Comparison of Teaching Methods for Energy Conservation

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Abstract. Three sections, taught by different instructors, of Conceptual Physics were taught energy conservation using three different techniques: traditional - no visualization, energy bar charts, and energy bars. Performance of the groups of students on final exam questions is compared and contrasted.

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INTRODUCTION

By now the idea that students learn via different modes has become part of the standard teaching lore.[1,2] In a related but distinct vein, there is evidence in physics that expert problem-solvers employ multiple paths in solving a single problem more often than novice problem-solvers do.[3-5] These strands come together in the command "Draw a picture" found in problem-solving rubrics over at least the last two decades and sometimes now divided into "picture" and "physical representation".[6,7]

Work and energy are standards of the introductory physics curriculum. Students struggle to apply these concepts in varied contexts and to apply concepts without a numerical check in qualitative problems.[8] Until 2001 there was no common (i.e. shared in the literature) physical representation system for work-energy problems. Van Heuvelen and Zou defined energy bar charts as a physical representation of work-energy problems and analyzed the effects of their use on Ohio State University students in the calculus-based introductory sequence. They found a positive effect on qualitative problem-solving success among students taught to use the energy bar charts though only some students spontaneously drew the charts on free-response questions when it was appropriate to do so.[6]

One of us [MLH] created energy bars as a means of making energy conservation easier to see. Horizontal energy bars are divided into sections for various types of energy. The lengths of sections change over time as energy is moved from one system to another or changes form within the system. In the following sections, we discuss a comparison, based on common exam questions, among three sections of the same course using respectively no physical representation, energy bar charts derived from those of Van Heuvelen and Zou, and energy bars.[6]

DESCRIPTION OF COURSE

We drew our comparison sections from a one-semester, conceptual physics course as part of the introductory component of the Southern Illinois University Edwardsville (SIUE) general education curriculum. The course is intended for freshmen and sophomores although, in practice, the course has a substantial population of juniors and seniors. This course is not a prerequisite for anything else in the curriculum, and as such there is considerable diversity in its teaching.

We used three regularly-existing Fall 2005 sections for this study, taught by three different professors of similar age and experience. Each instructor had taught this course recently at least once before the term in question and no instructor made substantial changes from these previous semester. All of the instructors volunteered to participate in the study and had already planned to spend approximately the same amount of time on the topic of energy. Students chose sections without any indication of teaching method. The sections were all of typical size for this class at SIUE (~50 students).

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Overview of Instructional Techniques

Each section spent approximately a week covering work and energy. The "traditional" section used lecture and examples. No system of physical representation was employed, although pictures were used in explanations and problems.[MJ] The energy bar charts section used interactive methods and a group activity involving bar charts based on those of Van Heuvelen and Zou.[6][RL] The energy bar section used lecture, examples, and group problem-solving all employing energy bars.[MLH] Figure 1 is an example of energy bar and work-energy bar chart physical representations of problems. The energy bars were taught using the simpler form shown in figure 1a.

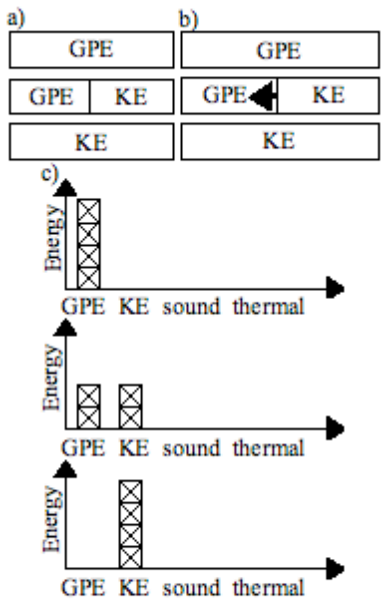

FIGURE 1. Sample Problem illustrating energy bars and energy bar charts: A ball is dropped from the top of a 10m tall building. How fast is it falling when it has fallen half-way to the ground if air resistance can be ignored? Physical representations in (a) the simple version of energy bars used in this study, (b) a more elaborate version of energy bars with an arrow indicating that GPE is increasing at the expense of KE as time passes, and (c) energy bar charts are shown. GPE=gravitational potential energy. KE=kinetic energy.

Research Questions

In this study we attempted to answer the following research questions. What effect do energy visualizations have on overall understanding of energy conservation? Do students using the energy bars conserve energy more frequently than students using energy bar charts?

Evaluation

We used common final exam problems addressing content common to all sections and within the typical styles of questions our students could expect on exams. These problems included multiple choice, numerical, physical representation (not for the traditional section), and free response qualitative and quantitative types. We will focus on the first three types here.

Common Exam Questions

MC1: A pendulum is released at an angle, and then swings back and forth for some time. After a while, it eventually comes to rest. Which of the following is a correct statement about the pendulum's energy? (a) The total energy of the pendulum is conserved, because any object's energy is always conserved. (b) The total energy of the pendulum is conserved, because it is on the Earth. (c) The total energy of the pendulum has increased. (d) The total energy of the pendulum has decreased.

MC2: A bullet is sitting in a gun. I point the gun in the air, and pull the trigger. The bullet comes out, and flies far up into the air, reaching a maximum height, high above my head. How, if at all, has the bullet's total energy changed, from the time just before I pulled the trigger, to the time it reached its maximum height in the air? (a) The total energy of the bullet has increased. (b) The total energy of the bullet has not changed. (c) The total energy of the bullet has decreased. (d) There is not enough information to choose between the above.

MC3: When a pendulum, with no friction or air resistance, is swinging, when is the total energy of the pendulum a maximum? (a) Never. Energy is conserved. (b) At the bottom, when the pendulum is moving the fastest, is when the energy is a maximum. (c) At the side, when the pendulum is at its maximum height, is when the energy is a maximum. (d) Somewhere just before the pendulum is at the bottom of its swing is where the kinetic energy and gravitational potential energy add to a maximum.

MC4 (bar charts and energy bars sections only): At the beginning of the test a popper toy was demonstrated. At the instant it was released on the table its energy could be described as below. [graphic of all initial energy as SPE] Which of the figures below best describes the energy of the popper toy at the top of its flight? (a) [graphic of sound and GPE – conserved] (b) [graphic of sound, GPE, and KE – less energy] (c) [graphic of KE and GPE – discrepant versions: conserved in bar charts, less energy in bars] (d/e) [graphic of SPE – conserved] (e/f) [graphic of sound and GPE – less energy] (f/d) [graphic of sound, GPE and KE – conserved]

WP1: You launch a ball directly up into the air. It is initially on the ground, with a kinetic energy of 60J (shown for bar charts and energy bars sections). Ignore air resistance. (A) Consider the ball when it has reached its maximum height. (i) What is the ball's kinetic energy? (ii) What is the ball's gravitational potential energy? (iii) (bar chart and energy bar sections only) Draw the energy bar (chart) for the ball at this point. (B) Repeat (A) for when the ball is moving up and halfway to its maximum height.

Data Analysis

Primary Trait Analysis[11] was utilized to determine the overall effectiveness of the three different instructional techniques by comparing the results on all common problems. The following coding scheme was utilized to compare energy bars to energy bar charts on problems referring directly to the representation technique.

Conservation of Energy	Energy Types	Relative Sizes
C - Conserved	C – Correct Energy Types	C – Correct
NC – Not Conserved	I – Incorrect Energy Types	I – Incorrect
B - Blank	B - Blank	B - Blank

Table 1: Coding scheme for analyzing energy bar / energy bar charts

RESULTS AND DISCUSSION

We addressed our first research question by the primary trait analysis discussed above. As shown in Table 2 and Figure 2, the results run counter to the leading belief that interactive engagement methods produce higher conceptual gains. In fact, the traditional section scored the highest.

Instructional Technique	N	Average Percent Correct (Standard Deviation)
Energy Bar Charts	46	55% (21%)
Energy Bars	55	59% (25 %)
Traditional	61	75% (22%)

Table 2: Primary trait analysis results for three instructional types. Results were calculated out of a possible seven points. Standard deviations shown in parenthesis. Using ANOVA results are significant at $p \leq 0.0001$.

We addressed our second research question by applying the coding scheme in Table 1 to student responses to MC4 and part (iii) of WP1. While Table 3 shows no significant difference between visualization techniques, Table 4 shows significant differences in particular sub-categories of applying the techniques.

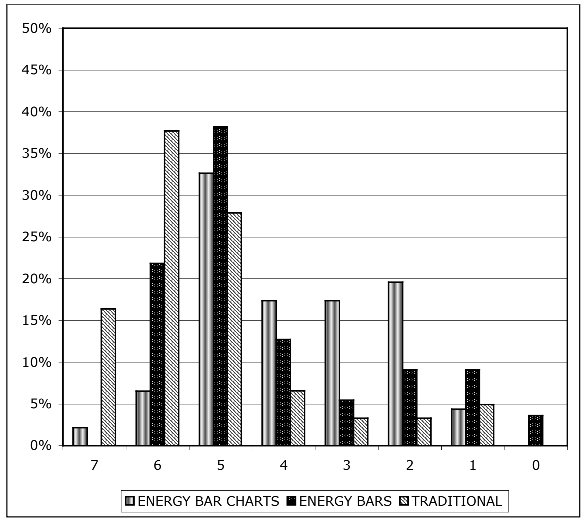

Figure 2: Distribution of student scores for each instructional technique. Results were calculated out of possible seven points. Results are significant at $p \leq 0.0001$.

Instructional Technique	N	Average Percent Correct (Standard Deviation)
Energy Bar Charts	46	71% (31%)
Energy Bars	55	74% (30 %)

Table 3: Comparison results for visualization questions. Results were calculated out of a possible seven points. Standard deviations are shown in parenthesis. Using a t-test, results not significant at the 0.05 level.

Instructional Technique Average Percent Correct (Standard Deviation)	Energy Bar Charts N = 46	Energy Bars N = 55
Energy Conservation $p \leq 0.0003$	84% (33%)	53% (48%)
Energy Types $p \leq 0.007$	63% (48 %)	80% (38 %)
Relative Sizes Not Significant at the 0.05 level	73% (39 %)	85% (30 %)

Table 4: Comparison results for visualization questions separated by content evaluated. Results were calculated out of a possible two points. Standard deviations are shown in parenthesis.

Students using energy bar charts were more likely to maintain energy conservation, while students using the energy bars are more likely to correctly characterize the types of energy present in the various situations. The latter results may be due to asking the students to ignore air resistance, which was specifically included in all examples utilized in that section. The former difference may be due to the ease with which energy conservation can be drawn using energy bars (drawing same-sized rectangles versus adding up the number of squares in various columns) so that the expected reinforcement is not occurring.

CONCLUSIONS & IMPLICATIONS

We observed several statistically significant results. According to these results, traditional instruction seems to be the superior technique. Energy bar charts and energy bars seem to be similar; energy bar charts seem to encourage the use of energy conservation, while energy bars produce a more correct analysis of energy types present. Although these results are statistically significant, they may not be educationally significant as there are numerous confounding factors that need to be taken into account.

Confounding factors

Differences between test versions: There were drawing errors between the two versions of MC4. Having one answer conserve energy on one exam and not on the other means the distribution of answers with respect to energy conservation and energy type was not the same for the two exams. It is possible that having the answers in a different order affected the outcome as well. In addition, one of us [MLH] wrote two versions of the exam as a deterrent to copying and altered the order of answers to the other multiple choice questions for approximately half of that section.
Inherent problems with questions: There may be an author effect occurring with the questions. Instead of using either standard questions or co-authoring problems, we used problems suggested or written by one person (most often MJ) with editing and approval from the other two. As the students in the traditional section were accustomed to questions written by this author it may have inadvertently biased the sample.
Lack of Randomness: While students self-assorted into sections, we do not have background information on the students to assess the randomness of this assortment.
Small Sample Size: Due to our class sizes, our sample size was small.
Student-Teacher Dynamics: Because three different people taught the sections, there are a host of possible teaching-method and student-teacher dynamics that we did not control for. On the other hand, each instructor used the methods he or she preferred, so there was no bias resulting from one instructor preferring or being more comfortable with one method.

FUTURE WORK

In addition to the questions discussed here, we had two free-response questions on a mid-term exam. We hope that analysis of these responses will illuminate causes of the trends discussed here.

Further studies of this type could be carried out, with either single or multiple instructors, in either the course used here, or other courses with multiple sections

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