Context sensitivity in the force concept inventory

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The force concept inventory and a 10-question context-modified test were given to 647 students enrolled in introductory physics classes at the University of Arkansas. Context changes had an effect ranging from −3% to 10% on the individual questions. The average student score on the ten transformed questions was 3% higher than the average student score on the corresponding 10 force concept inventory questions. Therefore, the effect of contextual changes on the total of the 10 questions is not sufficient to affect normal use of the force concept inventory as a diagnostic instrument.

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I. INTRODUCTION

Students often leave an introductory physics class with little more conceptual mastery than they had when they entered.[1] Halloun and Hestenes suggest that the difficulty students have in learning Newtonian concepts arises from the fact that before they set foot in any physics class, they already have fixed common sense beliefs learned from everyday experiences. However, these "common sense beliefs about motion are generally incompatible with Newtonian theory. Consequently, there is a tendency for students to systematically misinterpret material in introductory physics courses."[2]

Hestenes, Wells, and Swackhamer introduced the force concept inventory (FCI) in 1992,[3] and it has become a widely used tool for evaluating student comprehension of basic Newtonian concepts. This work is based on the revised version of the FCI included with Mazur.[4] The 30-question multiple-choice test challenges students to answer correctly with the one Newtonian choice over four common misconceptions. The FCI allows instructors to determine the extent to which their instruction addresses the misconceptions held by their students. The FCI has been used to show that conventional physics instruction does very little to alter student misconceptions.[1] This conclusion is consistent with studies using other conceptual instruments.[5]

The low FCI score found at many institutions using traditional modes of instruction[1] suggests that student knowledge after the completion of an introductory physics class is often incomplete, fragmentary, and still contains significant errors and misconceptions. One effect of the incomplete state of student knowledge is that a student will sometimes answer correctly on a question, but incorrectly on a closely related question; the student's application of knowledge is *uncertain*. Substantial research effort has been expended to further understand this uncertainty. Students may apply different reasoning methods based on their beliefs about what type of reasoning is appropriate for the situation[6,7] or their general beliefs about how a physics problem should be addressed.[8] A student's general attitude toward the material may also affect the effort or care used in solving problems.[9] Novice problem solvers group problems differently than expert problem solvers, and sometimes this grouping is based on problem context instead of actual problem structure.[10–12] Studies of the effects of problem context have evolved to investigate the consistency of student misconceptions[13] and the consistency of the reasoning behind those misconceptions.[14]

The unsure state of student knowledge reveals itself in performance differences that depend on the context of a question or evaluation. The misconceptions remaining in a student's knowledge may cause a sensitivity to the physical system used in the question: the physical context. Students may be sensitive to the distractors used, whether the test is multiple choice or free response, the presence of a figure, the order of distractors, or the previous questions in the evaluation: the testing context. A student's performance may be sensitive to the amount the examination is worth toward the class, the placement of the exam with respect to the covered material, or whether the exam was announced in advance: the situational context. All these effects will be considered forms of context sensitivity where a student answers differently to two closely related questions.

This work seeks to answer two questions.

(i) Are FCI questions substantially context sensitive to very restrictive context transformations?

(ii) Can the poor performance on the FCI observed at many institutions be explained by context effects; that is, do the context effects of individual problems tend to accumulate or to cancel?

The issue of the possible context sensitivity of the FCI first arose as a result of an analysis of FCI data by Huffman and Heller[15] where they found that student responses fail to cluster under the conceptual categories proposed by the FCI's creators.[3] As an explanation, Huffman and Heller suggested that students are using "bits and pieces of knowledge" to understand forces. In this case, the pieces of knowledge used may depend on how familiar the student is with the context of the question. "Students may be more familiar with hockey pucks than with rockets, and this experience with the context can affect their understanding of the concept."[15] The authors of the FCI challenge this conclusion, and a discussion was carried out in the literature.[16,17] The issue of context sensitivity is independent of Huffman and Heller's conclusion and is interesting and important in its own right.

An examination is a sequence of questions. Most physics questions can be rewritten in multiple ways, changing the wording, the physical system, or the distractors to yield a related question that tests the same physical concept. Therefore, each question can be viewed as a member of a set of

Measuring Earth's Magnetic Field Simply

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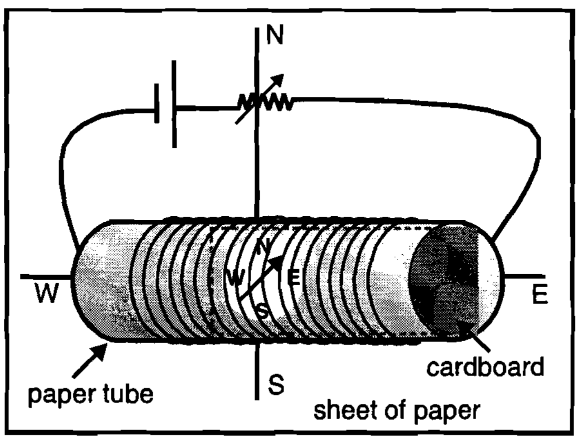
Of the 26 activities and demonstrations and two laboratory experiments in electricity and magnetism that our students do during a semester, the simple little experiment recounted here seems to have struck a special chord.[1] To our surprise, in 240 evaluation responses received over three semesters, this non-flashy, non-dramatic, "string-and-sticky-tape" type activity came in third place on a list of specific favorites. Perhaps it is because students rarely get the feeling of actually having discovered the truth about the natural world for themselves, since laboratory measurements are so often done on prepackaged devices. The popular activity is hands-on, inexpensive, memorable, and useful.

Rationale

The experiment of measuring Earth's magnetic field addresses a variety of goals. First, it provides students with the experience of using science to measure a quantity they view as a fundamental part of the natural world. They use something learned in class to accomplish a goal. We word the instructions to force the student to confront the quantities in the equation for the magnetic field in a solenoid in terms of things to measure, not sets of symbols to manipulate. Detailed procedural descriptions are avoided so that the students have to actively think about what they are doing and estimate in advance reasonable values for the variables. Even a fairly poor job of making approximations results in a final value off by a factor of two at most. Careful consideration of the meaning of variables during construction (such as if a field "escapes" due to separation of wires, or if a compass is slightly off-axis) leads to much better values, often within 10% of the accepted value. Students can determine that the answer is a lower limit, a particularly valuable skill for potential engineers.



Procedure

We divide the class into groups of three and give each group a toilet paper tube with a "window" cut in it, some 28-gauge enameled copper wire, clear tape, a "D" cell battery, a linear (500-Ω) variable resistor, a small (Scout type) compass, a piece of cardboard, a protractor, and an ammeter.

The groups separate themselves from one another as far as possible and place their compasses on a flat surface (wooden stools work well) to check that the compasses show north correctly. Now they tape a sheet of white paper with a north-south line (about 20 cm long) onto the wooden stool. With the protractor they draw the east-west line, and 45° lines through the center.

A 100-turn reference coil is uniformly wound around the tube to generate a magnetic field along the east-west line of the same magnitude as Earth's magnetic field. To keep the wire turns round, it helps to cover the window with a piece of clear tape. At the ends of the coil, tape the wire to the tube to hold things in place, but leave "tails" of wire about 20 cm long. Strip these tails of insulation with sandpaper. Tape the tube to the paper so the field generated in the center of the coil points east-west (thus fixing the direction of the field of a solenoid in students' minds). Cut a cardboard strip to fit across the diameter and down the length of the tube. Tape the compass to the cardboard and slide it into the tube so that it will be visible through the window and horizontally level, with the needle at the center of the solenoid, with regard to both length and radius.

Connect the coil to the battery, the variable resistor, and the ammeter. Adjust the current in the circuit with the variable resistor until the compass needle points along one of the 45° lines; record the value of the current. (A fixed resistor could be used and the field found by vector analysis.)

Students calculate the magnetic field in the coil from the current, assuming the field is that of an infinite solenoid, where n is the number

Using linguistic references to characterize class integration

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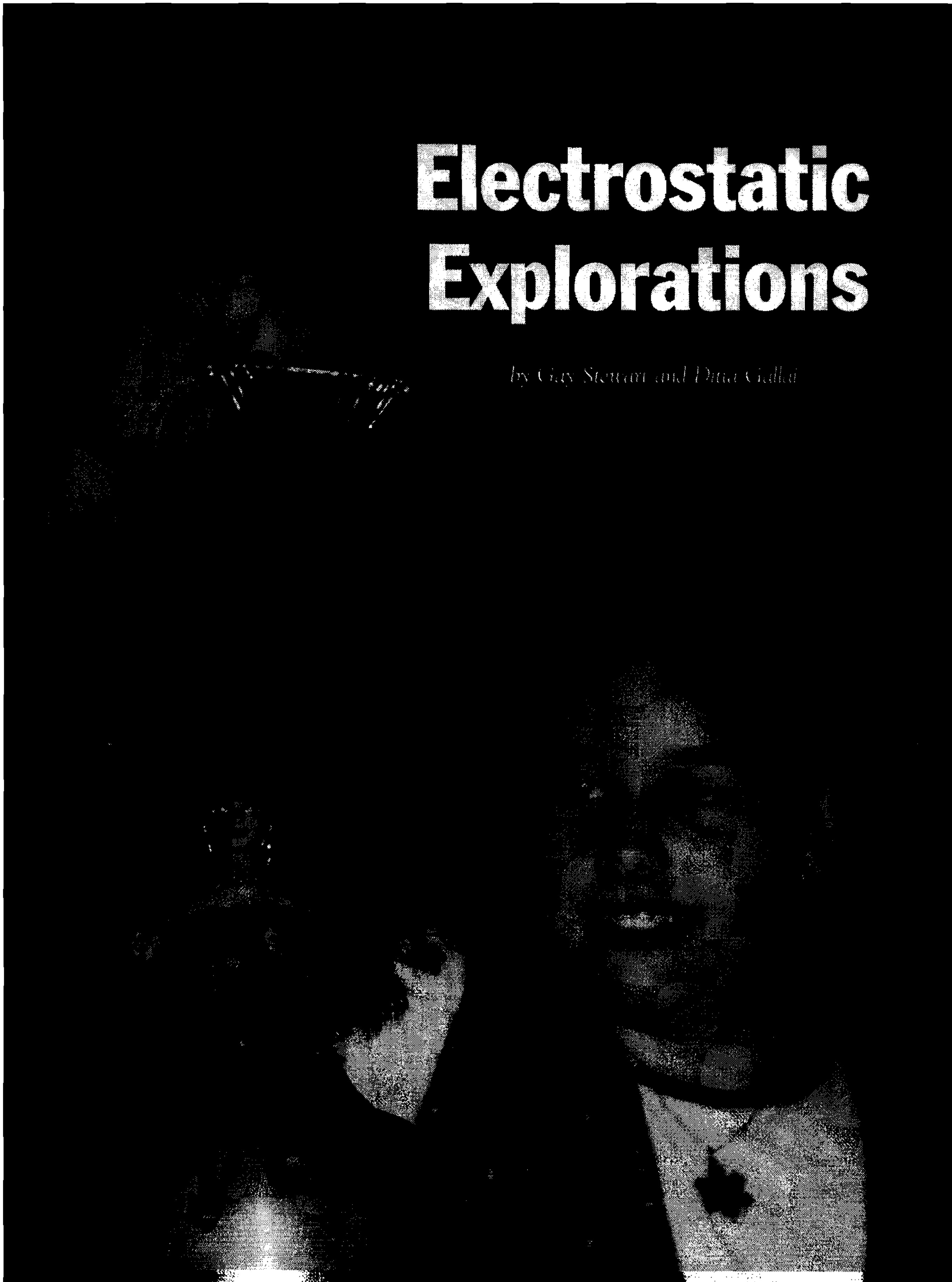
A technique using linguistic references in the communication of a physics class to characterize class integration is introduced. Measurement of a traditional physics class shows only marginal integration. Measurement of a modified physics class shows that integration can be dramatically improved. A measurement of a best-selling textbook shows very good integration of the section text, but poor integration of discretionary blocks, such as examples, problems, tables and illustrations. Various graphical techniques are presented to visualize the reference data.

Physics is a strongly interconnected discipline, but the connections are often not communicated to physics students. Students often view the parts of a physics class as totally disconnected. This paper uses references between pieces of communication within the class to measure, characterize and visualize the degree of integration of physics classes and class materials.

A reference occurs when one piece of communication explicitly mentions the existence of another piece of communication and directs the listener or reader to remember or refer to that communication. For example, if a lecturer said, 'As we saw in homework problem 1', a reference between the lecture and the homework exists. A measurement of references made within a science class offers a quantitative picture of the integration of the class made explicit to the students.

Education research shows that many student problems with learning physics come from a failure to correctly integrate the material. In one study [1], students successful in other fields audited physics classes. Each of the students commented on integration, for example: '... I never really got the idea that the professor had any understanding of how the concepts were related, as he rarely tied information together from more than one chapter...'. Another work [2] listed three issues of concern in revitalizing undergraduate science: misconceptions, expert/novice problem-solving differences, and how educators—and, as a result, their students—organize physical knowledge. 'Conventional instruction appears to students like building different rooms in a house one at a time.' While the connections seem obvious to an expert, a student just learning the material cannot reasonably be assumed capable of forming the proper connections without some guidance. Even the differences in expert and novice problem solving rest primarily on organization of knowledge, how it is connected in the student's mind [3–5].

Another example of the need for integration between class components is demonstrated by a number of studies on laboratory work. Laboratory work, according to a number of sources, is, in part, 'to illustrate lecture courses' [6], 'to help students come to a better understanding of the concept' [7] or 'to illustrate material taught in



Electrostatic Explorations

by Gay Stewart and Dana Gallai

More electrostatic explorations
Gay Stewart; Ditta Gallai
Science Scope; Apr 1998; 21, 7; Research Library
pg. 18

More Electrostatic Explorations

by Gay Stewart and Ditta Gallai

In the February issue of *Science Scope*, we introduced an activity worksheet dealing with electrostatics using common materials that allow students to discover certain laws of physics on their own.[1] This month the explorations continue.

In the last activity we used very simple objects to investigate electric charge. In this activity we will build two classic devices, the electrophorus and the leaf electroscope. These are better than the objects we used previously, because the electrophorus allows us to store a lot of charge, and the electroscope is much more sensitive than the hanging rods.

In the following worksheet activities, students will explore further the concept of induction and learn what grounding means (see Figure 1 for a teachers' answer key). They'll also discover how to charge an object by induction. In addition, they'll learn that a spark is actually charge transfer between objects.

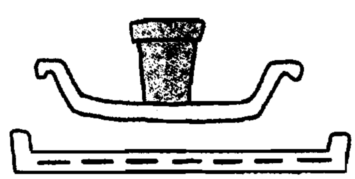
Hints and explanations

These activities use two electrostatic devices: an electrophorus and an electroscope. The electrophorus is used for storing and transferring charge. The electroscope detects whether an object is charged or not.

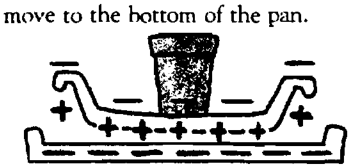
The electrophorus

It is important that students understand how the electrophorus works before moving on to the electroscope activities. The following diagrams illustrate what happens:

1. After charging the cutting board with a plastic bag, the cutting board has a negative charge. At this point, the electrophorus (pie pan) has not come into contact with the cutting board, so it is uncharged (neutral).



2. When students place the electrophorus on the negatively charged cutting board, the negative and positive charges on the electrophorus separate. Because like charges repel each other, the negative charges on the electrophorus move away from the cutting board, toward the rim of the pie pan. The positive charges on the electrophorus are attracted to the negatively charged cutting board and thus move to the bottom of the pan.



3. When students bring their finger near the rim of the electrophorus, the charge that is *not* attracted to the cutting board (the negative charge) escapes into their bodies.

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Pithy problems
Gay Stewart; Ditta Gallai
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pg. 18

Pithy Problems

by Gay Stewart and Ditta Gallai

This is the last in a series of articles published in *Science Scope* dealing with electrostatics. The activities presented allow students to gain an understanding of what can be a very confusing subject. Even some college textbook authors have made mistakes explaining induction—mistakes our fourth graders have been able to correctly explain after completing these activities.

Let's go over what students have learned with these activities.

1. There are two types of electric charges (negative and positive), and like charges repel.
2. Any charged object attracts an uncharged object, although the uncharged object must be light for the attraction to be observed.
3. A charged object can separate the charges in an uncharged object.
4. Grounding an object removes excess charge.
5. If charge separation has occured on a conductor, such as an electrophorus, it will lose a charge when grounded. The conductor will then have become charged by induction.
6. Conductors of different shapes and sizes hold different amounts of charge (in this month's activity, the pith ball only removes some of the charge from the pie pan because the ball is fairly small).

Many of these observations will become clearer to students as they develop a more technical language, but the activities establish a good foundation for that future learning.

This final activity includes observations that students seem to find just plain fun. Just make sure students understand how charges are distributed in metals. If you charge a metal object and it comes in contact with an uncharged metal object then both get charged. When the pith ball bounces between the pie pans, students—even college students—have been known to giggle. Let them learn and enjoy. And remember, if you have any problems visit our web site at *http://www.uark.edu/depts/physinfo/schoolmaterials*. ❑

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Answer key

1. The clear rod repels the pith ball.
2. Since we know that the clear rod charges up positively and there is repulsion between the rod and the pith ball, the ball must also have a positive charge.
3. The pith ball will be attracted to the golf tube.
4. The pith ball was charged up the same way as before. Therefore, it again must have a positive charge. We know that the golf tube has a negative charge because it attracts the pith ball. This agrees with what we learned in the first activity.
5. As the pith balls approach the electrophorus, they will be attracted to it because they are uncharged. When you touch the two pith balls with the electrophorus, they both will take on some of the positive charges and then repel each other.
6. When the electrophorus touches one of the pith balls, negative charges move from the pith balls to the electrophorus. (Remember that charges are free to move in a metal.) The two balls are touching each other so some charge moves onto each ball. Both of the balls become positively charged; therefore, they repel each other. The pith balls are like the leaves of an electroscope.
7. The uncharged pith ball is attracted by the electrophorus. Once it gets charged, it bounces away from the electrophorus and will hang away from it.
8. The pith ball, like a pendulum, moves back and forth between the two pans. If the pans are close to each other, the ball moves faster.
9. When the pith ball touches the charged electrophorus, it takes some of the electrophorus' charge, is repelled, and then hits the other (uncharged) electrophorus. When the ball hits the uncharged electrophorus, most of the charge from the ball moves to the electrophorus. Because the pan and the ball now have the same charge, the ball is repelled. Once again it touches the first electrophorus and the whole process starts again. The pith ball carries charge from one electrophorus to the other.

Journal of Women and Minorities in Science and Engineering, vol. 4, pp. 27–42, 1998

CLOSING THE GENDER GAP IN STUDENT CONFIDENCE: RESULTS FROM A UNIVERSITY OF ARKANSAS PHYSICS CLASS

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It is agreed that an increasing level of technical literacy will be needed to maintain the society of the future. A lower level of technical literacy for women and minorities translates into a perpetuating economic disadvantage for them and for our country. The question then becomes how to best include and educate this workforce. In this study, women's and men's perceptions of and confidence in an experimental physics class at the University of Arkansas, Fayetteville, are compared. The class is a National Science Foundation sponsored CCD project that does not address women specifically, but attempts to improve the educational experience for all students. The results presented indicate that women make statistically significant gains in confidence and attitude toward science in the experimental course when compared to a traditional course. "Statistically significant" *gain is taken to mean that a statistically significant gap between men and women favoring the men was reduced to a statistically insignificant gap or that a statistically insignificant gap between the men and the women became a statistically significant advantage to the women.*

INTRODUCTION

For years now there has been much discussion about the poor state of science and math education in America (Tobias, 1992). Science and engineering are two fields that still have a large gender gap as well as poor representation by certain minorities (American Association of University Women Educational Foundation, 1995). So there appears to be a twofold problem: first, how to get more students interested in science and engineering, and second, how to make sure that these students come from a larger cross-section of the population.

If, however, a program is designed to address one of these issues, it potentially will have an effect on the other, because both issues deal with the students' perceptions of the material. This study will address how a program designed to improve overall student interest affects the perceptions of female students versus male students. The program is the University Physics II (UP II) project currently underway at the University of Arkansas. A perception survey based on the "University of South Carolina System Model Project for the Transformation of Science and Math Teaching to Reach Women in Varied Campus Settings" (Rosser & Kelly, 1994) is the instrument that will be used to make the comparisons. Students' performance as they progress through the introductory physics program is being tracked by several methods, test scores, homework scores, etc. This particular study was done to give an indication if improvements seen in other data were due to an improved class atmosphere and not solely due to other factors.

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Part I: Toward a System of Educational Engineering for Traditional Class Elements: A Case Study in an Introductory Physics Course

Gay B. Stewart[1]

In this paper, we present a system for formally characterizing elements of an introductory science class, measuring the performance of a class based on this characterization, and modeling the value of the class based on the measurements. This system allows the iterative improvement of any educational presentation through a model, test, iterate cycle. We propose formal practices involved in iteratively improving an educational experience be called educational engineering.

KEY WORDS: Science education; educational engineering; modeling.

INTRODUCTION

An experimental class in Calculus-based Electricity, Magnetism, and Optics has been running at the University of Arkansas for the past two years. It is an experiment which mixes lecture and laboratory within a single classroom setting. Conventional Electricity and Magnetism (E + M) experiments have been replaced with numerous activities, using commonplace materials when possible. Discussion within class is lively and strongly encouraged. Novel class policies encourage students to do reading before the material is covered and to come to class prepared to ask good questions. The class still contains a strong traditional component in the form of an average of twelve homework (Tipler, 1991) problems a week. Student performance on exams is increased by a letter grade over previous offerings of the course on more difficult exams, and when a 50-minute exam from a 1990 offering of the course (almost classic bell-curve grade distribution, average = 53.8, σ = 2.6) was given in the new course the students finished it in 35 minutes or less with average = 69.2, σ = 2.0. Students routinely rank the course in the top 10-30% of all courses taken in college, and the best science class. They do well on qualitative exam questions and have performed well on standardized tests and exams given at other institutions. Outside evaluation of the course has been positive. Therefore, by the normal criteria of education research, we have produced a successful experimental physics class.

The class design is based on an adaptation of current ideas in physics education research and original ideas of the primary instructor to the staffing and facility parameters set up by the University of Arkansas. The current implementation of the course is analogous to an initial prototype of an invention. It contains rudimentary implementations of some original ideas plus traditional class elements adapted to support the novel presentation of the course. The particular form of the components of the course is based on the instructor's intuition and experience. If the class is analogous to the initial prototype of an invention, the next step should be to apply sound engineering practice to iteratively optimize the course so that the ideas involved reach their full potential. Once the course is optimized, the need for additional innovative components could be identified and implemented. A system that allows an educational

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Part II: A Computationally Based Modeling System for Class Elements Using Formal Observer-Based Experimental Connections

Gay B. Stewart[1,2] and John C. Stewart[1]

This article extends and refines the modeling system presented previously (Stewart, 1997). The initial system was sufficient for the optimization of delivery of education at a departmental level. This system is greatly more powerful, precise, and scientific, and fulfills the role of a modeling system for the research and development of educational practices. The model is applied to two widely diverse educational processes, Student Actions and Do Homework Problem, establishing the formalism and demonstrating its usefulness. The use of a rigorous computational syntax imposes completeness criteria on the modeling itself and uniformity. Experimental definition of the formation process of the patterns allows anyone to introduce new features of a model. This and the uniformity allows the models to become the property of the education community, not merely a single researcher, in the same way that mathematical models allow scientists to utilize and build upon previous research.

KEY WORDS: Science education; educational engineering; modeling.

INTRODUCTION

In a previous paper (Stewart, 1997), we presented a system for educational engineering which was appropriate for modeling and improving features of introductory science classes. The modeling system presented was designed to allow departments to model, measure, and iteratively improve their classes. In this paper, the system is refined to support the diverse modeling tasks of education research. The system in the previous paper will be extended in four main ways: (1) The addition of strong computational syntax rules and the introduction of basics types, (2) The extension of the modeling power by allowing logical relationships between patterns consistent with modern bject-oriented computer languages, (3) The extension of definition through observer-based experiment to all aspects of the modeling system, (4) The incorporation of statistics and merit dimensions directly into the modeling system.

The refinement will proceed by identification of weaknesses in the model presented in our previous paper and extending the power, precision, and experimental binding of the modeling system to eliminate those weaknesses. This puts us in the unusual position of criticizing the work in the first part of the paper in the second part. This unusual situation came about because the research presented in the first paper (Stewart, 1997) was completed earlier, yielding exceptionally promising results, but it was obvious that the modeling system was incomplete. To eliminate the incompleteness, the modeling system was more rigorously applied to characterizing physics textbooks and as a result, the system evolved to meet the greater challenge. The system presented in this paper is the one currently in use by the Arkansas Precision Education Group for making precise characterizations of educational objects. This system is greatly more powerful, precise, and scientific than

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Journal of Science Education and Technology, Vol. 6, No. 4, 1997

Optimally Engineering Traditional Introductory Physics Classes

Gay B. Stewart,[1] John C. Stewart,[1] Sean Slape,[1] and Jon Osborn[1]

This paper presents a measurement of the time and resources committed to traditional student actions such as reading and working homework. The perception of the educational value of each basic action for both students and faculty is captured. From this information, basic educational efficiencies are computed for a traditional mechanics course and a non-traditional hands-on Electricity and Magnetism course. The calculations show an allocation of resources in the traditional course which uses the most student time in the least educationally valuable activity. The computed efficiencies also show overseen student note-taking as potentially a very valuable general tool. The techniques presented allow any institution to carry out quantitative educational engineering of their course offerings at the highest level.

KEY WORDS: Science education; educational engineering; modeling.

INTRODUCTION

Section 1

In an earlier paper (Stewart, 1997), the concept of *educational engineering* was introduced as the key missing component in education reform efforts. *Educational Engineering* is defined as any set of methods which allow a model, measure, improve, iterate cycle to be applied to course offerings, thus ensuring the offerings improve within the level of refinement of the models. It is documented that educational reform initiatives have poor portability (Jackson, 1984). As will be shown in the analysis that follows, traditional offerings are not well time-optimized to either the student's or faculty's perception of educational value. So if the traditional offerings are very sub-optimal within the designer's opinions of value, it is unlikely that a more complicated educational reform offering will be correctly implemented in detail. It would seem a more rational approach to reform to first gain a quantitative understanding of the existing offerings, to optimize within that understanding, and then to identify parts of the optimized course which need replacement. The current technique of completely replacing a traditional course with a completely different educational reform course that is optimized for a different institution allows no real comparison. Any superiority of one course over another could be a result of accidental differences in the level of optimization, which could fluctuate as instructors and teaching assistants change.

In this paper, a high level model of student and faculty actions for introductory science classes at the University of Arkansas is presented, measurements are made based on the model, and a rich variety of statistics are calculated from the measurements. These statistics form the basic engineering quantities of a science class. Section 2 presents the model. Section 3 describes the measurement procedure. Section 4 reports the results and identifies a set of engineering statistics. Section 5 discusses the use of the measurement to engineer the classes measured. Section 6 discusses how educational engineering would be used to improve the class.

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APPARATUS FOR TEACHING PHYSICS

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The Rail Gun

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A rail gun demonstration can address a broad group of educational goals in introductory electricity and magnetism. Our rail gun uses a battery-powered circuit consisting of a moveable conductor (projectile) placed across two conducting rails in a magnetic field. We use the rail gun to review mechanics, foster approximate reasoning and lateral class discussion, and demonstrate the use of physics in calculating properties of the universe.

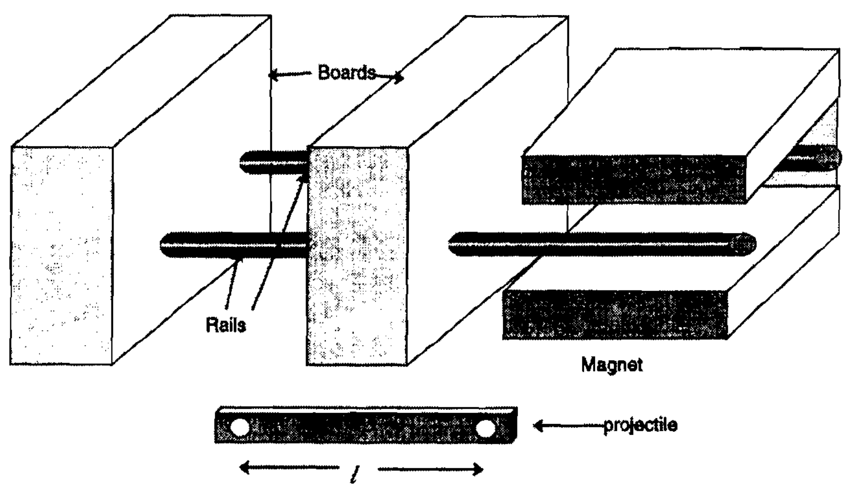

Fig. 1. Projectile with drilled holes and orientation of boards, rails, and magnet for rail gun apparatus.

Construction

Simple Model. Our original rail gun was two brass welding rods taped to a book and two aluminum spacers connected by a copper wire (total cost about $2). A broad magnet with narrowly spaced poles that will produce a strong, fairly uniform, field is required. This "bargain" rail gun is excellent for student familiarity and encourages the students to build their own, but requires constant adjustment.

More Dependable Model. An "upgraded" rail gun is also inexpensive, with only the magnet[1] being costly. Unlike the excellent set of experiments for $\vec{F} = q\vec{v} \times \vec{B}$ with an electron gun,[2] no elaborate support equipment is needed. The materials are familiar, and the force is something that can be felt as well as seen.

You will need two pieces of 1- × 4-in board an inch wider than the magnet, a piece of rectangular brass tubing (projectile) cut the same width as the magnet, two solid brass welding rods 10 in long, an ammeter, 6-V battery, meterstick, knife switch, and three alligator leads.

On a drill press, drill holes through the projectile that are 1/32 in larger than the rails. As shown in Fig. 1, the holes should be drilled through the broad side of the projectile. The rails should be inside the magnet, but close to the edge. Mark holes the same separation on the boards by using a nail to dimple the board through the projectile. The holes are positioned so that the rails run parallel through the center of the magnet, perpendicular to the field, and at a fixed separation so the projectile can pass between the magnet's poles. The rails must be smooth, with any corrosion removed so they conduct well, and the projectile must fall off the rail ends easily. Sliding the projectile along the rails