberate front-loading activities could potentially improve student confidence during the lab investigations. As such, I expect that students will conduct energy investigations in future sections of General Physics, but in a format that includes more teacher-led front-loading activities.

I believe teacher-led front-loading activities to be appropriate in the context of energy and work. Feynman noted that energy is a conserved quantity, yet also a mathematical contrivance (1966). As such, I think it is difficult for students to "discover" energy in a manner similar to their "discovery" of Newton's Laws and their relationship to observed motion. However, students can explore energy concepts in a lab interpretive setting and gain meaningful understandings.

The energy bar charts adapted from Van Heuvelen and Zou are an improvement over the LOL diagrams. They are easier to translate to mathematical conservation of energy statements. They also more clearly show energy changes due to external work

than the LOL diagrams. Although not evident in the results of this project, I observed that students who completed the LOL diagrams initially had more difficulty writing mathematical work and energy statements. Students who completed the LOL diagrams exhibited less confidence in correctly identify changes in energy due to mechanical work. The energy bar charts adapted from Van Heuvelen and Zou add “positive or negative” bars of work to account for energy changes. This was simpler for students to comprehend and translate to the mathematical conservation of energy model.

Drawing system diagrams yielded diminishing returns as the energy and work unit continued. Initially, this step in the analysis process was useful while students’ notions of energy and work were still fluid. The diagrams helped students become familiar with the concept of identifying energy stores present in the initial and final states of the system. It also helped students become more familiar with diagrams of scenarios shown on investigations and assessments. It may be appropriate to reduce or eliminate the emphasis on this step as students become more familiar with energy and work concepts.

This classroom research project helped me to identify how to assess the effectiveness of instructional methods from a less biased perspective. In terms of student performance on assessments, I think it’s easy for teachers to think “We covered that.” when students perform poorly on a particular test item. However, this project illuminated how instructional approaches can affect student performance on particular test items. It calls into question the fairness of some test items in light of the instructional approach students received. Given the amount of time spent developing this project, my bias was that the modified instruction was superior to instruction students received in prior years

of General Physics. However, the data suggested only slight differences in student performance. The data analysis helped me separate my feelings of excitement of teaching a concept in a new way from actual measurable student success.

I also found it beneficial to find the solution to a classroom problem in a methodical way. This project encouraged me to consider new, creative, and pragmatic ways to use the resources available in my classroom. The Arrowhead High School Physics Department purchased the Vernier Motion Encoder tracks several years ago. Yet this equipment was rarely used in the General Physics class. Although expensive, these tracks yielded precise and convenient data collection for students. The apparatus was simple for students to use. I was also able to consider how alternative instructional approaches can result in more student time on-task. My literature reviewed illuminated areas of student misconception that I hadn't considered. It also resulted in me finding new ways to present a concept that I would not have found in traditional physics texts. Prior to this project, I had never considered how I might modify the LOL diagrams to a format that was easier for students to translate. This project helped me develop instructional activities that are more engaging and resources that are simpler for students to interpret.

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APPENDICES

APPENDIX A
INSTITUTIONAL REVIEW BOARD EXEMPTION



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MEMORANDUM

TO: Chad Tschanz and Eric Brunzell
FROM: Mark Quinn *Mark Quinn*
Chair, Institutional Review Board for the Protection of Human Subjects
DATE: November 6, 2017
RE: "Energy and Work Instructional Strategies in General Physics" [CT110617-EX]

The above research, described in your submission of November 6, 2017, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- X (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- X (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.
- _____ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
- _____ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
- _____ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
- _____ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

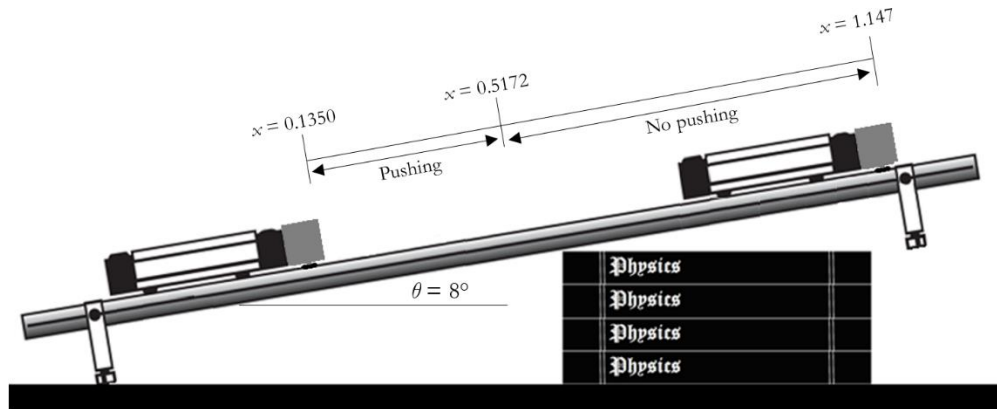
APPENDIX B
FREE RESPONSE QUESTIONS

FREE RESPONSE QUESTION 1: TRADITIONAL WORD PROBLEM

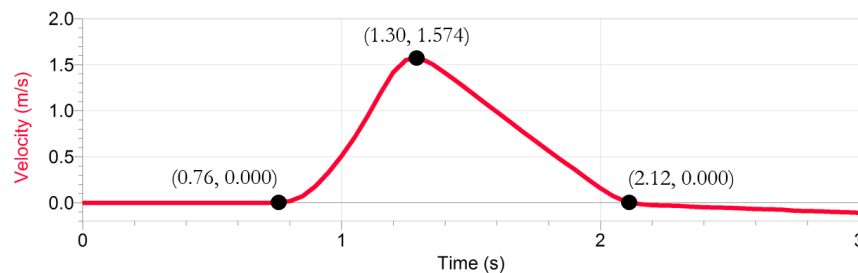
An object with mass $m = 7.0$ kg is sitting on a rough surface at rest. A string attached to the object pulls it with a constant tension force of 50 N directed at 22° above the horizontal. As it moves, a 34 N kinetic friction force opposes the motion as it moves along the surface through 15 m.

- a. Draw a diagram (not an energy diagram) of the initial state of the system in this situation. Include all of the given or implied information.
- b. Draw an energy diagram of the situation. Be sure to label all of the “bars” you include in the diagram.
- c. Calculate the work done by the tension force during the 15 m displacement.
- d. Calculate the work done by the friction force during the 15 meters.
- e. Calculate the final velocity of the object after the 15 meters

FREE RESPONSE QUESTION 2: LAB INTERPRETIVE



The above diagram shows the situation in this question and also gives some important data. A cart with a friction pad is at rest on an angled dynamics track. It is given a push over the interval labeled in the diagram, at which point the pushing stops. The cart travels up the track over the interval labeled in the diagram, and momentarily comes to a stop at the maximum position shown. The following velocity vs. time data was collected:



- a. For each time interval listed below, list all of the forces acting on the cart, and then indicate whether that force is doing positive, negative, or zero work. It's possible that there will be some empty rows.

From $t = 0.76$ s to $t = 1.30$ s	
Force	Work (+, -, 0)

From $t = 1.30$ s to $t = 2.12$ s	
Force	Work (+, -, 0)

- b. If we assign a height of 0 to the point where the pushing stopped, to what height did the cart rise before it came to a stop? Use the given information.
- c. Consider the interval from $t = 1.30$ s to $t = 2.12$ s. Write a mechanical energy statement that describes the initial and final energy of the cart-Earth system, and that also includes any work done by external forces. Put a box around any of the energy terms that would be **equal to zero**.

- d. Use your statement and the given information to calculate the magnitude of the frictional force acting between the cart and the track.

APPENDIX C
STUDENT SURVEY

General Physics Energy and Work Survey

Participation in this research is voluntary and participation or non-participation will not affect a student's grade or standing in any way. This survey is anonymous, optional, and has no impact whatsoever on your grade.

1. What hour are you in?

Mark only one oval.

- ☐ Tschanz Hour 3
- ☐ Tschanz Hour 6
- ☐ Tschanz Hour 9
- ☐ Tschanz Hour 10

2. I feel confident deciding when to use a force and motion approach and when to use an energy approach to solve a problem.

Mark only one oval.

	1	2	3	4	
Strongly Disagree	☐	☐	☐	☐	Strongly Agree

3. I prefer to conduct interactive investigations to learn about energy and work.

Mark only one oval.

	1	2	3	4	
Strongly Disagree	☐	☐	☐	☐	Strongly Agree

4. I prefer to analyze example investigations related to energy and work conducted by the teacher.

Mark only one oval.

	1	2	3	4	
Strongly Disagree	☐	☐	☐	☐	Strongly Agree

5. If given the opportunity to choose, which method would you prefer to help you learn about energy and work?

Mark only one oval.

- ☐ Analyzing example investigations conducted by the teacher.
- ☐ Performing interactive investigations myself.

10/21/2017

General Physics Energy and Work Survey

6. I prefer to observe teacher explanations of energy in front of the class.*Mark only one oval.*

	1	2	3	4	
Strongly Disagree	☐	☐	☐	☐	Strongly Agree

7. I prefer to observe the teacher solve work and energy problems in front of the class.*Mark only one oval.*

	1	2	3	4	
Strongly Disagree	☐	☐	☐	☐	Strongly Agree

8. I can identify all energy changes in a system at least 90% of the time.*Mark only one oval.*

	1	2	3	4	
Strongly Disagree	☐	☐	☐	☐	Strongly Agree

9. Completing bar graphs and drawing system diagrams helps me identify the energy changes in a system.*Mark only one oval.*

	1	2	3	4	
Strongly Disagree	☐	☐	☐	☐	Strongly Agree

10. Completing bar graphs and drawing system diagrams helps me solve problems using an energy and work approach.*Mark only one oval.*

	1	2	3	4	
Strongly Disagree	☐	☐	☐	☐	Strongly Agree

11. Completing bar graphs and drawing system diagrams helps me better understand the concepts of energy and work.*Mark only one oval.*

	1	2	3	4	
Strongly Disagree	☐	☐	☐	☐	Strongly Agree

APPENDIX D
STUDENT INTERVIEW QUESTIONS

- 1) Describe your experiences and feelings conducting the investigations related to energy and work. In what ways were the investigations helpful?
- 2) How might you change the energy and work investigations helpful?
- 3) If given the option, which do you think would be better: conducting the investigations yourself or analyzing data from a teacher conducted investigation? Please justify your choice.
- 4) In which ways were the energy bar charts and system diagrams helpful?
- 5) How might you improve the energy bar charts and system diagrams?
- 6) Discuss the process you use to identify the types or stores of energy present in a system in its initial and final state, as well as the work done on the system.
- 7) When solving a word problem, how would you decide whether to use a force and motion approach versus a work and energy approach?
- 8) How has your confidence in selecting an appropriate approach changed as a result of our studies of work and energy?