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A Graduate Education Course for Elementary School Teachers: Fostering Knowledge of Science and the Engineering Design Process

Augusto Z. Macalalag Jr.
Arcadia University

Karen Parker

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A Graduate Education Course for Elementary School Teachers: Fostering Knowledge of Science and the Engineering Design Process

Augusto Z. Macalalag, Jr.
Karen Parker

Abstract: This study provides insights to the successes and challenges of elementary school teachers as they refined their knowledge of specific physical science concepts and notions of the engineering design process. Our analysis of pre- and post-tests suggested that teachers significantly improved their knowledge after attending a graduate STEM education course.

***About the Authors**: Dr. Augusto Z. Macalalag, Jr. is an Assistant Professor of Science, Technology, Engineering, and Mathematics (STEM) Education. He led the development of the STEM Education Graduate Certificate program at Arcadia University that includes five graduate courses with environmental education field studies in Philadelphia, PA and Sicily, Italy. Dr. Macalalag teaches courses in the STEM program for practicing teachers and undergraduate and graduate science methods courses to prospective teachers.*

Karen F. Parker is a teacher of chemistry and physics at Spring-Ford High School and Chair of the Science Department. Prior to becoming a teacher, Mrs. Parker worked as an Editor's Assistant for the Journal of Agricultural and Food Chemistry and as a Research Assistant at the California Institute of Technology.

Introduction

Current reforms in Science, Technology, Engineering, and Mathematics (STEM) education require teachers to improve their knowledge of science and their ability to teach through science inquiry and the engineering design process (National Research Council [NRC], 2012; Duschl & Bismack, 2016). Teachers in the classroom have the ability to create and mold the environment in which students can effectively learn. Specifically, teachers' disciplinary content knowledge influences the learning environment, student interactions and student learning (Gess-Newsome & Lederman, 1995; Hill, Rowan & Ball, 2005; Berry, Friedrichsen & Loughran, 2015).

However, elementary school teachers held alternative conceptions that mirrored those of their students including the notions that engineers install wiring, repair cars, and drive machines. The teachers' attitude towards implementing engineering curricula was not as positive compared to their attitude towards science (Lachapelle et al., 2014). Moreover, the years of teaching experience did not contribute to the teachers' familiarity and perception toward teaching design, engineering, and technology (Hsu, Purzer & Cardella, 2011).

To address these challenges, Dr. Augusto Z. Macalalag, Jr. developed and taught a 3-credit graduate course, *Introduction to STEM Education,* to enhance teachers' content knowledge in science and the engineering design process (EDP). The course was also designed to support teachers' positive attitudes towards using engineering curricula and to help them implement the EDP in their classrooms. In this article, we present the instructional methods and assessments that Dr. Macalalag imbedded in the course to describe changes in elementary school teachers' content knowledge in physical science (motion, force, and energy), scientific models, and the EDP after attending the course. The following question guided our research and analyses of pre- and post-tests that we administered on the first and last day of the course: *Does the course, Introduction to STEM Education, enhance teachers' knowledge in science and the engineering design process?*

Literature Review

Recent developments in STEM education advocate for teaching that emphasize the development of scientific knowledge through engagement in science inquiry and the EDP (Duschl & Bismack, 2016). This new perspective on science teaching emphasizes the integration of STEM disciplines and knowledge building through iterative inquiry or problem solving as well as evidence-based modeling and argumentation (Stewart, Cartier & Passmore, 2005; Committee on K-12 Engineering Education, 2009). The NRC's *Framework for K-12 Science Education* (2012) provided three dimensions to guide the integrative STEM approach to teaching: (a) incorporating scientific and engineering practices, (b) promoting cross-cutting concepts (i.e. patterns, system models, etc.), and (c) enhancing disciplinary core ideas (physical sciences, life sciences, etc.).

However, incorporating these pedagogical practices is challenging, particularly for teachers with limited content knowledge or learning experiences in this domain. Teachers tend to hold to their inherent beliefs about teaching (i.e. didactic, procedural, and transmissionist approaches) but to some extent were successful in adapting new ways of pedagogy after attending a methods course (Hayes, 2002; Martin et al., 2015). Moreover, teachers need to conceptualize and develop their pedagogical content knowledge toward STEM teaching (Berry, Friedrichsen & Loughran, 2015).

Several professional development programs and university courses found successes and challenges in supporting teachers to develop their knowledge in science and the EDP. For instance, elementary teachers improved their notion about engineering and their attitudes toward teaching EDP after attending professional development in using the Engineering is Elementary (www.eie.org) curricula (Lachapelle et al., 2014). In another study, Lorreto-Perdue et al. (2015) found that by engaging elementary teachers in the EDP and by explicitly asking them to conduct failure analysis contributed to growing comfort of teachers with using fail or failure words in the context of the design improvement and creating a classroom culture that encourages failure analysis and discussions.

On the other hand, teachers new to incorporating the EDP in their classrooms often struggled to maintain their focus on the big idea (physics concepts) of the lesson. They tended to provide emphasis on skills such as teamwork and communication. Moreover, teachers placed their students' motivation and enjoyment as priority instead of focusing on the science concepts and the EDP (Dare, Ellis & Roehrig, 2014). Finally, the findings from the case studies of Wang et al. (2011) found that teachers were aware of the need to add more content knowledge in their STEM integration. However, teachers held different perceptions about STEM integration that contributed to varied classroom practices and experiences for students.

Methodology

Research Setting, Course, and Participants

Our study was conducted during the 3-credit course, *Introduction to STEM Education*, taught by Dr. Augusto Z. Macalalag, Jr. for 15 weeks at Arcadia University. Throughout this graduate methods course, teachers were introduced to the science and engineering practices, crosscutting concepts, and core ideas outlined in the *Framework for K-12 Science Education* (NRC, 2012). Specifically, the *Framework* guided the educational experiences and assignments of the teachers in the course: (a) defining problems, (b) developing and using models, (c) planning and carrying out investigations, (d) analyzing and interpreting data, (e) using mathematics and computational thinking, (f) designing solutions, (g) engaging in argument from evidence, and (h) obtaining, evaluating, and communicating information.

For example, in one of the instructional activities in the course (adapted from *Design Squad's Rubber-Band Car*), teachers learned the concepts of forces, motion, and energy transformations by working in groups to design a rubber-band powered car. Their objective was to design a car that can travel the farthest distance propelled by a rubber band. They worked in groups, discussed their prior knowledge about force, motion and energy, created a model that their group investigated, and made predictions based on their initial conceptual models. One group decided to investigate the effect of the number of rubber-bands to increase the car's elastic potential energy, a second group used different materials and shapes to reduce the car's weight, while a third group looked at the effects of changing the surface friction between the floor and wheels. After the investigations, each group analyzed their data and presented their findings in front of the class. Teachers revised their prototypes and conducted additional investigations based on evidence and findings from other groups. The lesson ended in a competition, evaluation of the different model cars, discussion of findings, and reflection of content and pedagogical learning.

Specific course objectives included: (a) developing or adapting a unit to incorporate science inquiry and EDP practices, (b) creating assessments to analyze students' conceptual understandings and difficulties in science, (c) implementing and reflecting on instruction, (d) utilizing the STEM curricula and resources, and (e) incorporating physical science concepts. The four core assignments consisted of writing a teaching statement, developing and implementing a STEM unit, writing reflections after watching video-captured instruction that focused on science or engineering lesson, and pre- and post-tests.

Participants in this study included 17 practicing elementary school teachers from a suburban school district with about 8,000 students in preK-12, 26% students of color, and 8% of students receive free and reduced lunch. Of the 17 participants, 13 teachers had seven or more years of teaching experience, while four teachers had six or fewer years of teaching. Furthermore, the teachers had varying backgrounds, with a majority (70%) having degrees in early childhood and elementary education. Others reported previous degrees or certifications in literacy, marketing and communications, mathematics, history, Spanish, and the Arts.

Data and Analysis

In order to answer our research question— *Does the course enhance teachers' knowledge in science and the engineering design process?*—we developed and administered identical *pre- and post-tests* that were administered on the first and last day of the course. The test consisted 22 multiple choice questions and 3 constructed response items. We used, with permission, the multiple choice questions from the science assessment items developed by the American Association for the Advancement of Science (http://assessment.aaas.org/pages/home). We identified three constructs for our test: force and motion (7 items), energy and its transformations (8 items) and models and modeling (7 items). Dr. Macalalag replaced the teacher's names with ID numbers before conducting our analysis, and we used ID numbers in this paper to protect the identity of our participants. We included the multiple choice items along with the average scores from pre- and post-tests in Appendix A.

The change in teacher performance overall, as well as the change for each of the three constructs individually, was analyzed by computer program JMP Pro 11.1.1(32 bit) (© 2013 SAS Institute, Inc.), using both a paired t-test and the Wilcoxon signed-rank test. These methods were chosen because both of these tests look at the change seen for each individual, rather than just the change in mean values for the group. The paired t-test is appropriate when the data is measured on an interval scale (i.e., measured on a scale with constant intervals), while the Wilcoxon signed-rank test is more appropriate when the data is measured on an ordinal scale (i.e., responses can be sorted into categories, but there isn't necessarily an arithmetical relationship between the responses). Furthermore, the paired t-test is a parametric test in that the analysis is based on parameters of the responses (means and standard deviations), assumes that the data is continuous and normally distributed, and compares the test statistic against a reference curve; whereas the Wilcoxon signed-rank test is a non-parametric test since the analysis is based on ranking the observations, does not assume that the data is continuous and normally distributed, and compares the test statistic against the distribution of all possible rankings. For either statistical procedure, the probability that a score increase is a random occurrence is computed. If this probability is small (≤ 0.05) then one rejects the hypothesis that the class had no impact on teacher performance and instead accepts the hypothesis that the class improved teacher performance with high confidence ($\geq 95\%$). Statistically significant results are indicated with an * in the tables in Appendices D, E and F. For analysis of individual questions the Wilcoxon signed-rank test is more appropriate (ordinal response is wrong or correct; with only two possible answers the distribution is discrete, non-continuous) whereas for analysis of groups of questions the paired t-test is more appropriate (value of the number of correct responses approaches a continuous distribution as the number of questions increases).

The concepts of Force and Motion and Energy were then further tested by asking open ended questions based on identifying and making suggestions to address the student alternative conceptions. Constructed Response Items (Question 23: Force and Motion, Question 24: Energy) are from the Physical Science Diagnostic Assessment at the University of Louisville Center for Research in Mathematics and Science Teacher Development. We employed the constant comparison method to identify themes and categories from the teachers' reflections (Merriam, 1998). Answers were then coded based on a 0-2 point scale, as detailed in the table below. Each response was evaluated by two coders, the level of agreement between the two was analyzed, and where the two coders disagreed the response was discussed and a consensus score was given to each. The consensus codes were then used for further analysis. Each student's change in understanding was then analyzed using both a paired t test and the Wilcoxon signed-rank test as described above. The Wilcoxon signed-rank test is the most appropriate given the ordinal nature of the codes. We provided the codes, acceptable answers and examples for questions 23 and 24 in Appendix B.

We also included an open-ended question (25) to test the notion of the EDP. The scenario used was adapted from the Museum of Science in Boston's Everest Trek Module. The steps for engineering design were broken down into 11 steps based on *A Framework for K-12 Science Education* (NRC, 2012). The 11 steps were: a. Defining problem, b. Identifying constraints, c. Brainstorming ideas d. Developing models/prototypes, e. Conducting background research (market, scientific, engineering, etc.), f. Planning investigations to test model/prototype, g. Conducting investigations to test model/prototype, h. Collecting data, i. Analyze and interpret data, j. Revising model/prototype based on evidence, and k. Presenting final model. The number of steps included were scored pre- and post- tests. All tests were scored by two coders, and the results between the two were compared to determine reliability of the score. In addition, the design process was broken into three phases, an initial set to be done prior to the actual design, encompassing steps a-e; an experimental phase, steps f-i; and a finalization phase, steps j and k. Scores were tabulated for each phase. Both the paired t-test and the Wilcoxon rank sum test were used for this question. We provided the categories, codes and examples for question 25 in Appendix C. The change pre- and post- tests in the overall number of steps, as well as the number of steps in each phase was analyzed using both a paired t-test and the Wilcoxon signed-rank test as described above.

Results

The average percentage score for the teachers on the pre- and post-tests was calculated for the test as a whole and then split into the percentages on each of the three main constructs. Overall teacher performance improved from an average of 60% correct to 78% correct. The construct about which the teachers had the deepest understanding on both the pre- and post-tests, at least by this measure, was Models, and the construct with the weakest understanding was Forces and Motion. While the test results improved in all areas, even after the course the average score on Forces and Motion was only 60%. These results are presented in Figure 1 below.

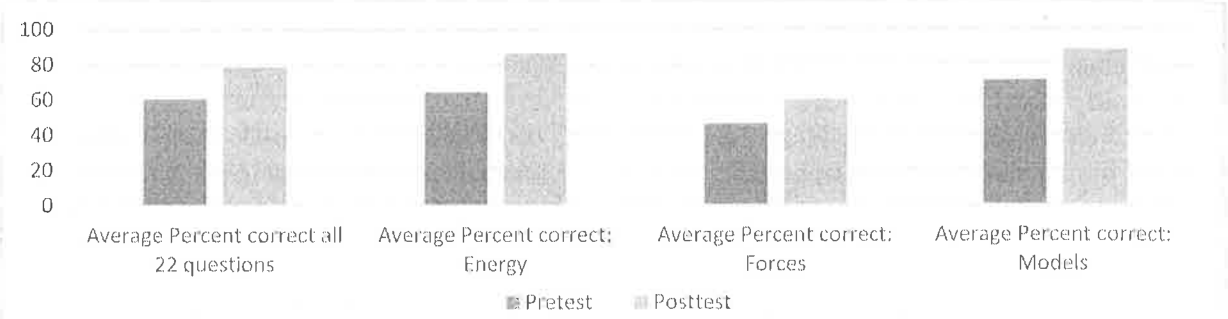

Figure 1. Comparison of Performance on Multiple Choice Items: Pre- and Post- Tests

The data was then analyzed to determine whether these changes were statistically significant. Statistically significant improvement at or above the 99% confidence limit was seen for the test overall and for all three subgroups. The data for the paired t-test and Wilcoxon signed rank tests are in the table in Appendix D.

Two open-ended questions, focusing on the teachers' understanding of the content needed to identify and address students' alternative conceptions, were also asked. These questions were scored on a 0-2 rubric as described in the methods and analyzed based on consensus scores. The agreement between the two coders' initial scores is noted at the bottom of table in Appendix E.

For question 23 on Forces and Motion, which focused on an understanding of inertia and how forces can stop as well as cause motion, almost half (8) of the teachers received an initial score of 0, demonstrating that they did not have a firm understanding of this concept. This matched very well with the multiple choice results, where the average on the force and motion questions on the pre-test was 46% correct. After the course, out of the 17 teachers, only 5 showed improvement over their original answer, and 2 had their scores decrease. Moreover, teachers were still unable to answer the question and either left the answer blank or gave an answer that did not address the question. Again, this matched well with the multiple choice question results, where post-test the average score was just under 60% correct. In addition, scoring for this item proved to be difficult. The agreement between the 2 coders was only 75%, which makes it difficult to draw conclusions from this question. When these results were analyzed by the Wilcoxon ranked-sum test, no statistically significant improvement was seen, as shown in Appendix D and Figure 2 below.

For question 24 on energy transformation, which focused on an understanding of how potential energy is transformed into kinetic energy, and that kinetic energy is associated with motion, more than half (11) of the teachers received an initial score of 0, demonstrating that they did not have a firm understanding of these concepts. This did not match well with the multiple choice results, where the average on the energy questions on the pre-test was 64% correct. After the course, out of the 17 teachers, again, only 5 showed improvement over their original answer, and 2 had their scores decrease. After the course 8 teachers were still unable to answer the question, with many either leaving the question blank, or giving an answer like "I would have to consult with colleagues." Again, this did not match well with the multiple choice question results, where post-test the average score was 86% correct. When these results were analyzed by the Wilcoxon ranked-sum test, no statistically significant improvement was seen, as shown in Appendix E and Figure 2 below. The agreement between the 2 coders for this question was 85%.

Figure 2. Comparison of Performance on Constructed Response Items, Pre- and Post-Tests

An additional question (25) was asked about engineering design practices. The focus of the question was not on the teachers' ability to design the object in question (a coat for use on Mt. Everest), but rather on their understanding of the design process. The teachers were asked to list and describe the steps needed to design and create the coat. The number of teachers, out of 17, who included each of the 11 possible steps is described in Appendix F. The agreement between the coders was 91%.

The greatest improvement in design process was seen in the areas of defining the problem and for collecting and interpreting data, where about three times as many teachers included these steps after the course than before. The areas which did not improve, and which were mostly skipped both on pre- and post-tests were identifying constraints and planning the investigation. It is interesting to note that while the number of teachers who included conducting an investigation increased from 11 to all 17, the number who included planning the investigation as a separate step actually decreased from 3 to only 1.

The 11 steps for the design process were then split into three phases, an initial set to be done prior to the actual design, encompassing steps a-e; an experimental phase, steps f-i; and a finalization phase, steps j and k. On the pre-test, five teachers did not include any steps in the experimental phase, and nine did not include any steps in the finalization phase. On the post-test, all 17 teachers included at least one step in the experimental phase (step g, conducting investigations), and only one teacher failed to include either step j or step k (revising the model and presenting final model). When analyzed as paired groups of data by either statistical test, statistically significant improvement was seen both overall and in all three phases. This data is presented in Appendix F and Figure 3 below.

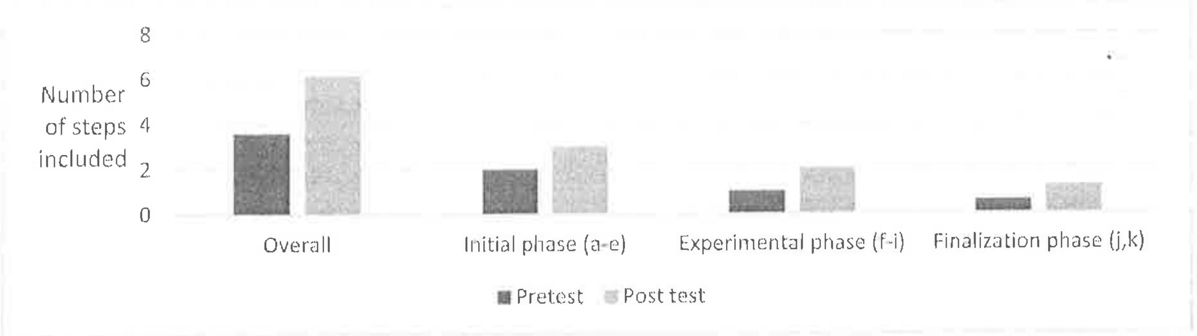

Figure 3. Comparison of Performance on the Engineering Design Items, Pre- and Post-Tests

Discussion and Implication

Our study described the successes and challenges of 17 elementary teachers in enhancing their knowledge of science and the EDP in the context of a graduate STEM methods course. Specifically, the pre-test scores showed minimal understanding of force and motion as well as energy and its transformations concepts. Based on the post-test scores on the multiple choice items, our teachers improved their knowledge in force and motion, energy and its transformations, and model and modeling. We saw a statistically significant improvement at or above the 99% confidence limit in the overall test and in all three constructs. In addition, our analysis of the constructed response item suggested growth in the teachers' notions of the EDP.

In particular, we found the greatest overall improvement in teachers' mentioning of *defining the problem* and *collecting and interpreting data* as steps of the EDP. On the post-test, all or almost all 17 teachers included at least one step in the *experimental phase* and *revising and presenting the final model.* Our findings can potentially expand the STEM education literature with regards to the contributions of a STEM graduate methods course in cultivating teachers' content knowledge of physical science and notions of the EDP (Lachapelle et al., 2015; Berry, Friedrichsen & Loughran, 2015).

On the other hand, even after the course, we saw that many of our teachers struggled to apply the science concepts in answering the constructed response items 23 and 24. They either did not answer the question or provided an answer that did not address the question. While the overall score for both items did improve slightly, the changes were not statistically significant. We also saw that, in general, most teachers had difficulty with the force and motion concepts even after the course. To address these challenges, we plan to review the instructional activities in the course and to do a better job in monitoring the teachers' content knowledge throughout the course in order to address their conceptual difficulties. Moreover, we are planning to revise and/or replace items from our pre- and post-tests.

In terms of the EDP, even after the course, we saw that the majority of our teachers' answers did not connect the object in question (a coat for use on Mt. Everest) to their descriptions of the steps. Specifically, most of our teachers did not include the essential steps in the EDP of *identifying constraints* and *planning the investigation* in their responses. The challenges of our elementary school teachers seem to be common to those teachers who are beginning to learn the STEM concepts and the EDP regardless of their years of teaching (Lorreto-Perdue et al., 2015; Dare, Ellis & Roehrig, 2014).

Study Limitations

We would like to acknowledge the limitations of our study and the test items. In particular, our study did not include a comparison group and hence we can only make a modest claim regarding our research findings and the success of our course. We also have some concerns about the items in our tests: (a) the questions pertaining to the *Models* construct seem very similar and easy for our teachers, (b) the constructed response items 23 and 24 need revision to better capture the teachers' pedagogical content knowledge, and (c) the constructed response item 25 needs modification to measure not only the engineering practices but also the content.

Areas for Future Research

The primary goal of our study was to improve teachers' content knowledge in science and the EDP. Our findings suggest successes and challenges of elementary school teachers in developing their knowledge in selected physical science concepts (motion, force, and energy), scientific models, and the EDP after attending the course. Further research studies are warranted to examine instructional activities that can support the development of teachers' knowledge in additional disciplinary core ideas (i.e. Life, Earth, and Space Sciences) or cross-cutting concepts (i.e. patterns, systems, etc.) and to study other ways to assess knowledge implementation.

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Contact Information

Augusto Z. Macalalag, Jr., Ed.D.
Arcadia University
School of Education
450 S. Easton Road
Glenside, PA 19038
macalalaga@arcadia.edu

Karen Parker
kapar@spring-ford.net

Appendix A

Questions Force and Motion	Performance Teachers	
	Pre	Post

2. A person is riding a snowmobile in a snowy field. Suddenly, a very strong wind begins to blow toward the oncoming snowmobile, and the wind continues to blow for a while. During the time the wind is blowing, the force of the wind is greater than the force that is moving the snowmobile forward. 29% 47%

What will happen to the speed of the snowmobile while the strong wind is blowing?

A. The snowmobile will slow down for a while and then move at a slower constant speed.
B. The snowmobile will move at constant speed for a while, and then slow down.
C. The snowmobile will move at constant speed the entire time.
D. The snowmobile will slow down the entire time.

7. An object is moving at a speed of 10 meters per second (m/s). A force begins to act on the object at exactly 9 o'clock in the morning (9:00 am) and continues to act until 9:06 am. The force is pushing the object forward. The strength and direction of the force stay the same the entire time. The force that is pushing the object forward is always greater than any forces slowing the object down. 0% 11%
Which table (A, B, C, or D) shows what the object's speed might be each minute? Assume that if a change in speed has occurred, the change is shown in the table. **(Answer: B)**

A.

Time	9:00 am	9:01 am	9:02 am	9:03 am	9:04 am	9:05 am	9:06 am
Speed	10 m/s	10 m/s	10 m/s	11 m/s	12 m/s	12 m/s	12 m/s

B.

Time	**9:00 am**	**9:01 am**	**9:02 am**	**9:03 am**	**9:04 am**	**9:05 am**	**9:06 am**
Speed	**10 m/s**	**11 m/s**	**12 m/s**	**13 m/s**	**14 m/s**	**15 m/s**	**16 m/s**

C.

Time	9:00 am	9:01 am	9:02 am	9:03 am	9:04 am	9:05 am	9:06 am
Speed	10 m/s	11 m/s	12 m/s	13 m/s	12 m/s	11 m/s	10 m/s

D.

Time	9:00 am	9:01 am	9:02 am	9:03 am	9:04 am	9:05 am	9:06 am
Speed	10 m/s	11 m/s	12 m/s	13 m/s	13 m/s	13 m/s	13 m/s

17 A ball is thrown straight up into the air. What happens to the ball's speed as it goes up and as it comes down? 82% 59%

A. The ball goes up at a constant speed, stops, and then comes down at a constant speed.

B. The ball goes up at a constant speed, stops, and then moves faster and faster as it comes down.

C. The ball moves slower and slower as it goes up, stops, and then comes down at a constant speed.

D. The ball moves slower and slower as it goes up, stops, and then moves faster and faster as it comes down.

18. A tire swing can be made by tying a car tire to a rope and then tying the rope to a tree branch. What are the forces acting on the tire in the tire swing shown below? 76% 100%

A. Only the pull of the rope on the tire

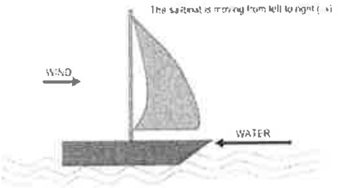
B. Only the pull of earth's gravity on the tire

C. Both the pull of the rope on the tire and the pull of earth's gravity on the tire

D. Neither the pull of the rope on the tire nor the pull of earth's gravity on the tire

19. In the drawing below, the arrows labeled WIND and WATER represent forces acting on a sailboat. The directions of the arrows represent the directions of the forces, and the lengths of the arrows represent the strengths of the forces. The force of the water on the sailboat is stronger than the force of the wind on the sailboat the entire time. 47% 71%

Which statement describes the sailboat's motion while these forces are acting? Assume that the sailboat does not stop or turn around.



A. The sailboat's speed will decrease the entire time.
B. The sailboat's speed will stay the same the entire time.
C. The sailboat's speed will decrease for a while and then stay the same.
D. The sailboat's speed will stay the same for a while and then decrease.

20 In the drawing below, the arrows labeled Force 1 and Force 2 represent two forces acting on an object. The directions of the arrows show the directions of the forces, and the lengths of the arrows represent the strengths of the forces. **(Answer: C)** 47% 76%

Which total force is equal to the two forces acting on the object?

A.

B

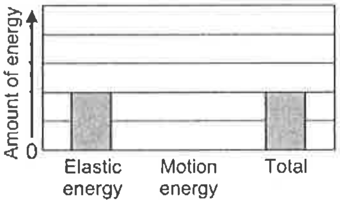
C. *

D.

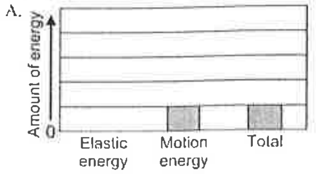
21. A person is riding a snowmobile in a snowy field. As the snowmobile reaches a frozen lake, the person turns off the snowmobile's engine and allows the snowmobile to slide across the lake. What will happen to the motion of the snowmobile if friction and air resistance act to slow the snowmobile down? **(Answer: A)** 41% 53%

A. The snowmobile will move slower and slower the entire time it is sliding across the lake.

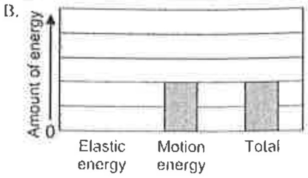
B. The snowmobile will move at a constant speed the entire time it is sliding across the lake.
C. The snowmobile will move at constant speed for a while and then slow down as it is sliding across the lake.
D. The snowmobile will slow down for a while and then move at constant speed as it is sliding across the lake.

Questions Energy	**Performance of Teachers**	
	Pre	Post
3 Two cars are traveling down a road at the same speed. Car 1 has more motion energy (kinetic energy) than Car 2. Does Car 1 weigh more than, less than, or the same as Car 2? A. **Car 1 weighs more than Car 2.** B. Car 1 weighs less than Car 2. C. Car 1 weighs the same as Car 2. D. More information is needed to compare the weights of the cars.	41%	71%
4. A student stretches a rubber band. The graph shows the amount of elastic energy the rubber band has before he lets go of it. The graph also shows the amount of motion energy (kinetic energy) the rubber band has before he lets go of it and the total amount of elastic and motion energy in the system.  The student lets the rubber band go and it flies across the room. Which of the following graphs represents the elastic energy, motion energy, and total amount of elastic and motion energy of the rubber band as it flies across the room and is no longer stretched? (We are assuming that no energy is transferred between the rubber band and the air around it and that any changes in the thermal energy and gravitational potential energy of the rubber band are so small that they can be ignored.) **(Answer: B)**	53%	88%

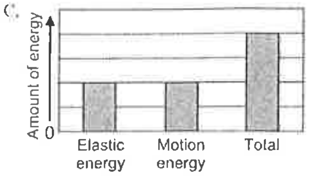
A.



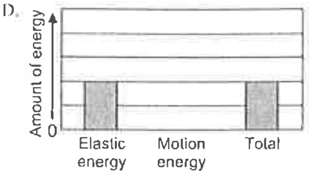
B.



C.



D.



5. The temperature of a plastic cup is 70°F. It is filled with water that is 40°F. Which of the following describes how thermal energy is transferred? 41% 82%

A. Thermal energy is transferred from the water to the cup until they are both at 45°F.
B. Thermal energy is transferred from the cup to the water until they are both at 45°F.
C. Thermal energy is transferred from the cup to the water until the cup is at 60°F and the water is at 50°F.
D. No thermal energy is transferred between the cup and the water, so the cup will stay at 70°F and the water will stay at 40°F.

6. The gravitational potential energy of an object depends on which of the following? 88% 88%

A. Both the mass of the object and the object's distance from the center of the earth
B. The mass of the object but not the object's distance from the center of the earth
C. The object's distance from the center of the earth but not the mass of the object
D. Neither the mass of the object nor the object's distance from the center of the earth

10. A rubber ball speeds up as it falls toward the floor. How do the motion energy (kinetic energy) and gravitational potential energy of the ball change as it falls and why? 65% 82%

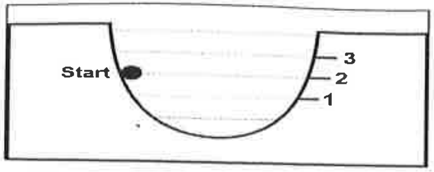
A. Both the motion energy and gravitational potential energy increase because new energy is always made as an object moves.
B. Both the motion energy and gravitational potential energy decrease because energy is always used up as an object moves and is not transformed into any other form of energy.
C. The motion energy decreases and the gravitational potential energy increases because the motion energy is transformed into gravitational potential energy.
D. The motion energy increases and the gravitational potential energy decreases because the gravitational potential energy is transformed into motion energy.

12A girl and a boy are playing on a teeter-totter. They both weigh the same. While the boy is down and the girl is up, which child has more gravitational potential energy? 35% 65%

A. The boy has more gravitational potential energy.
B. The girl has more gravitational potential energy.
C. They have the same amount of gravitational potential energy.
D. They do not have any gravitational potential energy.

14. Imagine a ball on a track where no energy is transferred between the ball and the track or between the ball and the air around it. The ball starts from rest at the position labeled Start and moves along the track toward Positions 1, 2, and 3.

82% 100%

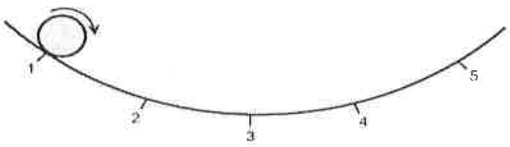


What is the highest position the ball will reach before stopping and going back down the track? (Remember that no energy is transferred between the ball and the track or between the ball and the air around it.)

A. Position 1
B. Position 2
C. Position 3
D. The ball will pass Position 3.

16A ball, starting from rest at Position 1, rolls along a curved track toward Position 5. The ball speeds up as it rolls from Position 1 to Position 3, and it slows down as it rolls from Position 3 toward Position 5. Just before it reaches Position 5, it stops and rolls back down the track. As the ball rolls back and forth along the curved track, the ball and the track get a little warmer.

76% 76%



When does the thermal energy of the ball and track increase and why?

A. Only when the ball rolls from Position 1 to Position 3 because the gravitational potential energy of the ball is converted into thermal energy
B. Only when the ball rolls from Position 3 toward Position 5 because the motion energy (kinetic energy) of the ball is converted into thermal energy
C. The thermal energy increases the entire time the ball is rolling along the track because both the gravitational potential energy and motion energy (kinetic energy) of the ball are converted into thermal energy.
D. The thermal energy increases the entire time the ball is rolling along the track, but the increase does not come from a change in gravitational potential energy or motion energy (kinetic energy) because motion energy and gravitational potential energy cannot be converted into thermal energy.

Questions Modeling	Performance of Teachers	
	Pre	Post
1. Which of the following can be used as a model? **A. Both a graph and a diagram** B. A graph, but not a diagram C. A diagram, but not a graph D. Neither a graph nor a diagram	18%	100%
8. How do the sizes of models compare to the sizes of the objects they represent? A. Models can be bigger than the objects they represent, but they cannot be smaller. B. Models can be smaller than the objects they represent, but they cannot be bigger. **C. Models can be bigger or smaller than the objects they represent.** D. Models have to be the same size as the objects they represent.	82%	88%
9. An engineer made a model of a ship to help him think about how it works. He made sure that some characteristics of the ship were accurately represented, but he did not include all of the ship's characteristics in his model. Is it okay that he ignored some of the ship's characteristics? **A. It is okay, but only if he represented the characteristics that affect how the ship works, because models need to include the characteristics that are relevant to what is being studied.** B. It is okay, but only if he represented the characteristics that affected whether the model looks like the ship, because models should look like the things that they represent. C. It is okay, but only if he represented the characteristics that people would be interested in knowing about, because models are only used to communicate information to others. D. It is not okay that he ignored some of the ship's characteristics. A model should be like the object it is representing in every way possible.	76%	82%
11. Can a model of an object be used to predict how an object will behave? A. No, a model is only useful for communicating to others what an object is like, not for making predictions about an object. B. No, predictions made with a model are never useful because a model is never exactly the same as the object it represents. C. Yes, a model will behave exactly as the object it is representing behaves because a model is exactly the same as the object it represents. **D. Yes, but the predicted behavior of the object may not be the same as the actual behavior of the object because a model is never exactly the same as the object it represents.**	88%	94%
13Which of the following could be represented with a model? A. An object but not an event B. An event but not an object **C. Both an object and an event** D. Neither an object nor an event	100%	100%

15Which of the following could be represented with a model? A. An object, but not an event or process B. An event or process, but not an object **C. An object, event, or process** D. Neither an object, event, nor process	100%	100%
22Which of the following statements about models is TRUE? A. Making models look more like the objects they represent always makes them better models. B. The main difference between a model and the object it represents is that the model is a different size. **C. Models sometimes look quite different from the objects they represent.** D. Models must be made of the same material as the objects they represent.	29%	53%

Appendix B

Question 23. When studying inertia, your students point out that Newton's First Law of Motion (an object in motion continues in motion unless acted on by an outside force) cannot be true because otherwise nearly everything around us would still be moving since it had likely been moving at least once in the past. Please describe the currently accepted scientific explanation of the phenomenon that the students do not understand.

Codes	Acceptable Answers and Examples
2	Acceptable answers include the idea that there are forces that oppose motion and cause motion. AND Explains how these forces can cause an object to stop moving. Example: The students do not understand that everything around us is being acted on by outside forces. The force of gravity is pulling everything around us towards the Earth's surface. Friction forces between objects are constantly acting to slow down motion. Objects will continue to move until these forces reach a balanced or stable state. (694-14-05-03)
1	Answer includes the ideas that there are forces acting on the object, may describe these forces, but are not clear about how these forces change motion. Example: These students do not fully understand the phenomenon of outside forces acting on an object. While their assertion that everything around us has likely been in motion at some point, accordingly these objects have all likely had some outside force acting upon them, (i.e. gravity, friction, air resistance, decomposition). The students need to investigate these forces. (694-14-15-03)
0	Answer shows little or no understanding of the forces involved. May include names of forces, without any understanding of what they are or how they would affect an object in motion. Example: Let me start by stating that I do not have a thorough knowledge of the underlying science in order to accurately answer this question. However: I would think that the explanation has to do with gravitational pull/energy as well as the transfer of energy (which is neither created nor destroyed). (694-14-06-03)

Question 24. To investigate conservation of energy, students are setting up a model roller coaster where a marble is released and rolls to the end of the track. Assume the friction in this situation is small and can be safely ignored. When designing a roller coaster, the students state, "Since conversation of energy means that all of the initial potential energy is converted to kinetic energy by the end, the roller coaster must end at the lower point since that will be where the marble has the greatest speed." Please describe the currently accepted scientific explanation of the phenomenon that the students do not understand.

Codes	Acceptable Answers and Examples
2	Answers include the idea that energy is converted back and forth between potential and kinetic energies without loss. OR The kinetic energy can also be converted back to potential energy, but it will not stop at the bottom of the track. Example: Kinetic energy can be converted back to potential energy as it moves back up to a highest point, on the track (694-14-05-03)
1	Answer contains statement that the object can go back up OR at least does not stop. AND No explanation or inaccurate explanation. Example: Assuming that kinetic energy will propel the ball beyond the lowest point? (694-14-07-03)
0	Answers are incorrect. Examples: When the object reaches the bottom it will only be at its top speed if it continuous at the same slope once it levels out it will slow (694-14-17-03)

Appendix C

Question 25. Read the following scenario and answer the questions below. On the border of Tibet and Nepal, among the beautiful Himalayas, lies the highest mountain the world, Mount Everest. Often referred to as "Top of the World," Mount Everest's peak stands at about 8,850 meters (29,035 feet) above sea level. Imagine standing atop a stack of 5,000 people piled head-to-toe! That is about what it would be like to stand on the summit of Mount Everest. An adventure team from your school has read about some famous mountaineers who have managed to summit their great peak, and the team want to take on the challenge for themselves. Your job is to design and create a coat to protect your team members from Everest's year-round harsh, frigid weather conditions. In January, the coldest month, the summit temperatures average -33 deg. Fahrenheit and can drop as low as 76 deg. F. In July, the warmest month, the average summit temperature is -2degF. At no time of the year does the temperature on the summit rise above freezing. List and describe the steps you are going to take to design and create a type of coat for your team members.

Categories and Codes	Examples
Category 1: *Initial Phase*	
A. Defining problem	Ask – here we define the problem; define the challenge as it relates to a "real-world" problem. (694-14-12-04)
B. Identifying constraints	Identify cost, weight of materials, protection from harsh elements, durability. 694-14-17-04
C. Brainstorming Ideas	Brainstorm all the necessities of the coat (i.e. small, package able, lightweight, weatherproof, durable).2. Brainstorm list of experts we could then interview (mountaineers, clothing designers). 3. Brainstorm list materials to test and design. (694-14-17-03)
D. Developing models or prototypes	Once materials have been identified prototypes designs should be created. (694-14-08-03)
E. Conducting research (market, scientific, engineering, etc.)	Research materials that can adequately slow heat loss at these temperatures. (694-14-06-03)
Category 2: *Experimental Phase*	
F. Planning investigations	What elements will you combine in order to create an effective product? How will you proceed? (694-14-07-04)
G. Conducting investigations	Once the coat prototypes have been created, more research is done on the coat's effectiveness. Did it meet the needs of the problem defined in step 1? Test, test, test!(694-14-12-04)
H. Collecting data	Record and demonstrate data. (694-14-14-04)
I. Analyzing and interpreting data	Discuss/Analyze results (694-14-17-04)
Category 3: *Experimental Phase*	
J. Revising model or prototype	Re-design prototype for final product (694-14-16-03)
K. Presenting final model	Present final model. (694-14-17-04)

Appendix D

Statistical Data for Multiple Choice Items: Pre- and Post-Tests

Statistical Data for Multiple Choice Questions	*All 22 questions*	*Energy*	*Force and Motion*	*Models*
Pretest score	60.4%	63.9%	46.2%	70.6%
Posttest score	78.3 %	86.0%	59.7%	88.2%
mean difference	17.9 %	22.1%	13.5%	17.6%
standard error	2.5 %	4.0%	5.2%	3.7%
N	374	136	119	119
Paired t-test statistic	7.17	5.51	2.59	4.76
Probability > t	<0.0001*	<0.0001*	0.0054*	<0.0001*
Wilcoxon Signed Rank test statistic	1675	277.5	164	126
Probability > S	<0.0001*	<0.0001*	0.0048*	<0.0001*

(*Statistically Significant)

Appendix E

Statistical Analysis of the Constructed Response Items, Pre- and Post-Tests

Open-Ended Question Statistics	*Question 23: Forces and Motion*	*Question 24: Energy Transformation*
Pre-test score	0.94	0.41
Post-test score	1.12	0.71
mean difference	0.18	0.29
standard error	0.21	0.21
N	17	17
Wilcoxon Signed Rank test statistic	4.5	8
Probability > S	0.30	0.125
Agreement between coders	75%	85%

Appendix F

Statistical Analysis: Steps of the Engineering Design Process, Pre- and Post-Tests

	Step in design process	*Number of teachers who included this step*	
		Pre-test	Post-test
a.	*Defining problem*	3	9
b.	*Identifying constraints*	1	1
c.	*Brainstorming Ideas*	6	12
d.	*Developing models/prototypes*	14	16
e.	*Conducting research (market, scientific, engineering, etc.)*	14	13
f.	*Planning investigations*	3	1
g.	*Conducting investigations*	11	17
h.	*Collecting data*	3	8
i.	*Analyze and interpret data*	0	8
j.	*Revising model/prototype*	8	15
k.	*Presenting final model*	3	5

	overall	*initial phase (a-e)*	*experimental phase (f-i)*	*finalization phase (j,k)*
Pre-test score (12 possible)	3.6	2.0	1.0	0.59
Post-test score(12 possible)	6.2	3.0	2.0	1.24
mean difference	2.5	1.0	1.0	0.65
standard error	0.54	0.27	0.26	0.21
N	17	17	17	17
Paired t-test statistic	7.72	3.69	3.89	3.10
Probability > t	<0.0001*	0.0010*	0.0007*	0.0035*
Wilcoxon Signed Rank test statistic	68	35	40.5	33.5
Probability > S	<0.0001*	0.0020*	0.0012*	0.0082*

(*Statistically Significant)