Influence of Visual Cues on Eye Movements and Reasoning in Physics Problems

INTRODUCTION AND OBJECTIVES

Many studies have investigated how visual cues overlaid on static visualizations and animations can benefit learners by guiding attention and assisting in organizing and integrating visual information (Grant, 2003, Thomas, 2007, De Koning, 2007, 2009, Ozcelik 2010, Kriz, 2007, Mautone, 2001, 2007). We extend work in the area of attentional cueing to introductory physics problems to answer the following research questions:

1. Do dynamic visual cues patterned after experts' eye movements scaffold students' understanding of physics concepts?
2. Does students' ability to apply a given concept to a new problem improve after seeing visual cues on similar problems?
3. Do students' eye movements change on current and subsequent problems a result of seeing dynamic visual cues?

THEORETICAL FRAMEWORK

Koning (2009) proposes a framework for classifying different functions of attentional cueing. This framework is grounded in Mayer's cognitive theory of multimedia learning (Mayer, 2001) as well as Sweller's cognitive load theory (Sweller, 1988, 1999). Mayer and Sweller both assume a limited processing capacity of working memory. To maximize learning one must ensure most of the learner's cognitive resources are spent on relevant tasks and avoid instructional environments that facilitate focusing on the irrelevant. Mayer's cognitive theory of multimedia learning explains that learning occurs when relevant information is successfully selected, organized into a coherent representation and integrated into the existing knowledge base. This all occurs in ones working memory. Often learners are faced with learning environments which impose a high cognitive load and max out the limited capacity of working memory. To help alleviate this problem, visual cues can be used. Koning (2009) devised a framework to describe three specific functions of cueing. These are:

1. Guiding learners' attention to facilitate the selection and extraction of essential information.
2. Emphasizing the major topics of instruction and their organization.
3. Making the relations between elements more salient to foster their integration.

Our study primarily aims to address the first function of attentional cueing, namely guiding learners' attention to the relevant information in the physics problem diagrams. Koning explains that novice learners often do not have adequate prerequisite knowledge to determine which portions of a visual representation are relevant and which are irrelevant. Cues can redirect learners' attention to task relevant areas in a diagram or animation and help prevent them from using cognitive resources on irrelevant information, freeing up more mental resources for understanding the concepts at hand.

METHODOLOGY

Participants in the study were 55 individuals currently enrolled in an introductory algebra-based physics course. All participants were paid ten dollars and were recruited through their physics course. To ensure that participants had sufficient prerequisite knowledge to understand the study questions, each completed a pre-test consisting of four open-ended questions on speed and energy.

The participants took part in individual sessions lasting between 30 and 60 minutes. They were first given an explanation of what to expect during the session and the eye tracker was calibrated to the individual. Next, the participant was instructed to spend as much time as needed on each question and when ready to answer, press any key on the keyboard. At this point the participant verbally explained their answer and reasoning. Participants in the cued condition were told that colored shapes may appear on some of the problems. When these appeared, they should follow them with their eyes. Eye movements were recorded with an Eye Link 1000 eye-tracking system. Participants utilized a chin and forehead rest.

The materials consisted of four sets of conceptual physics problems covering energy and kinematics. Within each problem set, there was an "initial" problem, four "similar" problems and a "transfer" problem (Figure 1). First, students answered the initial problem to demonstrate their current level of understanding. If they answered incorrectly, they saw a series of "similar" problems, which contained the same problem statement as the initial problem, but a different diagram. When the student answered a similar problem correctly, they saw the transfer problem. The surface features of the transfer problems were different than the initial and similar problems, though the concept tested was the same. All participants viewed the four sets of problems in the same order as follows: "roller coaster" problem (Figure 2), "ball" problem (Figure 3), "skier" problem (Figure 4) and "graph" problem (Figure 5).

Students in the cued groups saw colored shapes overlaid on the problems appear four seconds after the problem was initially seen. Each colored shape appeared for 500 ms at 12 different positions in the diagram for a total cueing time of six seconds. The visual cues were designed to mimic the eye movements of highly experienced physicists viewing and answering the same problems, which had been recorded and analyzed in a previous study (Authors, 2010). The visual cues did not follow the exact same pattern as the experienced physicists' eyes, but modeled an expert-like way of viewing the diagram.

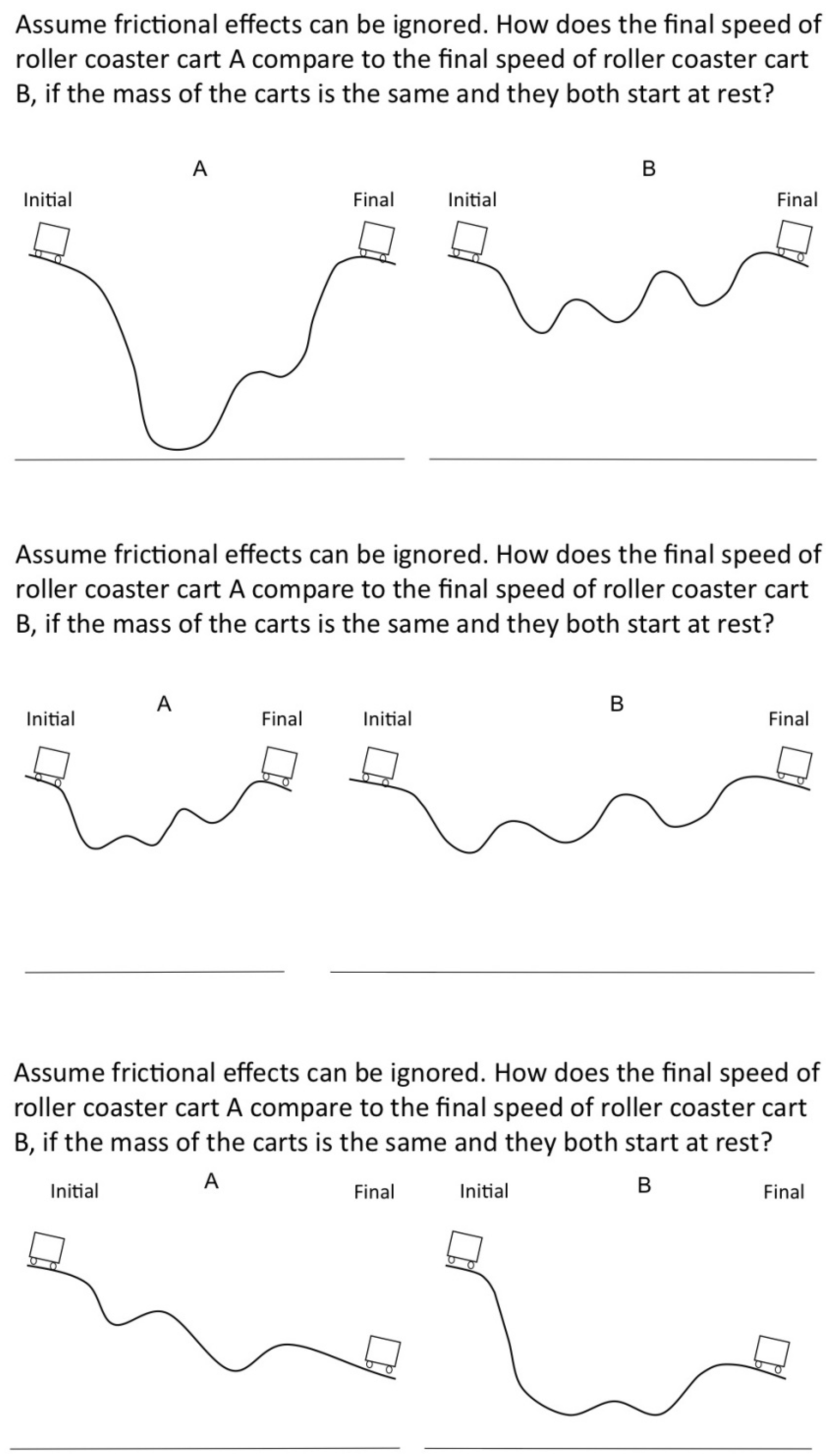

Figure 1. Example of initial problem (top), similar problem (middle) and transfer problem (bottom) used in study.

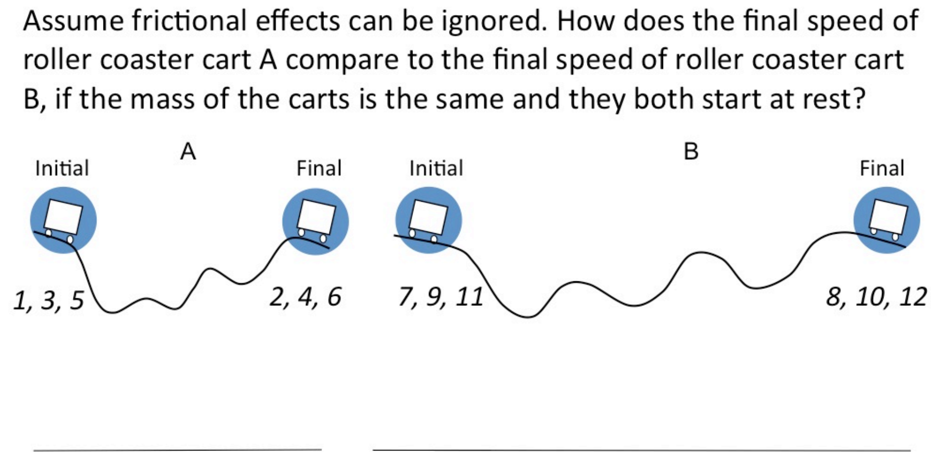

Figure 2. Problem 1 used in study. Blue circles are the visual cues overlaid on the diagram. Numbers in italics show sequence of animated cues (the numbers were not seen by study participants).

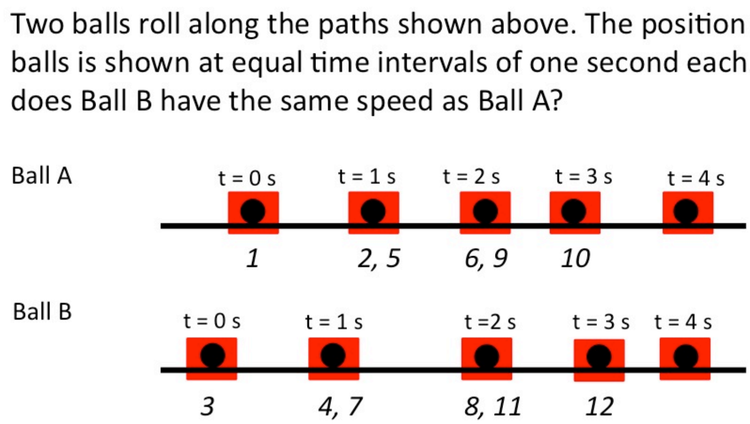

Figure 3. Problem 2 used in study. Red squares are the visual cues overlaid on the diagram. Numbers in italics show sequence of animated cues (the numbers were not seen by study participants).

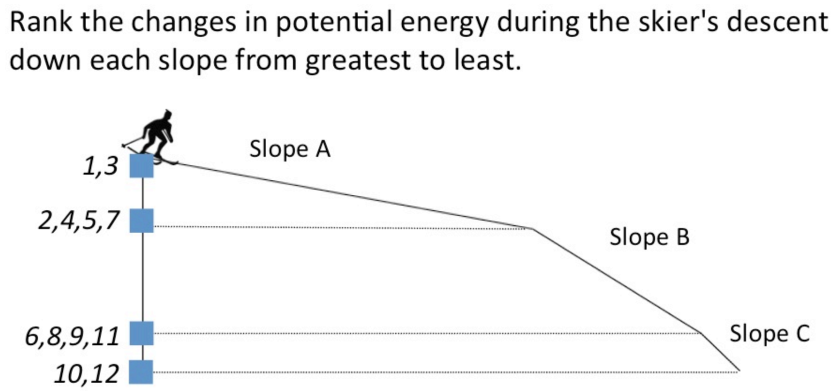

Figure 4. Problem 3 used in study. Blue squares are the visual cues overlaid on the diagram. Numbers in italics show sequence of animated cues (the numbers were not seen by study participants).

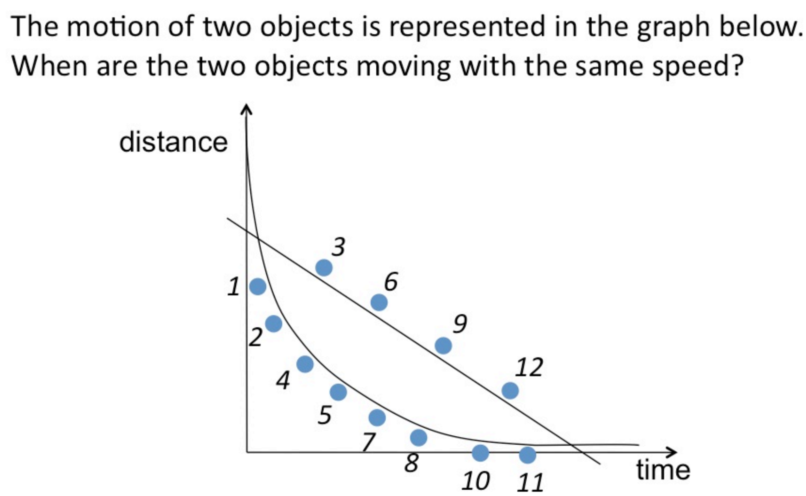

Figure 5. Problem 4 used in study. Blue dots are the visual cues overlaid on the diagram. Numbers in italics show sequence of animated cues (the numbers were not seen by study participants).

DATA SOURCES

To measure students' initial understanding of physics concepts, students completed a pre-test containing four open-ended questions about speed and energy. During the experiment, verbal explanations and gestures were recorded with a Flip video camera. Additionally, participant's eye movements were recorded with an Eye Link 100 eye-tracker (http://www.sr-research.com/).

RESULTS

Changes to Correct Answer on Similar Problems

Figures 6 through 9 show the number of students who answered the initial problem incorrectly and then changed to a correct answer and reasoning on a similar problem. Using a Mann-Whitney U test to compare the number of participants in the cued and no cue groups who changed to a correct answer, we found a significant difference on the roller coaster problem (p=.002) where six students in the cued group (N=18) changed to the correct answer while zero students in the no cue group (N=14) made this change. There were no significant differences between groups on the ball, skier or graph problems. The particular aspects of each problem and associated cues will be further analyzed to determine where the differences in effectiveness originate.

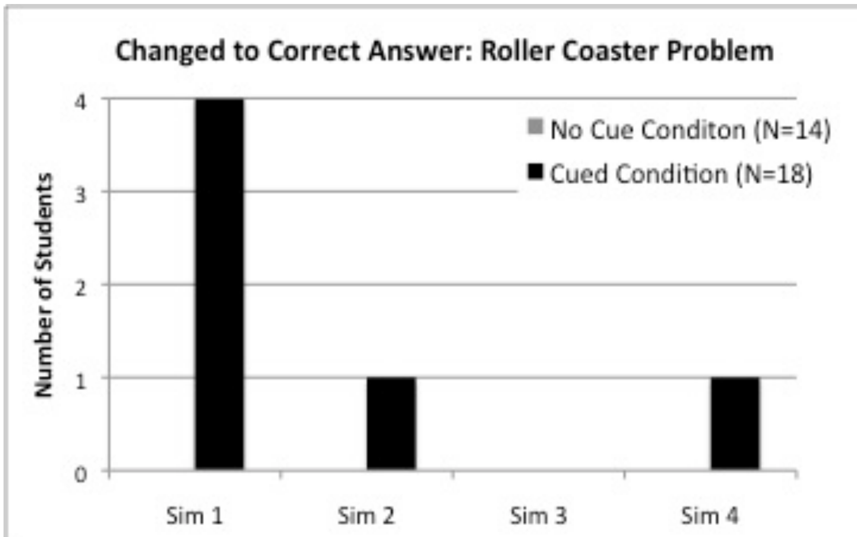

Figure 6. Number of students in "cued" and "no cue" conditions who answered initial roller coaster problem (problem 1) incorrectly, but answered similar problem ("Sim 1-4") correctly.

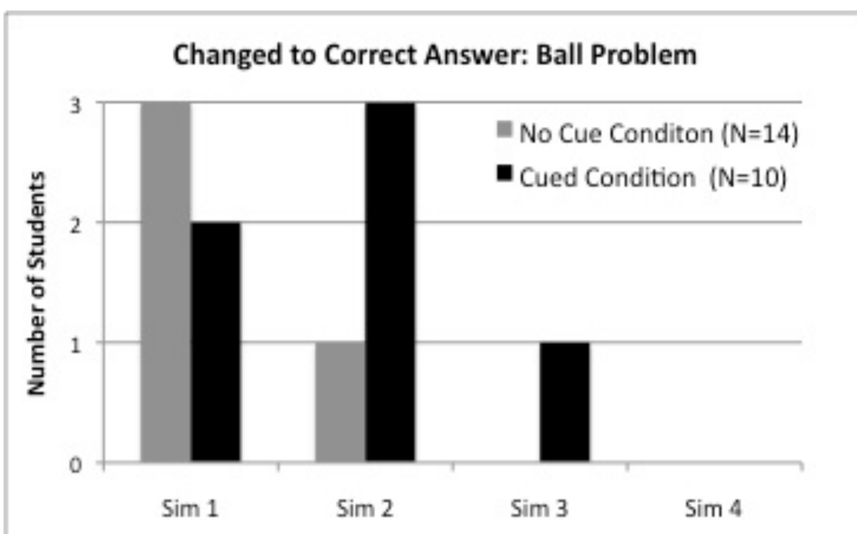

Figure 7. Number of students in "cued" and "no cue" conditions who answered initial ball problem (problem 2) incorrectly, but answered similar problem ("Sim 1-4") correctly.

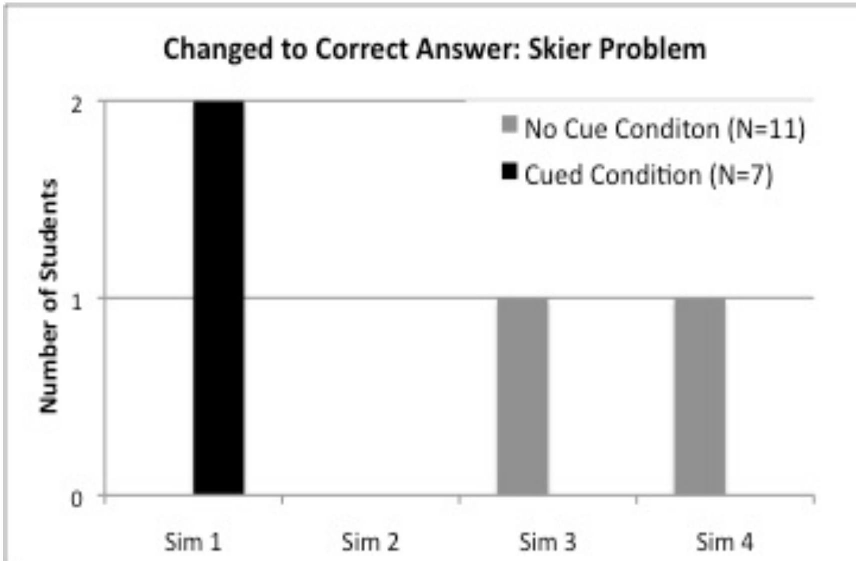

Figure 8. Number of students in “cued” and “no cue” conditions who answered initial skier problem (problem 3) incorrectly, but answered similar problem (“Sim 1-4”) correctly.

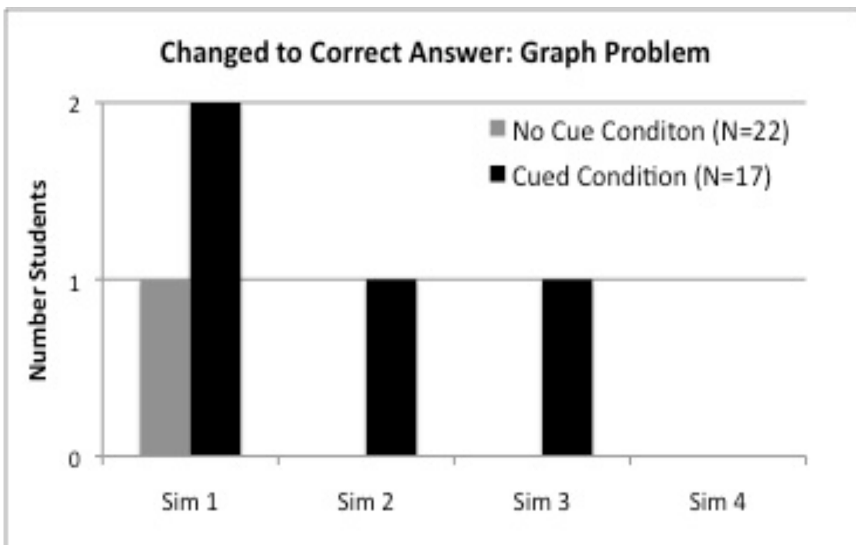

Figure 9. Number of students in “cued” and “no cue” conditions who answered initial graph problem (problem 4) incorrectly, but answered similar problem (“Sim 1-4”) correctly.

Transfer Problem Correctness

To determine if visual cueing is useful for learning beyond the problem being cued, participants answered a transfer problem for each problem set. Figure 10 shows the percentage of participants who answered the transfer problem correctly after answering the initial problem incorrectly. We compared the cued and no cue groups performances on the transfer problems using the Mann-Whitney U test. We found that there is a nearly significant difference for the ball transfer problem (p=.06) and the graph transfer problem (p=.054). There was no difference found for the roller coaster and skier transfer problems. These results suggest the visual cues in the ball and graph problem sets positively influenced performance on the related transfer problems.

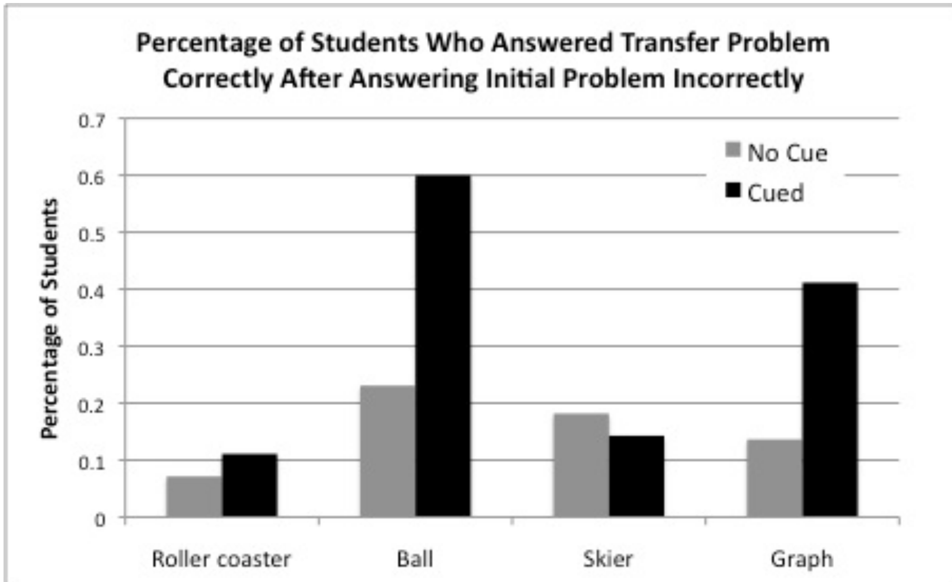

Figure 10. Percentage of students in "cued" and "no cue" conditions who answered initial problem incorrectly, but answered transfer problem correctly.

Eye Movements on Roller Coaster Problems

To further investigate the positive effect of the visual cues on the problems, we looked at the eye movements of the students. First, we investigated how well students in the cued group followed the visual cues with their eyes. To do this, we created four interest areas where the cues began and ended (around the roller coaster carts). We then counted the number of saccades each participant made between these interest areas and the total number of saccades made within the diagram during the four seconds that the cues appeared.

On the roller coaster problem, of participants in the cued group, 52.6% of the saccades followed the cues while in the no cue group 0.96% of the saccades were in a pattern similar to the cues (though the no cue group did not see any cues).

Next we looked for a correlation between following the cues closely with the eyes and changing to the correct answer on a similar problem. We counted saccades between the same areas of interest described above for those in the cued group only. Using a one-way ANOVA, we found a significant difference in the percentage of saccades that correctly followed the cues between those who changed to a correct answer on a similar problem and those who did not ($F(1,14)=10.8$, $p=.005$). Students who answered a similar problem correctly made 85.5% of their saccades in a manner that followed the cues. Students who did not answer any of the similar problems correctly made only 46.4% of their saccades in a manner that followed the cues. This suggests a relationship between closely following the visual cues and coming to the correct answer on the roller coaster similar problems.

On the ball problem, we found a nearly significant difference in transfer problem performance between groups. In the cued group, 60% of students answered correctly while in the no cue group, 23.1% answered correctly. This suggests that seeing the visual cues positively influenced performance on the transfer problem. To further investigate this finding, we looked at the eye movements on this problem.

The visual cues used in the similar ball problems had the students compare the distances between balls at each time interval. If the visual cues influenced how students look at the transfer problem, we anticipate that the cued group would show a greater number of saccades comparing the distance between balls. In the case of the transfer problem, these would be vertical saccades within interest areas 1 and 2 (Figure 11). Table 1 compares the percentage of saccades within interest area 1 or 2 between the cued and no cue groups. No differences are found. This suggests that this difference in performance on the transfer problem is not reflected in the participants' eye movements.

We further looked at the percentage of saccades within interest areas 1 and 2 by those in each group who answered correctly versus incorrectly. We anticipate that those who answer correctly would display more saccades within the interest areas. The results are shown in Table 2. Once again, we find no differences between the cued and no cue groups in this analysis. This suggests that the visual cues are not changing the way participants view the ball transfer problem.

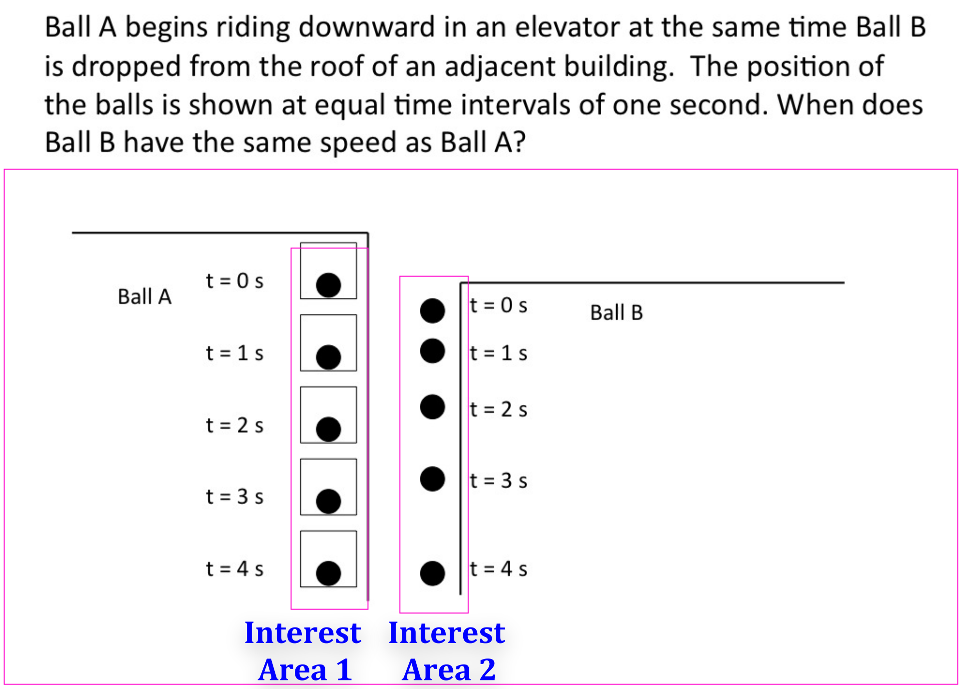

Figure 11. In the ball transfer problem the leftmost pink rectangle is interest area 1 and rightmost pink rectangle is interest area 2. These interest areas were used when analyzing eye movements.

	Saccades Within Interest Areas 1 and 2
Cued	23.0%
No Cue	24.1%

Table 1. Comparison of cued and no cue group on percentage of saccades made within interest area 1 or interest area 2 for ball transfer problem.

		Saccades Within Interest Areas 1 and 2
Cued	Correct Answer	18.2%
	Incorrect Answer	26.1%
No Cue	Correct Answer	17.4%
	Incorrect Answer	28.6%

Table 2. Comparison of participants who answered correctly versus incorrectly in the cued and no cue groups on the ball transfer problem. We compared **the** percentage of saccades made vertically within interest area 1 or interest area 2.

CONCLUSIONS AND SIGNIFICANCE OF THE STUDY

In this study we find some evidence that viewing a physics problem overlaid with short duration visual cues can indeed help students correctly answer and reason about problems they were previously unable to. Of the four problem sets used, we found on one of these problem sets significantly more students changed to a correct answer after seeing cues. It is not enough, though, to provide visual cues to help students answer a given set of problems.

In looking at transfer problem performance, we found nearly significant differences on the ball and graph transfer problems with the cued group outperforming the no cue group. Thus, we find some evidence that repeatedly showing novices visual cues on related problems may help them to properly apply the factual knowledge on similar future problems viewed without cues. We also looked at the eye movements of participants in the cued group and found a significantly higher percentage of saccades that closely followed the visual cues in those who changed to a correct answer on a similar problem. This suggests that following the cues closely is related to changing to a correct answer. Further, we looked for evidence that seeing cues changes the way in which one views future problems with no cues and found no evidence for this on the ball transfer problem.

This work is important as it offers a new way to scaffold students' understanding and application of physics concepts. Often instructors present a new concept and then ask students to apply the idea in a problem or questions containing a diagram. As these novice learners apply newly acquired knowledge, attentional cueing can help students focus on the information relevant for solving the problem and ignore salient but irrelevant and potentially distracting information.

REFERENCES

Authors (2010). Title withheld for blind review – will be reported in final manuscript.

de Koning, B. B., Tabbers, H. K., Rikers, Remy M. J. P., & Paas, F. (2009). Towards a framework for attention cueing in instructional animations: Guidelines for research and design. *Educational Psychology Review, 21*(2), 113-140.

de Koning, B. B. (2007). Attention cueing as a means to enhance learning from an animation. *Applied Cognitive Psychology, 21*(6), 731.

de Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (2010). Attention guidance in learning from a complex animation: Seeing is understanding? *Learning and Instruction, 20*(2), 111-122.

Grant, E. R. (2003). Eye movements and problem solving. *Psychological Science, 14*(5), 462.

Kriz, S., & Hegarty, M. (2007). Top-down and bottom-up influences on learning from animations. *International Journal of Human-Computer Studies, 65*(11), 911-930.

Mautone, P. D., & Mayer, R. E. (2001). Signaling as a cognitive guide in multimedia learning. *Journal of Educational Psychology, 93*(2), 377-389.

Mautone, P. D., & Mayer, R. E. (2007). Cognitive aids for guiding graph comprehension. *Journal of Educational Psychology, 99*(3), 640-652.

Mayer, R. E. (2001). *Multimedia learning*. New York: Cambridge University Press.

Ozcelik, E., Arslan-Ari, I., & Cagiltay, K. (2010). Why does signaling enhance multimedia learning? Evidence from eye movements. *Computers in Human Behavior, 26*(1), 110-117.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257-285.

Sweller, J. (1999). *Instructional design*. Melbourne: ACER Press.

Thomas, L. E. (2007). Moving eyes and moving thought: On the spatial compatibility between eye movements and cognition. *Psychonomic Bulletin Review, 14*(4), 663.