Effects of Visual Cueing on Beginner Problem Solvers in Physics

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Abstract

Previous research suggests that manipulating learners' eye movements may affect cognitive processing. This study builds on a previous study by investigating problems that were found to have large differences in eye-movements between beginner problem solvers and expert problem solvers. In this study, beginner physics problem solvers were asked to solve problems with highly visual components, adapted from our previous study (Carmichael 2010). If students gave an incorrect answer and/or verbal explanation for their answer, they were shown scaffolding problems. In each scaffolding problem, students in the treatment group were cued to look at colored shapes overlaid on the problem diagram that moved in some pattern. Students in the control group viewed the problem diagram with no overlays. Cues were designed to direct attention to relevant areas of the problem. After a given number of scaffolding problems, students were shown a transfer problem which assessed conceptual understanding of the material tested in that problem set. After the initial, scaffolding, and transfer problems, students were asked to give a verbal explanation of their answer. We found that students performed better on later problem sets after receiving cueing, and a larger number of students answered the scaffolding problems with correct explanations in the cued group. Students who received cueing also changed their explanations more often and were more likely to mimic the cueing sequence on similar problems. Future work is needed to test these ideas for larger numbers of students.

Background and Introduction

Previous research has suggested that manipulating learners' eye movements may influence their cognitive processing (Grant, 2003; Thomas & Lleras, 2007) and that cognitive processes may be affected by directing eye movements (de Koning, 2007, 2010). Specifically, previous research has shown correlation between eye movements in "thematically relevant" (TR) areas of a problem diagram and higher problem solving accuracy; similarly, looking at "perceptually salient" (PS) areas that are not meaningful to the problem correlate to lower problem solving accuracy (de Koning 2007). Perceptually salient areas are features of the diagram which are initially most noticeable, or in other words those that draw attention via bottom up processes. Thematic relevant areas are portions of the diagram that contain visual information required for the problem solution. Carmichael (2010) has shown that among students solving visually-based physics problems, students who chose the correct answer looked at the TR areas of the problem more frequently, and students choosing incorrect answers looked at the PS areas of the problem more frequently.

This exploratory study builds on Carmichael's (2010) study by using four problems from that study which showed the greatest difference in percentage of eye-fixations in PS and TR areas between correct and incorrect problem solvers. In this study we add visual cues that move in a pattern related to the problem solution. Addition of visual cues has improved problem solving speed and correctness on Dunker's radiation problem, an insight problem, (Grant, 2003; Thomas & Lleras, 2007), but has not been tested in the domain of physics.

We investigated the application of this idea to introductory physics problems. We compared the effect of providing scaffolding using isomorphic problems with and without cueing of TR areas of the problem. Specifically we seek to determine how visual attentional cueing affects the likelihood of correctly answering the transfer problem, the number of scaffolding problems needed before proceeding correct solution, the quality and correctness of verbal explanations provided for solving the problems, and the scan path of the eye movements of students after viewing cued isomorphic problems.

Design and Method

Experimental Design

The volunteers recruited for this study were either previously or currently enrolled in an introductory physics course. Volunteers first completed a survey to assess their prior physics knowledge of concepts relevant to problems used in this study. Only those students whose survey responses indicated knowledge of the concepts used in the study were chosen to participate. The chosen participants were divided into two groups: cued (N=8) and non-cued (N=7).

Students in both groups were asked to solve four sets of problems with highly visual components, adapted from our previous study (Carmichael, 2010). In each set, students answered an initial problem and provided a verbal explanation for their reasoning. The initial problem in each of the four problem sets was identical to the problems in our previous study. If the student answered the initial problem incorrectly or provided an incorrect verbal explanation, they were presented a scaffolding problem which was isomorphic to the initial problem in that it had an identical problem statement but a different diagram as illustrated in Figure 1.

Students in the cued group were asked to follow colored shapes overlaid on the scaffolding problem as they moved across the screen in one seconds intervals. The motion of these colored shapes was based on results of our previous study (Carmichael, 2010). Care was taken to make sure that cueing did not only occur near the area with the correct solution, but across several areas relevant to the correct conceptual understanding of the problem. This was done to avoid cueing students to only the correct answer, rather to cue them to the right concept without explicitly indicating the answer. After answering the problem, students were asked to provide an explanation.

Students in the non-cued group were shown the same sequence of scaffolding problems, but without any colored shapes overlaid on the problems. They too were asked to provide their answer and reasoning for each problem. In other words, students in the non-cued group experienced exactly the same problems as the cued group, except they did not receive any visual cueing.

In both the cued and the non-cued group, if the student answered a scaffolding problem correctly and provided correct reasoning, they were presented with the transfer problem. Conversely, if the student answered a scaffolding problem incorrectly or provided an incorrect explanation they were presented with another scaffolding problem. This sequence was repeated until a maximum of three scaffolding problems had been presented. After that a transfer problem was presented, regardless of whether the student had answered the third scaffolding problem correctly. The flowchart shown in Figure 2 depicts this decision tree for one problem set for either the cued or non-cued condition. Throughout the problem solving process, students' eye movements were tracked using an EyeLink 1000 eye tracker, to both verify that the cued participants were following cues and to compare the eye movements of the cued and non-cued groups.

Individual Problem Set Design

Each set of problems used was derived from an initial problem taken from our previous study (Carmichael, 2010). The scaffolding problems in each set were used to target common misconceptions with the concept presented. The transfer problem in each set contained a slightly different context than the initial and scaffolding problems, and aimed to test the depth of the student's knowledge on the concept.

The first problem set involved two roller coaster carts of the same mass traveling down frictionless tracks as shown in Figure 3. Both carts start and end at the same height, but the hills along each track differed in both height and width. Further, there were different numbers of hills on each track. The problem asked the students to compare the final speeds of the two carts, if both carts started from rest. The multiple-choice options provided to the student consisted of the first cart (A) traveling faster, the second cart (B), traveling faster, both carts ending with the same speed, and an option for ‘not enough information.’

Each scaffolding problem associated with the aforementioned initial problem contained an identical problem statement and multiple-choice answers. The scaffolding problems differ only in the shape of track presented. The differences between the tracks in each scaffolding problem targeted commonly encountered misconceptions. For example, one scaffolding problem showed two tracks that travel to the same minimum height, but contain a different number of bumps, while another problem contained two tracks that are identical in their height at each point and contain the same number of bumps but differ in total horizontal length traveled.

The cueing process in these scaffolding problems was designed to help students attend to the thematically relevant regions in the diagram, or in other words, the regions of the diagram that contained the information necessary to answer the question. In the roller coaster problem, students needed to attend to the initial and final heights of Cart A and Cart B. Colored circles were overlaid on the problem image, flashing first between the initial positions of Cart A and Cart B, then the final positions of Cart A and Cart B. This pattern of eye-movement is similar to the observed patterns in our previous study (Carmichael, 2010).

After completing the scaffolding problems, students were given a transfer problem. The roller coaster transfer problem contained the same problem statement and answers, but differed in the type of track displayed. In the initial problem, initial and final heights of Carts A and B were all identical, while in the transfer problem, Carts A and B still have the same starting and end elevation, but the change in elevation was non-zero. This transfer problem aimed to test the student's understanding of conservation of energy in a slightly different context than the initial and scaffolding problems.

The second problem set involved two balls rolling along two separate flat paths, one path located above the other (Fig. 4, left). The position of each ball was shown on the diagram at one-second intervals, creating a freeze frame diagram. The students were asked to determine the time at which both balls were moving at the same speed. Six multiple-choice answers were provided, ranging over the time period displayed in the diagram up to 0.5 second accuracy.

Each scaffolding problem depicted the same two flat tracks with balls shown at one-second time intervals as the initial problem, though the exact position of the balls on each track differed between problems. Each scaffolding problem contained the same problem statement as the initial problem, but contained different answer choices due to the differing positions of the ball in each of the scaffolding problems. Efforts were made to ensure the interval over which the balls traveled the same distance were not directly above or below each other, to test better conceptual understanding of the concept of speed.

The cueing process for these problems involved colored squares overlaid on the problem behind the ball at various times. The cues moved, for example, from 1s to 2s on Ball A, then to 1s and 2s on Ball B, then from 2s to 3s on Ball A, etc. This ordering was chosen due to evidence from our previous study that correct problem solvers compared the distances between adjacent balls on track A to those at the same time on track B (Carmichael, 2010).

The transfer problem in this set showed a similar problem situation, but dealt with vertical motion instead of horizontal motion. The problem statement introduced Ball A in an elevator traveling downward at constant velocity, while Ball B fell freely from an adjacent building's rooftop, and both Ball A and B were dropped at the same time.

The third problem set involved a skier traveling down a hill with a changing slope (Fig. 4, right). The slope had three different constant values. The different slopes varied in vertical distance and horizontal distance covered, and therefore varied in steepness. The student was asked to rank the skier's change in potential energy as he traveled down each slope. To assist with this problem, a vertical bar on the edge of the diagram helped to show the amount of vertical displacement over each slope.

The scaffolding problems depicted different values for the three slopes on the hill. Efforts were made to adjust the steepness and vertical displacement in different combinations to test the understanding of the factors affecting potential energy. The shape of each hill was notably different, to determine the effect of this perceptually salient feature of the problem.

The cueing in this problem draws the student's attention to the vertical displacement for slope. A colored square would flash between the starting elevation of one slope and the ending elevation of that slope twice, then move to the next slope and repeat this process. This was intended to bring the student's attention to the vertical displacement of each slope, rather than the steepness of the slope on the other side of the screen.

The transfer problem for this set involved a ball traveling in parabolic motion. Three portions of the ball's motion were noted, A-C, and students were asked to rank the change in potential energy over each of these segments. This different context expanded on the previous understanding by now incorporating positive and negative changes in the potential energy.

The last problem set showed a distance vs. time graph with two lines on it representing the motion of two different objects (Fig. 5). One object was moving at a constant speed, while the speed of the second object was changing. There was one point on the graph where the lines representing the object's motion intersected. The students were asked to determine the point at which both objects are traveling at the same speed. Five points (A-E) were labeled on one object's graph, with at least one point where the two graphs intersect. The student then chose from one of the five points (Answers 1-5) or chose that the objects were moving the same speed at all points (Answer 6).

Similar to the initial problem, each scaffolding problem contained one object that moved at a constant velocity, depicted with a line of constant slope in the graph, while the other object had a changing velocity, depicted with a line with changing slope. The scaffolding problems also contained at least one intersection point between the lines representing the motion of the two objects. The scaffolding problems provided the same problem statement answer choices as the initial problem. The difference between the initial and scaffolding problems was the specific motion of the two objects.

The cueing process in these problems involved a small circle flashing at the position of each answer choice on the line on the graph depicting changing velocity. The circles were flashed in the shape of the tangent line at the point of each answer choice. The circles flashed back and forth twice on each point surrounding the correct answer. It has been found that experienced problem solvers judge the slope of the changing velocity line and compare it to the slope of the constant slope line. The cue in the shape of the slope was created to mimic this.

The transfer problem for this set again showed a distance vs. time graph for two objects. This problem showed one object with a constant velocity, while the other object's motion was no longer a smooth curve but a piecewise function consisting of several segments, each with a constant slope. Of the five points denoted on the graph, three were at intersection points of the two lines, while the other two were at points when both objects had a constant zero velocity.

Analysis and Findings

Analysis

A total of 15 students (8 cued, 7 non-cued) participated in the study. Participants' verbal explanations were coded for the concepts used to solve the problem. A phenomenographic approach (Marton, 1986) was used to code these responses. Four kinds of analysis were completed.

1. *Performance on Transfer Problem*: We compared the number of students in the cued group versus the non-cued group who changed from incorrect answers or explanations for the initial problem to correct answers and explanations for the transfer problem.
2. *Number of Scaffolding Problems Needed*: We compared the average number of scaffolding problems students in the cued group versus the non-cued group were presented before they answered the scaffolding problem correctly with a correct explanation and were presented with the transfer problem.
3. *Changes in Verbal Explanations:* We compared the correctness of students' explanations in the cued and non-cued conditions and how many times the students changed the concept they used in both the cued and non-cued condition.

4. *Eye Movements after Cueing:* We compared the students' fixation time on the relevant areas of the problem in the cued and non-cued groups, as well as the number of transitions that mimic the cueing sequence.

Performance on Transfer Problem

We compared the accuracy of responses to the transfer problem in the cued and non-cued groups. We found that the cued group gave the correct answer with correct reasoning more often (34% vs. 26%) than the non-cued group. The percentage of students who answered the transfer problem correctly in each problem set is shown in Figure 6. The non-cued group answered transfer problems in sets 1 and 2 correctly more often than the cued group, whereas the cued group answered transfer problems in sets 3 and 4 correctly more often than the non-cued group. The non-parametric Fisher's exact test indicated no statistically significant difference in performance on any of the transfer problems between the cued and non-cued group.

We see evidence of the cued group outperforming the non-cued group on the transfer problem, though the small numbers of students tested resulted in no statistical significance. The data does reveal an interesting trend. As students progressed through various problem sets, the cued group was more likely to answer the transfer problem correctly, while those in the non-cued group were less likely to answer the transfer problem correctly. In other words, the results suggest a cumulative effect of cueing. It appears that overall participants in the cued groups were improving in their response to the cueing, even though each problem set covered a different concept.

Number of Scaffolding Problems Needed

To investigate how many scaffolding problems participants needed to solve before moving to the transfer problem we analyzed only the data from participants who provided an incorrect explanation for the initial problem. There were a total of six (6) cued participants changing to the right explanation of a problem, and three (3) instances of non-cued participants changing to the correct explanation. The data shown in Figure 7 is aggregated over all four problem sets. Figure 7 shows the total number of participants who gave a correct answer and explanation at or before each scaffolding problem and thus proceeded to the transfer problem. From Figure 7 it is clear that participants in the cued group were more likely to correctly answer the scaffolding problem and thus move to the transfer problem.

Changes in Verbal Explanations

We also analyzed each participant’s verbal explanations. While conducting interviews, there was a noticeable difference between the two groups in their explanations of their problem solutions. Participants in both groups stated that they were unsure of their answers, but participants in the non-cued group did not change their previous reasoning as frequently. For example, many students in the cued group made statements such as, “Maybe [my first answer] wasn’t right”, or “That one threw my last rationale out the window.”

By coding verbal responses and categorizing the explanations used in solving these problems, we investigated whether the cueing condition caused participants to change existing explanations more than the non-cued condition. Using a phenomenographic approach (Marton, 1986), each participant’s answers to each problem were categorized into different explanations provided in solving the problem. Table 1 shows the codes for the explanations in each problem set. The codes were categorized primarily by the common misconceptions in each of the problem sets. In Problem Set 1 (Fig. 3), the features of each track are the perceptually salient parts of the problem. Many students based their explanations on various features in the track, such as the height, steepness, or number of hills. The correct conceptual understanding of this problem would involve explaining how energy is conserved or that the carts start and end at the same heights and therefore must be going the same speed at the end. The correct explanation in Problem Set 2 (Fig. 4, left) involved relating the distance traveled by the ball over a time interval to its speed. Common incorrect explanations included reasoning that the balls were traveling the same speed when their positions matched up or when one passes the other. In Problem Set 3 (Fig. 4, right), a correct explanation would determine that the change in height is what determines the change in potential energy. Incorrect explanations included relating the slope, overall height, or distance traveled to the potential energy. In Problem Set 4 (Fig. 5), the correct explanation would relate the slope of the graph to the object's speed, while incorrect explanations regarded intersection as matching speeds. As shown in Figure 8, we found that the average number of changes in explanations provided in going from one scaffolding problem to the next was higher in three of the problem sets (Problem Sets 2, 3 and 4). Although a Mann-Whitney test indicates that these results are not statistically significant, they seem to suggest that participants that were provided visual cues are more inclined to change their initial explanations about the problem, while participants that are not being cued were not as likely to change their initial explanations about the problem.

Eye Movements after Cueing

To assess the effect of visual cueing on students' subsequent eye-movements, we compared the percentage of fixations in the areas of interest on the initial problem of the first problem set (Fig. 3, top). Students in the cued group fixated on the track for an average of 27.2% of their total viewing time on the problem, while students in the non-cued group fixated on the track for an average of 29.9% of the total viewing time. A Mann-Whitney U test of the percentage of fixation time showed no significant differences at the α=.05 level, indicating minimal differences between students' initial eye movements between the two groups. We also analyzed eye movements on the transfer problem in this problem set to determine whether cueing had an effect on the students' eye movements compared to the non-cued group. Students who correctly answered the initial problem with a correct explanation, who therefore saw no scaffolding problems, were discarded from this analysis. This left seven (7) students from the cued group who saw scaffolding problems and four (4) students in the non-cued group. Using the same areas of interest, we compared the number of transitions between Track A and Track B, mimicking the visual cue presented in this problem set. We found that students in the cued group transitioned from Track A to Track B an average of 9.71 times while solving the transfer problem, whereas students in the non-cued group transitioned an average of 6.25 times. A Mann-Whitney U test again showed no significant difference in the number of transitions at the α=.05 level. Even though the results show no statistical significance, the data suggest that cueing students' eye-movements in a certain sequence impacts their eye-movements on subsequent similar problems.

Conclusions and Implications

Our results show that students who were cued were more likely than the non-cued students to answer the transfer problem correctly. A larger number of students in the cued group, compared to the non-cued group proceeded to answer the scaffolding problems correctly before proceeding to the transfer problem. Our results also showed that students who were provided visual cues to solve the problems were more likely to change their verbal explanations for solving the problem. Our results show that students who were cued were more likely to mimic the cueing sequence eye-movements on subsequent similar problems.

It is important to keep in mind that these trends may be solely due to the effect of showing a moving colored shape over the thematically relevant areas and not due to the embodiment of the correct solution. An important limitation of this pilot study is the small number of participants. Future work is needed to test these ideas for larger numbers of students.

As the use of multimedia becomes more prevalent in science teaching, it is important to understand how visual media influences students' learning. As educators and researchers we must seek the optimal way to present such media to facilitate students' constructing scientifically correct understanding. When personal guidance from a human tutor or facilitator is not available, directing a student's eye movements can be a crucial factor in altering students' pre-existing thinking and facilitating students' construction of new, more scientifically accurate ideas. This study builds on previous research to explore the value of attentional cueing for solving physics problems, and can potentially impact teaching and learning in the future.

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Table 1

Codes for explanations provided for problems in each problem set

Set 1 (Roller Coaster)	**Set 2 (Ball Race)**	**Set 3 (Skier)**	**Set 4 (Distance vs. Time Graph)**
Same Height, Same Speed	Distance related to speed	Height changes PE	Same slope implies same speed
Size of hills matters	Same point, same speed	Higher up, more PE	Intersection implies same speed
Steepness of hills matters	Balls pass at same speed	Steeper, more PE	Second level intersection arguments
Number of hills matters		Distance traveled	No force, same speed always
Same Path, Same Speed		KE vs. PE	
Energy Conservation		Other/None	

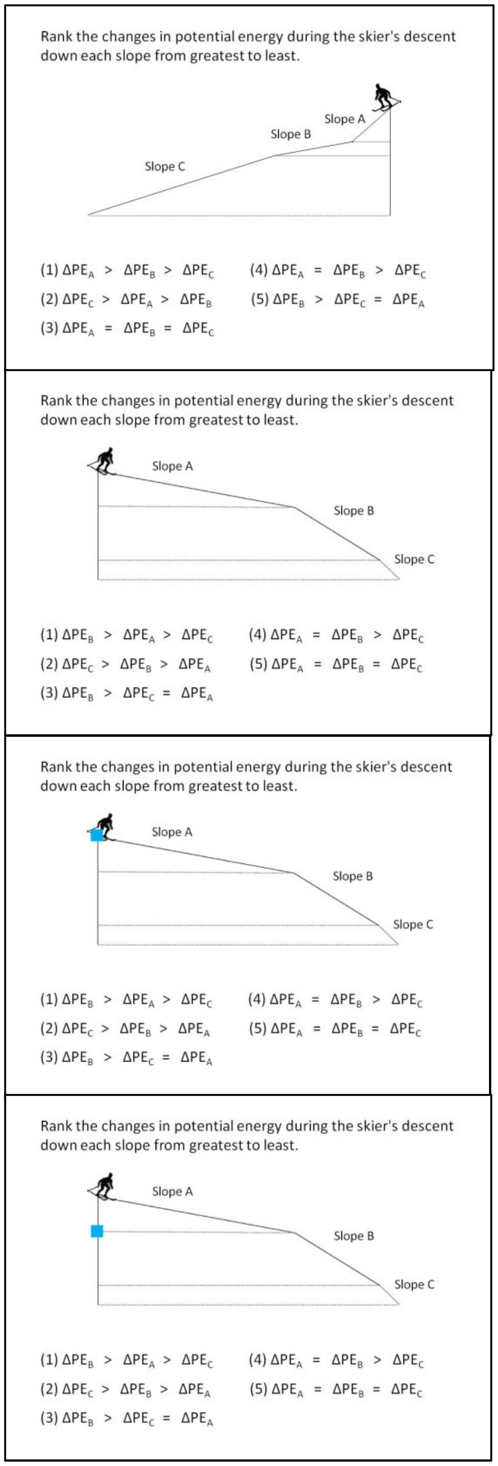


Figure 1. (From top to bottom) Panel 1: Example of an initial problem, panel 2: scaffolding problem without cues, panel 3 & 4: scaffolding problem with cues.

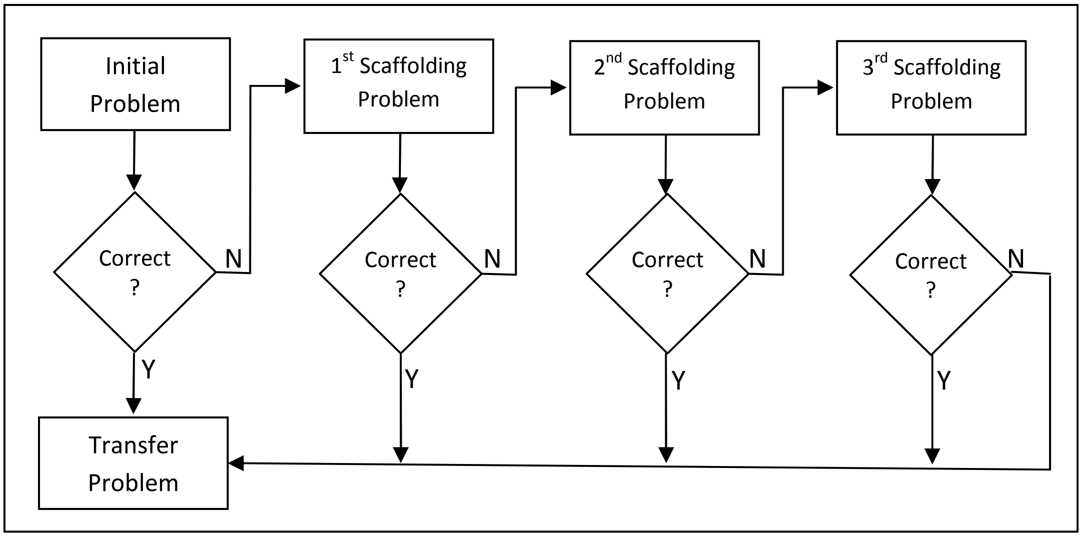


Figure 2. Flow chart for the experimental design. This sequence is repeated for each problem set.

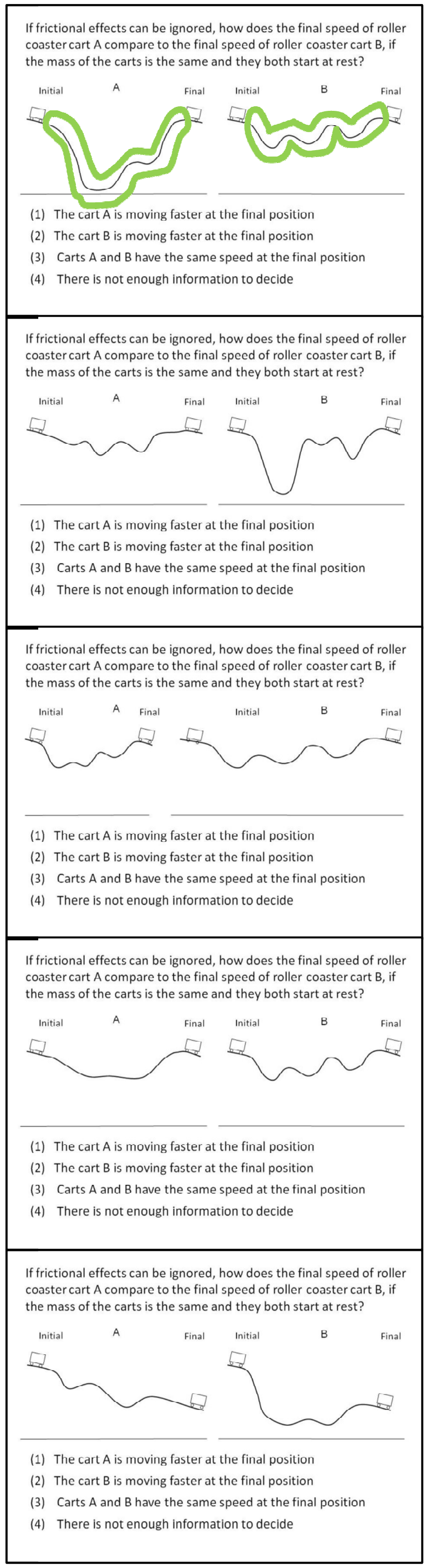


Figure 3. (From top to bottom) Initial problem with areas of interest, three scaffolding problems, and transfer problem from first problem set.

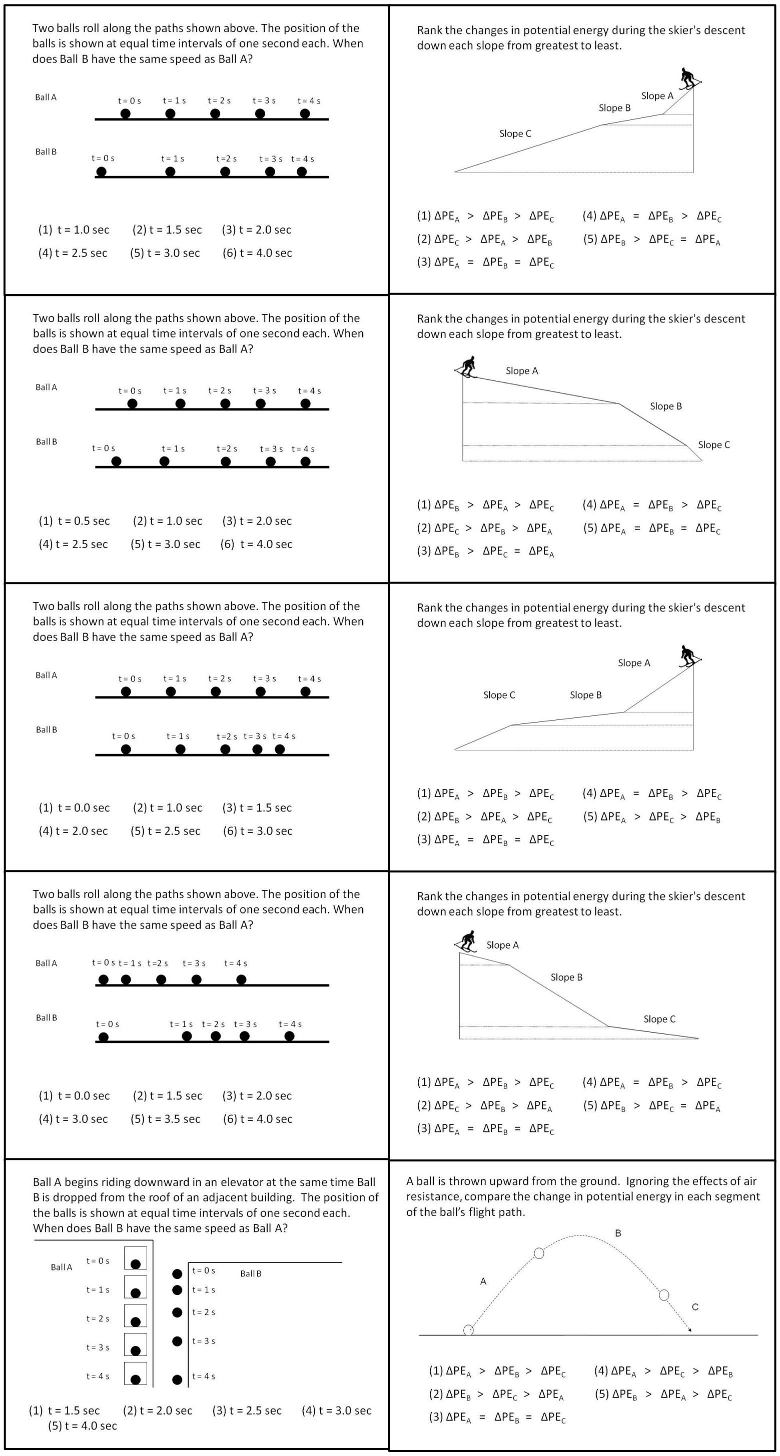
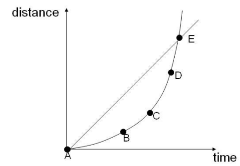


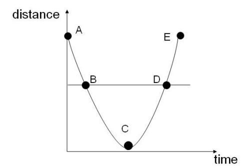
Figure 4. (From top to bottom) Initial problem, three scaffolding problems, and transfer problem from the second problem set (left) and third problem set (right).

The motion of two objects is represented in the graph below.
When are the two objects moving with the same speed?



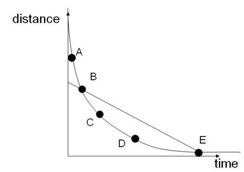
(1) Point A (2) Point B (3) Point C (4) Point D
(5) Point E (6) At all points

The motion of two objects is represented in the graph below.
When are the two objects moving with the same speed?



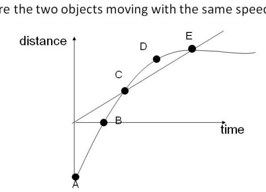
(1) Point A (2) Point B (3) Point C (4) Point D
(5) Point E (6) At all points

The motion of two objects is represented in the graph below.
When are the two objects moving with the same speed?



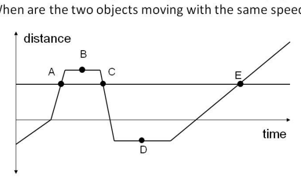
(1) Point A (2) Point B (3) Point C (4) Point D
(5) Point E (6) At all points

The motion of two objects is represented in the graph below.
When are the two objects moving with the same speed?



(1) Point A (2) Point B (3) Point C (4) Point D
(5) Point E (6) At all points

The motion of two objects is represented in the graph below.
When are the two objects moving with the same speed?



(1) Point A (2) Point B (3) Points A, C, & E
(4) Points B & D (5) Point E (6) At all points

Figure 5. (From top to bottom) - Initial problem, three scaffolding problems, and transfer problem from the fourth problem set.

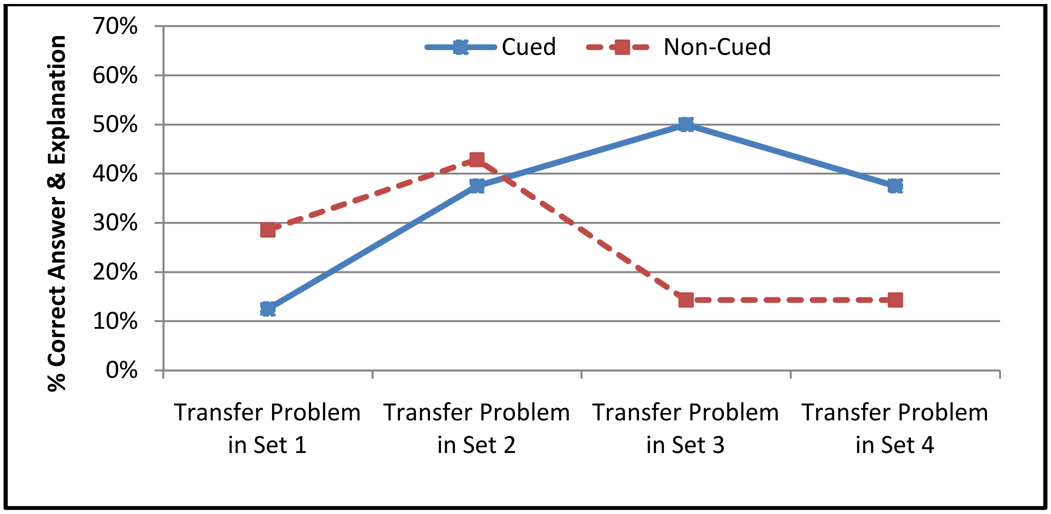


Figure 6. Percentage of participants who provided a correct answer and explanation for the transfer problem in each problem set.

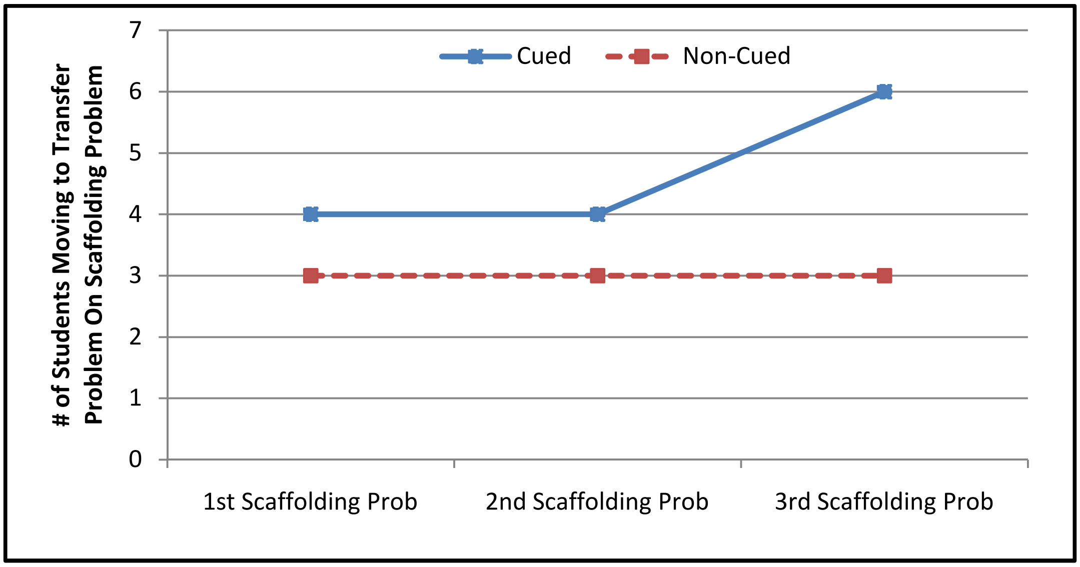


Figure 7. Total number of students who correctly moved to the transfer problem at or before each scaffolding problem

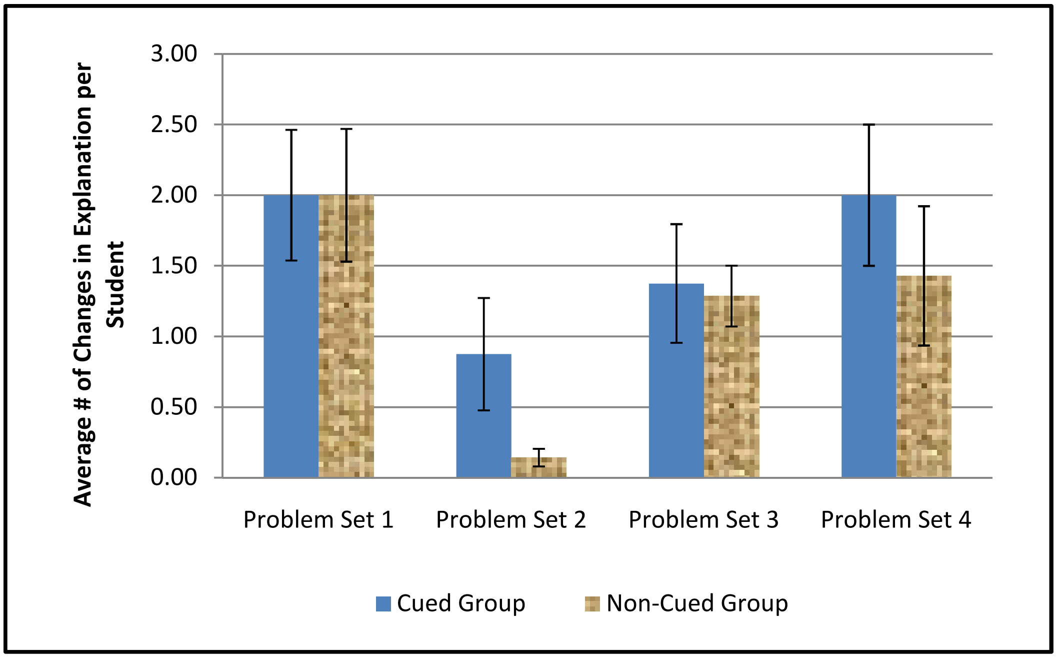


Figure 8. The average number of changes in explanation per student per problem set. The error bars are the standard error.