Assessing Changes in Student Attitudes and Knowledge in an Engineering for Educators Class

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ABSTRACT

The authors have created and taught for the past five years a course in *Engineering Problem Solving for Future Teachers*. This is taught to pre-service teachers as a physical science course. Most of them take it during their sophomore year. While it is open to all education majors, most of the students will eventually teach in elementary or middle schools.

The authors have previously reported on the nature of the course[1]. It has a significant hands-on laboratory component[2]. Each year during the course the authors survey the students' attitudes toward engineering science at the beginning of the course and at the end of the course. In the spring 2004 offering of the course the authors made some significant changes to the course content. It was originally taught using materials engineering and chemistry as the main content areas. This time it was team taught, with five different engineering faculty taking turns leading the students in different topical areas. The students were given pretests and posttests of engineering science content. This paper reports on the changes in student attitudes and abilities that were observed as they took the course.

Student attitudes towards engineering science were taken through the use of a 20 question survey. Students were presented with statements and had to answer on a 6 point scale ranging from strongly disagree (1) to strongly agree (6). Significant changes in attitude were found in several areas when the end of class results are compared to the beginning of class results.

- Students are more likely to believe that basic engineering concepts are understandable to the average person.
- Students are less intimidated by engineering professors.
- Students are more likely to integrate engineering concepts into their future classes.
- Students are confident they can integrate problem solving techniques into their future classes.

We examined the students gain in content knowledge in six topical areas:

- Materials science
- Fatigue and statistics
- Structures
- Behavior of fluids (particularly Archimedes principle and the nature of colloids)
- Highway engineering
- Rocketry

Dramatic gains in knowledge were shown in the fatigue/statistics, fluids, and highway

engineering. There were smaller gains in the materials engineering and structures topics, however, we should note their prior knowledge in materials was the highest of the topics we covered in the class. There was a mild gain in the rockets section concerning design of rockets.

We believe that this class has been successful. The students' attitudes to engineering science have significantly improved, and they are more likely to include engineering concepts in their future classes. Student content knowledge has improved on most of the topics we covered in the class.

BACKGROUND TO COURSE

This course was initially created as part of NASA's NOVA Program. This program had the goal of improving the future math and science education of K-12 students by improving the math and science education of future teachers. Each university in the program was composed of a team of content faculty and education faculty. At Louisiana Tech University we created a team that would teach engineering concepts to future teachers. Our course, *Engineering Problem Solving for Future Teachers* is a three semester hour course that is taught every year in the spring. It is considered a physical science course by the students. Most of the students who take the course are sophomore elementary education majors. We have previously reported on different aspects of this course [1,2,3,4,5] . The most complete description of the course is in reference [1].

We teach this course in two class meetings per week that each last 110 minutes. This allows us to utilize active learning concepts in each class. There was a significant laboratory component to each of the topics.

This past year we revised the engineering content of the course. It was originally taught using materials engineering and chemistry as the main topical areas. This time we included topics from the following areas:

- Materials engineering
- Fatigue and statistics
- Structures
- Behavior of fluids (particularly Archimedes principle and the nature of colloids)
- Highway engineering
- Rocketry

Each of the areas was covered for one to two weeks in the course.

Each of the topic areas will be briefly discussed below.

<u>Materials Science</u>
Students were introduced to several types of solid materials: metals, polymers, and ceramics. They explored how all of these materials have been used to contain soft drinks. The effect of the type of material on how fast a soft drink container would cool down (or warm up) was examined with an experiment. An aluminum can, a plastic bottle, and a glass bottle were cooled down in ice. They were removed from ice and the students measured how fast they would warm back up to room temperature. The reverse experiment was done where the students measured how fast

the containers would cool down when placed in the ice. The rate of cooling was related to the internal atomic structure of the materials.

The students were introduced to the concepts of time dependent material properties when we had them make a “silly putty” type material. This lead to an interesting discussion of whether the polymer they made was a liquid or a solid.

Fatigue and statistics

The concepts of metal fatigue and statistics were combined into a single module. First, metal fatigue was discussed followed by an experiment in metal fatigue to set up a discussion of statistics and basic probability. Concepts such as fatigue limit, cyclic loading and crack propagation were introduced to the students. The student teams were then given several samples of two different types of metal paper clips and asked to bend them back and forth until they broke. The students recorded how many cycles it took for each paper clip to break and the entire class’ data were compiled.

After all of the samples were tested, the students were instructed in the creation of a histogram. The histogram and data set were used to present statistical terms such as mean, median, mode and standard deviation. The students understood these concepts, but were reluctant to deal with such a large set of data (there were around thirty samples for each type of paper clip). Standard deviation was discussed only to the point of how it represents the “spread” of the data. The concept of a normal distribution was also discussed along with several types of non-normal distributions.

Structures

The structures lecture began with an introduction to forces, equilibrium, stress, strain and some common modes of failure of structures such as buckling. To demonstrate these concepts, basic trusses and evaluation methods for these trusses were discussed. In addition, the students were guided through the construction of several simple trusses. During the discussion of forces and equilibrium, the concept of X and Y components of forces was discussed. The students showed a basic understanding of equal and opposite reactions, but were not comfortable with determining X and Y components of a force using trigonometry.

After the introduction to structures, the class built and tested a variety of small trusses. The trusses were built from to-scale plans distributed by the instructor. The students were divided into teams of four and each team was given a different truss design to build. The trusses were built from $1/8^{th}$ by $1/8^{th}$ inch balsa sticks. Some of the trusses were purposely designed to be very weak while others were designed to be much stronger. There were five truss designs (two weak trusses with square design features and three trusses with triangular features). The two square trusses were the same design only different heights and the three triangular trusses were of the same design with different heights. Before testing the trusses, the teams predicted which trusses would be strongest. The trusses were placed in a special fixture and loaded in the center. Metal washers were added one at a time to increase the load on the truss until failure. After all of the trusses were tested the previous predictions were compared to the actual results. Each of the teams predicted the correct order for the relative strengths of the trusses.

<u>Behavior of Fluids</u>
There were two modules presented to the students which focused on different aspects of fluid properties, buoyancy and colloidal properties. The first module dealt with "Why Things Float" based on the relations described by Archimedes Principle. This module began with an introduction to liquid and solid densities. The students were given three 1 inch cubes made of wood, plastic and aluminum. They measured the mass on top loading balances and determined the volume based on length dimensions and using a water displacement method. They then compared their results. In order to address the basic misconception that states an object will float if it is lighter than water, the plastic cube, which had sunk when placed in water, was placed in a container of corn syrup. In the syrup the plastic cube floated. This lead to the concept that the density of both the object and the fluid determined whether or not an object would float, i.e. Archimedes Principle. This principle was presented to the students with the purpose of the student teams designing a craft capable of floating a known mass (a bag of sand) and being able to predict the depth of submersion. It quickly became apparent that the concept of unit conversions was a huge barrier. The crafts were designed and built, but not in the independent manner that was planned. In addition to the barrier presented by a lack of understanding of fundamental unit relations, one of the teams found that neglecting the diameter of the bucket in which the craft was to float when constructing a craft with a rectangular cross-section, resulted in a craft too large to fit in the bucket provided.

Prior to introducing the students to the colloid module, additional time was spent on the concept of mathematical relationships. When asked for their first response to the word "math," there was not a single positive response. This reaction is all too common. In an attempt to bring about a more positive attitude toward mathematical concepts, the students were led through a series of exercises that had them apply mathematical relations to everyday and not so everyday problems. Based on the volume equation for a cube that they had worked with in the buoyancy module, we expanded to the problem to determine, with the help of units and chemical relationships, how many aluminum atoms were in the 1 inch cubes that they had used in the density demonstration. At the end of this exercise, the class discussed ways in which the concepts presented could be presented to an elementary or middle school class. The idea of using marbles or small balls in cubic or cylindrical containers was proposed. The mathematical concepts presentation was concluded with the students solving two additional problems based on volume and density that required the use of unit conversions and fundamental relations.

The second module presented to the students was based on the affect of colloids, in this case, dish soap and laundry detergents, on the surface tension of water. In order to understand engineering applications of colloids, students first have to understand the underlying scientific concepts. These concepts were demonstrated using two experiments. In the first experiment an aluminum boat was moved across a pan of water by placing a drop of soap in a notch at the rear of the boat and another in which two identical paper men were floated on plain water and on water in which detergent had been added. The teams were asked to observe the resulting behavior. The demonstrations were varied for each of the teams by using different kinds of paper and detergents. The use of the different materials was done in order to provide the students with options in designing similar modules for their own classes.

Highway Engineering
Students were introduced to several issues related to the design of highway intersections. A simple experiment was done in the class dealing with the issue of how quickly can a group of cars get started when the light in their direction turns green. The delay time between each car follows a typical pattern. This pattern is shown as part of the answer to the pre and post test in the Appendix.

Rocketry
Basic rocketry concepts were presented to the students in the form of a brief lecture. The concept of aerodynamic drag was introduced. The students were broken into teams. Each team was given a model rocket kit. They had to modify the kit to create the best rocket possible. On the last day of the class we launched the rockets in the football stadium parking lot. The winning team was the one whose rocket went the highest. We showed the students how rocket height could be calculated using a protractor type device a known distance from the launch pad.

In the spring 2003 class offering, students varied their rockets from the kits by designing and building different shapes of nose cones. In 2004, they all used the supplied nose cones, but had to design different fin structures to try to keep their rockets stable during flight.

Student Teaching of an Engineering Science Lesson
At the end of the course the students had to present a science/engineering lesson to fourth grade students in a local public school. Students had to integrate the engineering concepts they learned into lesson plans that they would then teach to fourth graders. They had to involve active learning concepts in what they taught to these students.

Each year we have done pre and post surveys of student attitudes toward engineering topics. This past year we have combined this with pre and post tests of student content knowledge. The purpose of this paper is to analyze the assessments we have done in this course. We will offer some recommendations for others who may wish to teach a similar course.

ASSESSMENT OF STUDENT ATTITUDES

One of the main goals we had at the very beginning was to demystify engineering for future teachers. As such, we began the pre and post survey of attitudes the first year we have taught the course. We reported some preliminary analysis of our data on the first two year's surveys in a conference paper[6]. We continued to conduct the surveys the last three years. We have also analyzed the results in more detail for this paper.

Student attitudes to engineering science were taken through the use of a 20 question survey. Student were presented with statements and had to answer on a 6 point scale as shown below:

1 strongly disagree
2 disagree
3 tendency to disagree
4 tendency to agree
5 agree

6 strongly agree

Significant changes in attitude were found in several areas when the end of class results are compared to the beginning of class results.

The questions were phrased so that the desired changes were not always to higher numbers. This was deliberately done to make sure that the students would read each statement more carefully.

Table 1
Areas where student attitudes significantly changed
Survey Average for all Five Times Course has been Offered

Statement	Pre Course Survey Average	Post Course Survey Average	Average Change
I feel secure in my knowledge of basic engineering concepts	2.87	3.94	1.07
Basic engineering concepts are understandable to the average person	3.73	4.53	0.80
Engineering professors are a bit threatening to me	3.38	2.81	-0.57
I fell able to integrate engineering concepts into the grade level I will teach	3.99	4.72	0.73
I think that I know enough to integrate problem solving skills into the grade level I plan to teach	4.14	4.92	0.78
I am able to write appropriate goals and objectives for lessons which integrate problem solving techniques into classroom instruction	4.17	4.87	0.70

We will now analyze the results of the survey statements in the following section:

I feel secure in my knowledge of basic engineering concepts
While student attitudes significantly increased, they started on a low level. Originally they were at 2.87 which is between disagree and tendency to disagree. They improved to being just below the tendency to agree statement. The relatively low level in the final attitudes is a probably a reflection of their realization of how complicated engineering might actually be.

Basic engineering concepts are understandable to the average person
The students went from 3.73 to 4.53. They realize that the average person can understand the

basic concepts. This is one of the most important conclusions of the course, for it shows that the students see engineering as something that they (and their future students) can understand.

<u>Engineering professors are a bit threatening to me</u>
Students started out by being relatively intimidated by the engineering professors who teach the course. The attitudes changed from 3.38 to 2.81. Once they began to know the engineering professors, they saw them as real people who were not threatening to them. However, the engineering professors they were exposed to were all volunteers who wanted to teach engineering concepts to non-engineering students. This does not mean that all engineering professors would be so unthreatening to them.

<u>I feel able to integrate engineering concepts into the grade level I will teach</u>
On this topic the students went from 3.99 to 4.72. Students now believe they understand engineering concepts enough to be able to teach them to their future students.

<u>I think that I know enough to integrate problem solving skills into the grade level I plan to teach</u>
As part of the presentations on engineering, we sought to teach problem solving skills at the same time. The students gained 0.78 points in their confidence of their abilities to teach problem solving to their students.

<u>I am able to write appropriate goals and objectives for lessons which integrate problem solving techniques into classroom instruction</u>
Part of this course involved the education professor partners teaching the students how to write lesson plans for the material they are creating. Students improved 0.70 points in this area.

Table 2
Areas where student attitudes did not significantly change
Survey Average for all Five Times Course has been Offered

Statement	Pre Course Survey Average	Post Course Survey Average	Average Change
I am strong in analytical reasoning and logical thinking	3.97	4.19	0.22
I am strong in computational math	3.52	3.67	0.15

In both the areas mentioned in Table 2 above, there is only a slight change in the students' opinions. However, the content pre and post tests indicated a significant improvement in the student's capabilities. It appears that the students may have been overconfident in their abilities. Once they were exposed to the content of this course, the realized how difficult some of the math and engineering concepts actually are. While their opinions did not change greatly, they probably have a more solid basis for their opinions at the end of the course.

ASSESSMENT OF STUDENT GAIN IN CONTENT KNOWLEDGE

We gave the students this test at the beginning of the course. We gave them the same exam at the end of the course. When the students took the post-test, they were allowed to use their notes to aid in answering the questions. Each question was graded on a scale of 0, 1, or 2 points. The test questions and their grading rubrics are shown in Appendix I.

Summary of student results are shown in Table 3 below. The results below have been changed into percentage terms to make comparisons easier. For example, if everyone had scored a perfect score of 2 on all questions, that would be a score of 100%.

Table 3
Changes in Student Content Knowledge

Topic Area	Number of Questions	Pre-Test Average	Post-Test Average	Change in Percent Score
Materials	2	81	88	7
Fatigue/Statistics	4	23	50	27
Structures	2	18	18	0
Archimedes Principle	2	26	50	24
Colloids	2	21	35	14
Highways	1	17	56	39
Rockets	2	38	46	18
Overall Average Score	15	33	51	18

In five of the seven topical areas students had a significant increase in their content knowledge. The gain in material was relatively low, but this was the topic where the students had the greatest initial knowledge, and there was not much room for improvement in their scores. The structures topic was one the students appeared to enjoy, as they build straw structures that had to hold an object. The tallest structure that could hold the object was the winner of the contest. On the other hand, the structures questions may have been too abstract for these sophomore educational majors.

The area with the biggest increase in knowledge was the one with the smallest amount of initial knowledge: highway engineering.

The overall gain in knowledge was 18%, which appears to be substantial. This is comparable to the amount of gain reported using a Materials Concept Inventory in an introductory materials engineering course.[7]

CONCLUSIONS

We have created a course in *Engineering Problem Solving for Future Teachers*. Pre and post surveys of student attitudes show that their attitudes toward teaching engineering concepts has significantly increased. Pre and post tests of knowledge show that their knowledge had increased significantly.

APPENDIX I—Pre and Post Test Questions and Scoring Rubric

Test questions are shown in black. Correct answers and the grading rubric for each question are shown in blue.

PRE-TEST
SPRING 2004

Please answer the following questions as best you can. If you cannot answer a question, that is fine. We are using this pre-test to measure your skills at the beginning of class. You will take a similar test at the end of the class to measure you skills at the end of the class.

Materials Engineering

1. In the first class we will examine three different types of soft drink containers. Which one will cool the quickest? The slowest?

Al
Plastic

2	Al, Glass, Plastic: Complete sequence correctly identified
1	Quickest or slowest identified
0	Neither correctly identified

2. For the one that will cool the quickest, why do you think it behaved that way? For the one that cooled the slowest, why do you think it behaved that way?

Al – electrons free to move $\Rightarrow$ conducts heat and electricity well
Plastic – electrons held tightly to atom $\Rightarrow$ does not conduct heat and electricity well

2	Both rationales are correct
1	One rationale is correct
0	Neither rationale is correct

Fatigue and Statistics

3. Describe what is meant by the term "Fatigue Failure."

A material breaks because it is placed under load or stress repeatedly.

2	Defined correctly
1	One or more important components missing, i.e. does not include "load or stress"
0	No attempt or incorrect answer

4. Give an example of fatigue failure.

   Answer like the following exemplars:
   Repeatedly bending a paperclip until it breaks.
   Rocking backing and forth in a chair until it breaks.
   Airplane rivet fails after repeated wiggling due to wind as a result of flight

2	Example is a novel answer not directly discussed in class ⇒ translated concept to related topic.
1	Example is one given in class
0	No answer or incorrect answer

5. What does "normally distributed" mean as it relates to statistics?

   Graph closely approximates a bell-shaped curve

2	Definition is correct
1	No mention of approximate. In other words, the answer does not reflect an understanding of the inherent nature of variability in data collection
0	No answer or incorrect answer

6. Give definitions for men, median, and mode as they relate to statistics.

   Mean – arithmetic average of all scores
   Median – center score when all scores are ranked from highest to lowest or lowest to highest
   Mode – most frequent score

2	All terms defined correctly
1	Most terms defined correctly
0	Most or all terms define incorrectly

<u>Structures</u>

7. What does the term "static equilibrium" mean?

   No **net** force on an object.

2	Correctly defined and includes force diagram.
1	Correctly defined, but does not include a force diagram.
0	Incorrectly defined.

8. What is meant by the terms "X and Y components of a force?"

   A force can be defined into components x, y, and z.
   X – force in horizontal direction
   Y - force in vertical direction

Z – force into and out of the plane of the paper (for example)

2	Correctly defined, including force in z direction
1	Correctly defined, but no mention of z direction
0	Incorrectly defined or no answer

Archimedes Principle

9. If a piece of steel sinks, how do ships such as aircraft carriers or destroyers weighing thousands of pounds float?

The large ship displaces an amount of water so that the upward force on the boat is greater than the downward force of gravity.

2	Water displacement and forces correctly described, along with a force diagram
1	Water displacement and forces correctly described, but no force diagram included
0	Answer is incorrect or incomplete or no answer

10. You are swimming in a pool on a hot summer day and decide to float in the water without a floatation device. Why does your body stay afloat when it is spread-out, but tends to sink if you curl up into a ball?

When you stretch, you have more surface area exposed to the water. More water pushes up against you. When you curl up into a ball, you have less water pushing up against you. The more surface area, the more likely the upward force of the water is greater than the downward force of gravity.

2	Water displacement, surface area, and forces correctly described, along with a force diagram
1	Water displacement, surface area, and forces correctly described, along with a force diagram
0	Answer is incorrect or incomplete or no answer

Colloids

11. Why does dishwater containing dish soap clean better than just water alone?

The soap molecules are attracted to the oils and/or dirt through "like dissolves like." Oil ⇒long chain carbon molecules. Soap ⇒ long chain carbon molecules terminating in a positive ion (Na^+ for example). The positive ion is attracted to the partially negative ion (O^{-2}) in water.

http://chemistry.about.com/library/weekly/aa081301a.htm (image from)

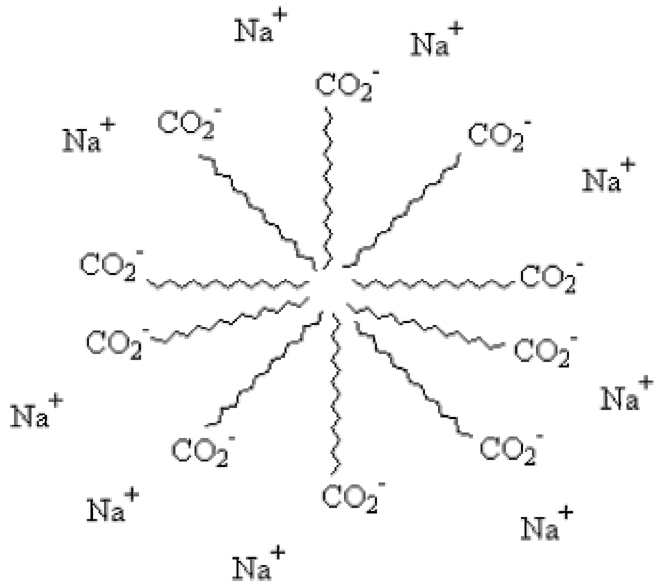

Diagram of Soap Micelle

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2	Definition is correct and answer includes a diagram
1	Definition is correct, but answer does not include a diagram
0	Definition is incorrect or incomplete or no answer

12. It's one of those days. You dropped a mercury thermometer and spent a long time cleaning up all of the little balls of mercury that were rolling around on the floor. Later in the day, you spilled some water you were drinking and spent some more time cleaning up the mess. While you are cleaning up the water, you notice that the water spilled on the floor tends to spread out but that the mercury had tended to form balls. Why do these two liquids form different shapes when placed (spilled) onto a surface such as a floor?

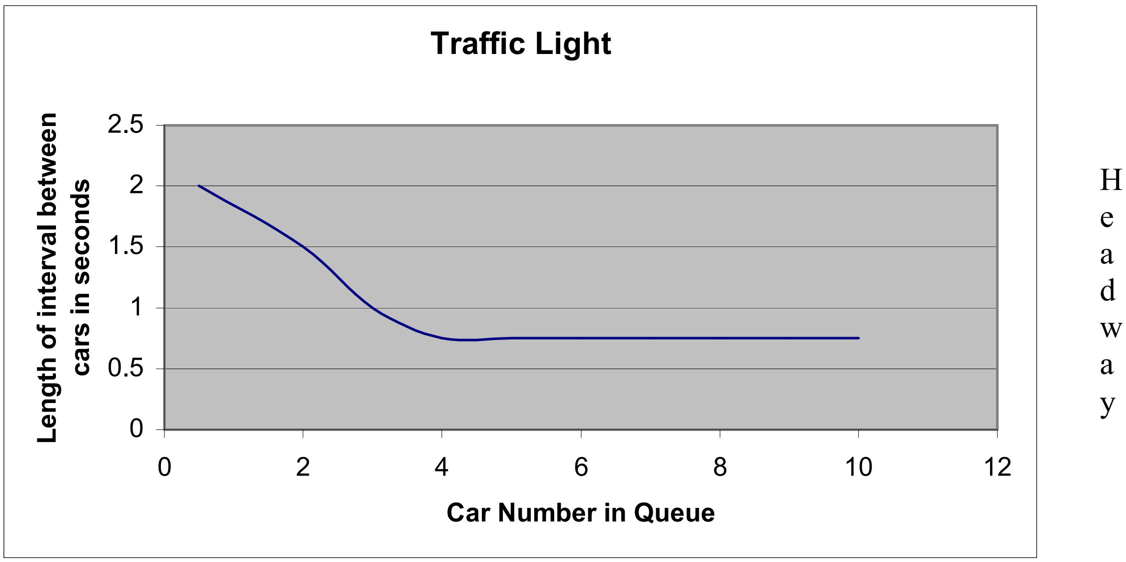
Cohesion is a force of attraction between molecules below the surface of a liquid. Surface tension is a net attractive force on molecules on the surface of a liquid. The liquid tries to take the shape that has the smallest possible surface area, a sphere. Mercury has a greater surface tension than water and makes a ball, while water makes a hemisphere on a surface such as a floor.

2	All terms correctly defined.
1	Most terms correctly defined.
0	Most or all terms incorrectly defined or no answer.

Highways

13. You are a pedestrian standing at an intersection waiting for the traffic signal to change to green so that you can cross the street. While you are standing there, you are bored so you decide to use the

stopwatch feature on your wristwatch to measure the time that lapses between cars as they cross the stop bar (the line across the road at the intersection behind which you stop when the light is red). You start the stopwatch when the car's bumper crosses the stop bar. This gives you the time interval number 1 in seconds. You continue doing this between cars 2 and 3, 3 and 4, etc. until 11 cars have passed through the intersection so that you have 10 time intervals. Now you want to plot the data. If you set the time interval number as the horizontal axis and length of the interval in seconds as the vertical axis, you will plot 10 points. If you connect these points with lines, what shape will the line plot have? Explain what is happening to make the plot have this particular shape.



When the light turns green, it takes a few moments for the firs car to recognize that the light has changed, to move her foot from the brake to the accelerator, and to begin to accelerate/ She is accelerating as she crosses the stop bar. The second car is also accelerating when he crosses the stop bar, but he is moving faster than car 1. As subsequent cars cross the bar, the speed at which they are moving begins to level off when the 5th or 6th car crosses the bar. The interval at this point is called the headway.

2	Graph is provided with proper labels and the explanation includes: what is happening and identifies why the interval levels off.
1	Graph is provided with proper labels, but does not completely explain what is happening or graph is incomplete.
0	Graph is missing and/or explanation is missing, or no answer.

Rocket Engineering

14. Most rockets have rounded nose cones. Why do you think this is the case?

There is less drag because there is less surface area on the part of the rocket meeting the air as the rocket is pushed forward. Aerodynamics.

2	All terms correctly defined.
1	Most terms correctly defined.
0	Most or all terms incorrectly defined, or no answer.

15. Rocket engines are very different from airplane jet engines. How are they different from each other?

Rockets carry their own oxidizing agent. Both jet engines and rockets carry their own fuel. Jet engines take in air from the atmosphere.

2	All terms correctly defined and difference between rocket engines and jet engines correctly delineated.
1	Most terms correctly defined and for the most part, the difference between rocket engines and jet engines correctly delineated.
0	Most or all terms incorrectly defined or difference between jets and rockets not delineated or no answer.

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BIOGRAPHICAL INFORMATION

WILLIAM JORDAN is Professor and Program Chair of Mechanical Engineering at Louisiana Tech University. He has B.S. and M.S. degrees in Metallurgical Engineering from the Colorado School of Mines. He has an M.A. degree in Theology from Denver Seminary. His Ph.D. was in mechanics and materials engineering from Texas A & M University. He teaches materials oriented courses and his main research area deals with the mechanical behavior of composite materials. He also writes and does research in the areas of engineering ethics and engineering education.

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NORM PUMPHREY is an Associate Professor of and a former Program Chair in the Civil Engineering Program at Louisiana Tech University. He has B.S., M.S., and Ph.D. degrees in civil engineering from Louisiana Tech, the University of Missouri – Rolla, and Purdue University, respectively. In July 2004, Dr. Pumphrey was named the Director of Advising and Retention at Tech, but he continues to teach in the College of Engineering and Science on a limited basis. He is a registered professional civil engineer in Louisiana. In his spare time, Dr. Pumphrey writes children's curriculum materials for a Christian organization in Atlanta and has refereed junior high and high school soccer.