EFFECT OF VISUAL CUES AND OUTCOME FEEDBACK ON PHYSICS PROBLEM SOLVING IN AN ONLINE SYSTEM

by

NANDANA WELIWERIYA LIYANAGE

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College of Arts and Sciences

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Approved by:

Major Professor
N. Sanjay Rebello

Abstract

With the progressive development of the educational technology, online learning systems are becoming a prominent feature in education today. We conducted a study to explore the effects of visual cues and outcome feedback on learning experience of students in an online environment. Our study was a follow up study to a previous research, which demonstrated the effectiveness of visual cues and feedback to improve physics problem solving. The participants (N=164) were enrolled in an algebra-based introductory level physics course at a U.S. Midwestern University. Participants completed a sequence of conceptual physics problems in an online environment. The study used a between subjects 2×2 quasi experimental design. Two groups of participants received visual cues and two did not receive cues. Two of the groups of participants received outcome feedback and two did not receive feedback. The effect of visual cues, feedback and their combination on the correctness of students' responses to the online questions was analyzed. Implications of the study for online learning systems are discussed.

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Dedication

To my parents

Chapter 1 - Introduction

When we hear about education, the first thing comes to our mind is traditional face–to-face teaching and learning. The effective use of technological tools in learning is becoming ubiquitous. Educational technology uses the very powerful medium of the internet to enable learning and teaching anytime, anywhere. An online learning system (or an e-learning system) is a virtual learning environment that inspires interactive and collaborative learning without the need of a physical classroom. When we compare traditional teaching and learning with online learning, we realize how it can change the way in which we provide education. Online learning systems are becoming more and more used in the system of education. As many of the higher education institutions have already integrated online learning into their program.

Homework is a key part in every college level physics courses. It is considered to be an effective tool for learning physics, it is generally believed, although not necessarily supported by research, that practicing more homework will lead to better understanding in physics concepts and improved success on exams. The development of the online learning in education have empowered the instructors to make the use of efficient online homework systems that can process hundreds of students without the need for manual grading.

Background

Among many of the studies have been done on the advantages and disadvantages of the online learning systems, Pascarella *et al*. [3] found that some students switched their problem solving behaviors from guessers to thinkers and vice versa, when they analyzed problem solving characteristics of students using web-based and traditional homework. Bonham *et al*. [4] concludes that Web-based homework is a sustainable substitute to the traditional paper-based homework and it also allows the instructor to provide more academically comprehensive instruction resources for other aspects of the course. Similarly, Kortemeyer *et al*. [5] found that the feedback generated by the online homework system on student's work, will help to identify those doing very poorly quite early, which will eventually increase course grades.

Richards-Babb *et al.* [11] found that replacing quizzes directly with online homework significantly improved success rates. Further, almost all students recommended that online homework should continue and instructors were able to save a fair amount of time by using online homework. Shaw *et al.* [12] reports that the students' average in-progress grades were moderately improved soon after on-line homework were put to use. Also students expressed very positive learning experience. Robus *et al.* [11] found that the ratio of successful to unsuccessful grades increased significantly when Sapling Learning was utilized, along with favorable responses from students. All of this research converges on the conclusion that online homework can show promise in improving student learning and for the most part, students like it.
There have been many steps to be taken to improve the outcome of the online learning system in physics. Our study was conducted in order to explore the use of visual cues and outcome feedback to enhance the learning experience of students in a computer based learning environment.

When we talk about problem solving, solving physics problems containing diagram is a major area of concern. Physics education research [8] has investigated how visual cues could help focus learners' attention on relevant areas to approach solving problems; Koning *et al*. [9] concluded that cues could enhance understanding and cues may make easy to select information and sometimes improve learning. Eye movement data [10] could also be used to show the effectiveness of the visual cues to draw the attention in relevant areas. As we suppose that eye movements reflect a person's moment-to-moment cognitive processes.

Previous studies such as those by Madsen *et al.*, 2013 [1] have found that the correct solvers spent a higher percentage of time looking at the relevant areas of the diagram, and without surprisingly the incorrect solvers spent a higher percentage of time looking in relevant areas. When the problems were overlaid with the dynamic visual cues as expected visual cues influenced visual attention and final result was improved problem-solving performances. A slight change luminance contrast showed that no effect on participants' visual attention or answers. It could be concluded that the study on visual attention and visual cueing shows that attention is an important component of physics problem-solving and could be used to improve student performance.

A follow up study was completed by Rouinfar [2] to explore how visual overlaid on diagrams, animations and outcome feedback facilitate students' reasoning as they solve conceptual physics problems. In her study the participants (N=90) were enrolled in an algebra-based physics course and were individually interviewed, in order to investigate the influence of visual cues and outcome feedback on students' problem solving, performance, reasoning, and visual attention as they solve conceptual physics problems containing a diagram. During each session students solved four problem sets while their eye movements were recorded. Each problem set contained an initial problem, six isomorphic training problems, and a transfer problem. Each problem set contained an initial problem, six isomorphic training problems, and a transfer problem. In each problem diagrams contained regions that were relevant to solving the problem correctly and separate regions related to common incorrect responses. Those in the cued condition saw visual cues overlaid on the training problems. Those in the feedback conditions were told if their overall responses (both answer and explanation) were correct or incorrect. Students' verbal responses were used to determine their accuracy.

Among the two major findings, first - short duration visual cues coupled with correctness feedback could improve problem solving performance on a variety of insight physics problems, including transfer problems not sharing the surface features of the training problems, but instead sharing the underlying solution path. Thus, visual cues can facilitate re-representing a problem and overcoming impasse, enabling a correct solution. Importantly, these cueing effects on problem solving did not involve the solvers' attention necessarily embodying the solution to the problem. Instead, the cueing effects were caused by solvers attending to and integrating relevant information in the problems into a solution path. Second - these short duration visual cues when administered repeatedly over multiple training problems resulted in participants becoming more efficient at extracting the relevant information on the transfer problem, showing that such cues can improve the automaticity with which solvers extract relevant information from a problem. Both of these results converge on the conclusion that lower-order visual processes driven by intentional cues can influence higher-order cognitive processes associated with problem solving.

Motivation

A limitation in Rouinfar's study [2] was that there was a human dependence on the final correctness result as the person who was conducting the survey decided whether the answer and reasoning were correct or incorrect. Also, the process of asking follow up questions for the interviewee to clarify their response may have led inadvertently provided hints to the interviewer. In any case, the use of a human asking the question can potentially lead to results that may not be applicable in completely automated, online environment. In our study an online computer environment decided correctness of the student response and provided the necessary feedback, thus mitigating the issue of interviewer subjectivity.

Research Questions

The study was conducted to answer the following research questions:

1. Does the combination of short duration visual cues and/or outcome feedback train students to correctly solve online conceptual physics problems?

2. Does such training help students solve a subsequent transfer problem with neither cues nor feedback?

Chapter 2 - Method

Students enrolled in an algebra-based course at Kansas State University were invited though a common email to participate in this study, also they were rewarded with extra credit. Participants were asked to come to a session to take the online survey which last for 40-50 minutes. For each session there were 10-15 students and totally 164 participants in this study.

On the survey there were four sets of conceptual physics problems covering the topics speed and energy conservation. The survey was conducted after the required material was covered in the lecture. Each problem set consists of an initial problem, four isomorphic training problems and a near transfer problem. The transfer problem had different surface features but based on the same concept like other problems in the set. Figure 1 shows a representation of the study design.

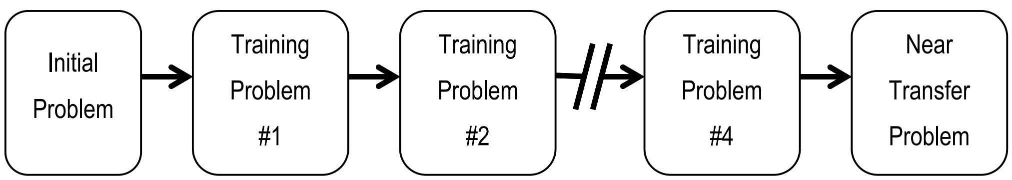


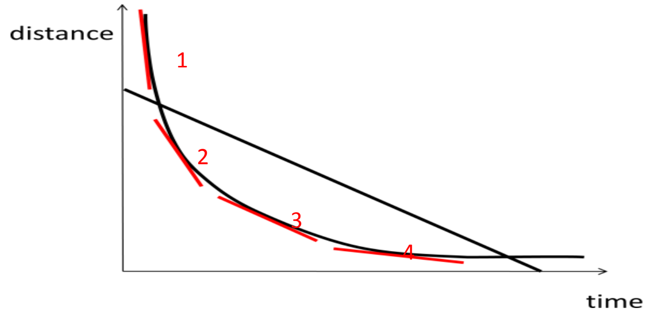
Figure 2-1 Design of the study

Each problem had two parts and they appeared on two separate pages. In the first part students had to answer the problem by selecting one of the multiple choices and then on the next page they had to select a reason for their answer. In order for a response to be considered correct students needed have to have selected both the correct answer and the correct reason.

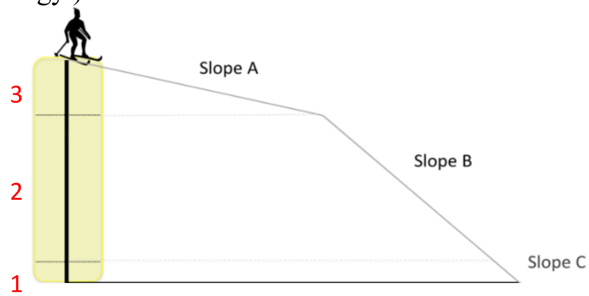
Cue Design

Before they started the survey, students were told in the initial instructions that they may see shaded shapes overlaid on the problem diagram and the purpose of these shapes is to help them solve problems. Only the participants in the cued condition (cue only, cue + feedback) were allowed to see a short video containing visual cues superimposed on the diagrams of training problems. Also they were allowed to re-play the video as many times they wanted. The problem statement was typed at the top of the page and it was there for the entire time so that they could refer back to it whenever they wanted. The whole video lasted for 10-12s including 2-3s of the static problem and remaining time for the visual cue. The visual cue contained colored shapes highlighting the features relevant to solving the problem correctly. Figure 2 shows examples of the problems used in the study.

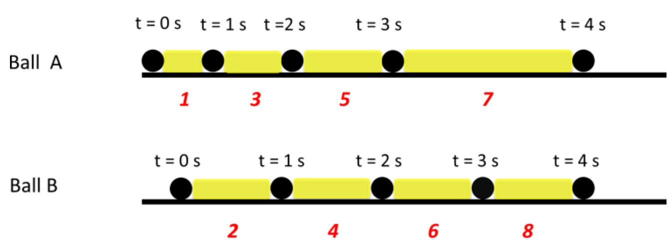
The motion of two objects is represented in the graph. When are the two objects moving with the same speed?



Rank the changes in potential energy during the skier's descent down each slope from greatest to least. (That is, rank the change in potential energy from the start of A to the end of A vs. the start of B to the end of B vs. the start of C to the end of C; not the total value of potential energy.)



Two balls roll along the paths shown. A snapshot of the position of the balls is taken every second. At what time does Ball B have the same speed as Ball A?



How does the final speed of cart A compare to the final speed of cart B if the mass of the carts is the same and they both start at rest? (Frictional effects can be ignored.)

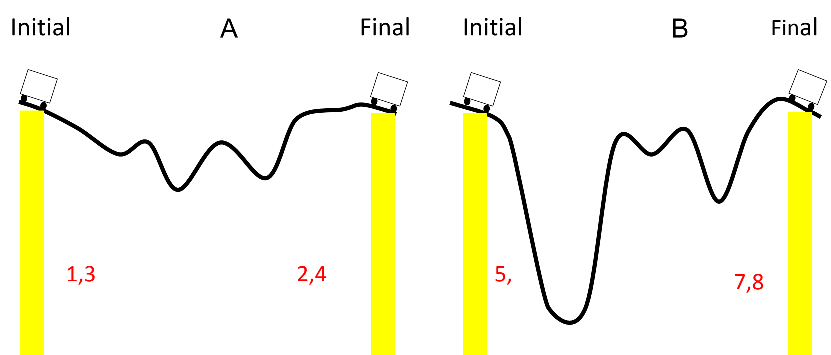


Figure 2-2 Training problems with cues for graph, skier, ball and roller coaster problem sets. The number indicates when the colored shape occurred.

Reasoning Question Design

On the second page they were asked to select a reasoning choice or their answer to the problem. On the top of the page we placed a static image of the problem, without cue. Basically the cued video didn't appear on the reasoning page. Each problem had 5-6 reasoning choices and all the choices came from previous study by Rouinfar *et al.*[2]. All the choices were based on the most common explanations given by the students.

Code	Explanation	Frequency
Change in Height	Change in height = change in kinetic energy/speed	46.4%
Smoother Track	Smoother tracks with fewer/smaller hills will have faster carts	9.1%
Overcome Hills	Deeper dips in the track are harder to overcome and slow down the cart	8.8%
Deeper Track	Deeper dips in the track will increase the speed of the cart	6.0%
Shorter Track	Shorter tracks (in terms of physical distance traveled) = faster carts	4.9%
Slope Under Cart	Steeper slope at final position = faster cart	4.2%
Similarly Shaped Tracks	Tracks with similar shapes will have the same final speed	3.7%
Steeper Hills	Steeper hills will increase the speed of the cart	1.86%
Same Horiz. Distance	Same horizontal distance traveled = same final speed	0.9%

Table 2-1 Summary of the most common explanations for roller coaster problem, given in Rouinfar study [2].

All the answer and reasoning choices were modified continuously after each pilot testing conducted within the group members.

Design and Procedure

Participants were randomly assigned to one of the four conditions. No cue + No feedback (NC+NF, N=37), No cue + feedback (NC+F, N=48), cue + No feedback (C+NF, N=39) and cue + feedback (C+F, N=40). Those in the cued condition (only in the training problems) saw videos last for 10-12 seconds, which contained colored shapes superimposed on the diagrams. Initially the students were instructed to play the video at least once but there was no limit on the number of times they could replay it. Students in the feedback condition were told if their overall response (answer and reasoning) is correct or incorrect without any further explanation.

Chapter 3 - Data Analysis and Results

First we looked into the overall problem solving performance by averaging each participant's performance for each problem within the set across the four problem sets. The average performance of all four conditions is shown in Figure 3-1.

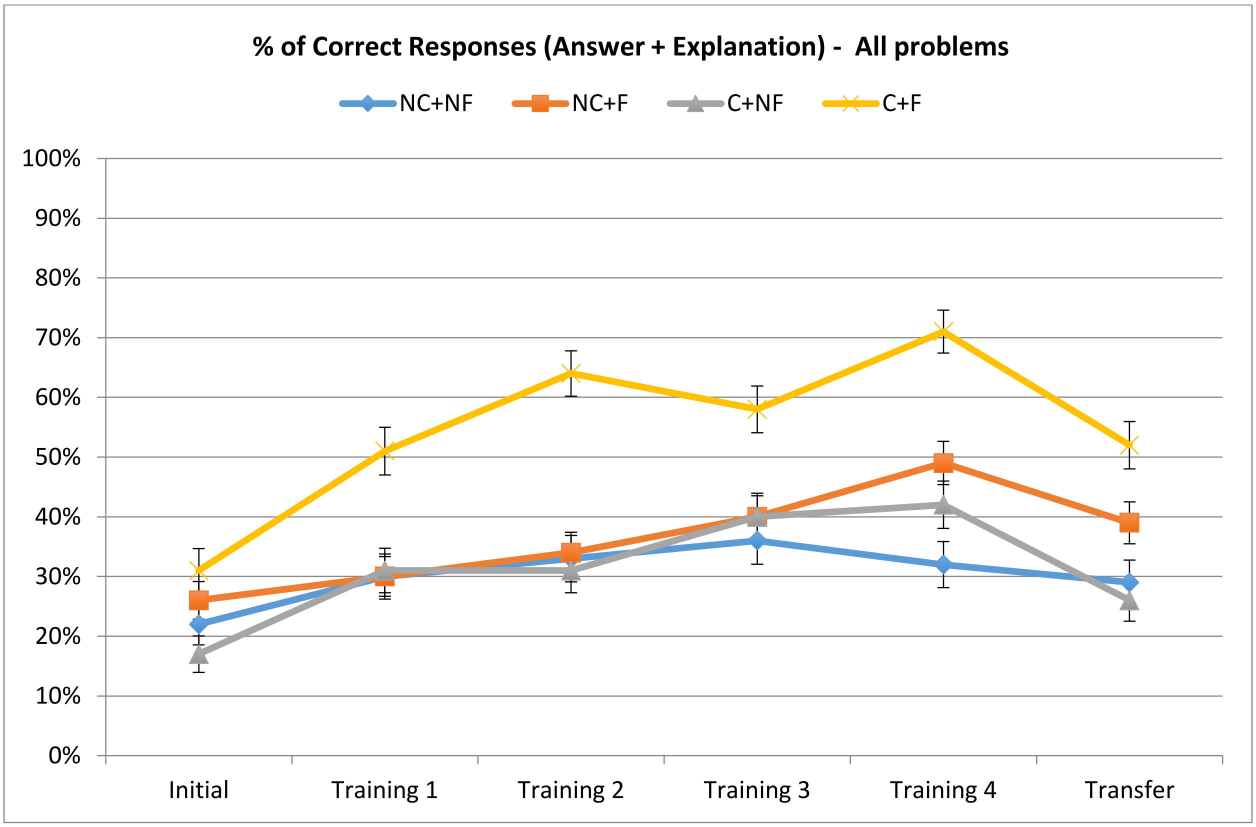


Figure 3-1 Average percentage of students correctly solved each problem across all four sets.

A chi square test was conducted to determine the dependence between initial problem correctness and condition. $\chi^2(3,\ 656) = 8.84,\ p = .031.$ Results show that overall there is a significant dependence between the initial problem correctness and condition. But when looked problem by problem, the results indicate that the initial problem correctness is independent of condition for each problem set. Table 3-1 below shows the results by problem set.

Problem	Condition	Number Correct	Number Incorrect	χ^2	df_{effect}	df_{error}	p	Cramer's V
All problem sets	NC+NF	33	115	8.84	3	656	.031	.12
	NC+F	49	143					
	C+NF	27	129					
	C+F	50	110					
Ball	NC+NF	8	29	2.67	3	164	.440	---
	NC+F	3	35					
	C+NF	8	31					
	C+F	14	26					
Graph	NC+NF	3	34	1.01	3	164	.817	---
	NC+F	5	43					
	C+NF	4	35					
	C+F	6	34					
RC	NC+NF	8	29	4.99	3	164	.174	---
	NC+F	15	33					
	C+NF	6	33					
	C+F	14	26					
Skier	NC+NF	14	23	2.97	3	164	.400	---
	NC+F	16	32					
	C+NF	9	30					
	C+F	16	24					

Table 3-1 Summary of Chi square results for initial problem performance

Results of the Chi square analysis between the initial problem correctness and cue or feedback conditions show that overall there is no significant difference between the percentages of students solving the initial problem correctly on the cue vs. no cue condition. But there is a significant dependence of the initial problem correctness on the feedback condition. When looked into problem by problem, there is no significant dependence between the initial problem correctness in the feedback condition on the Ball, Roller Coaster, Graph, and Skier problem sets.

Problem	Condition	Number Correct	Number Incorrect	χ^2	df_{effect}	df_{error}	p	Cramer's V
All problem sets	Cue	77	239	0.01	1	656	1.000	---
	No Cue	82	258					
	Feedback	99	253	6.25	1	656	.014	.10
	No Feedback	60	244					
Ball	Feedback	27	61	1.96	1	164	.213	---
	No Feedback	16	60					
Graph	Feedback	11	77	0.45	1	164	.619	---
	No Feedback	7	69					
RC	Feedback	29	59	4.45	1	164	.050	.17
	No Feedback	14	62					
Skier	Feedback	32	56	0.68	1	164	.507	---
	No Feedback	23	53					

Table 3-2 Summary of Chi square results for initial problem performance

Overall Training Problem Performance

Because there was a significant difference in performance on the initial problem, we decided to do a covariate analysis of variance (ANCOVA) on the average correctness on the training problems as the dependent variable, cue and feedback as the between subjects factors, and the initial problem correctness as a covariate. The omnibus ANCOVA compares the training problems performance between conditions averaged over all four problem sets while taking into account the differences in the initial problem performance between conditions.

Results of the omnibus ANCOVA indicate that

1.) There is a significant main effect of cue after controlling for the initial problem correctness. As participants who saw cues on the training problems solved a significantly higher percentage of training problems correctly than participants who did not see cues on the training problems.
2.) There is a significant main effect of feedback after controlling for the initial problem correctness. Participants who received outcome feedback on the training problems solved a significantly higher percentage of training problems correctly than participants who did not receive outcome feedback. These main effects are qualified by the interaction between cue and feedback.

By probing the interaction, we find that for

3.) Participants who did not view cues on the training problems, there is no significant difference on the percentage of training problems solved correctly between participants who received outcome feedback and participants who did not receive outcome feedback.
4.) Participants who saw cues on the training problems, participants who received outcome feedback solved a significantly higher percentage of training problems correctly than participants who did not receive outcome feedback.

Effect	**F**	**df_{effect}**	**df_{error}**	**P**
Main Effect of Cue	27.39	1	651	<.001
Main Effect of Feedback	17.07	1	651	<.001
Interaction Cue*Feedback	6.60	1	651	.01
Simple Main Effect of Feedback (Cue Condition)	23.75	1	651	<.001
Simple Main Effect of Feedback (No Cue)	1.15	1	651	.284

Table 3-3 Summary of Omnibus 2 (Cue vs. No Cue) X 2 (Feedback vs. No Feedback) ANCOVA with % of Training Problems as the DV and Initial Problem Correctness as the Covariate

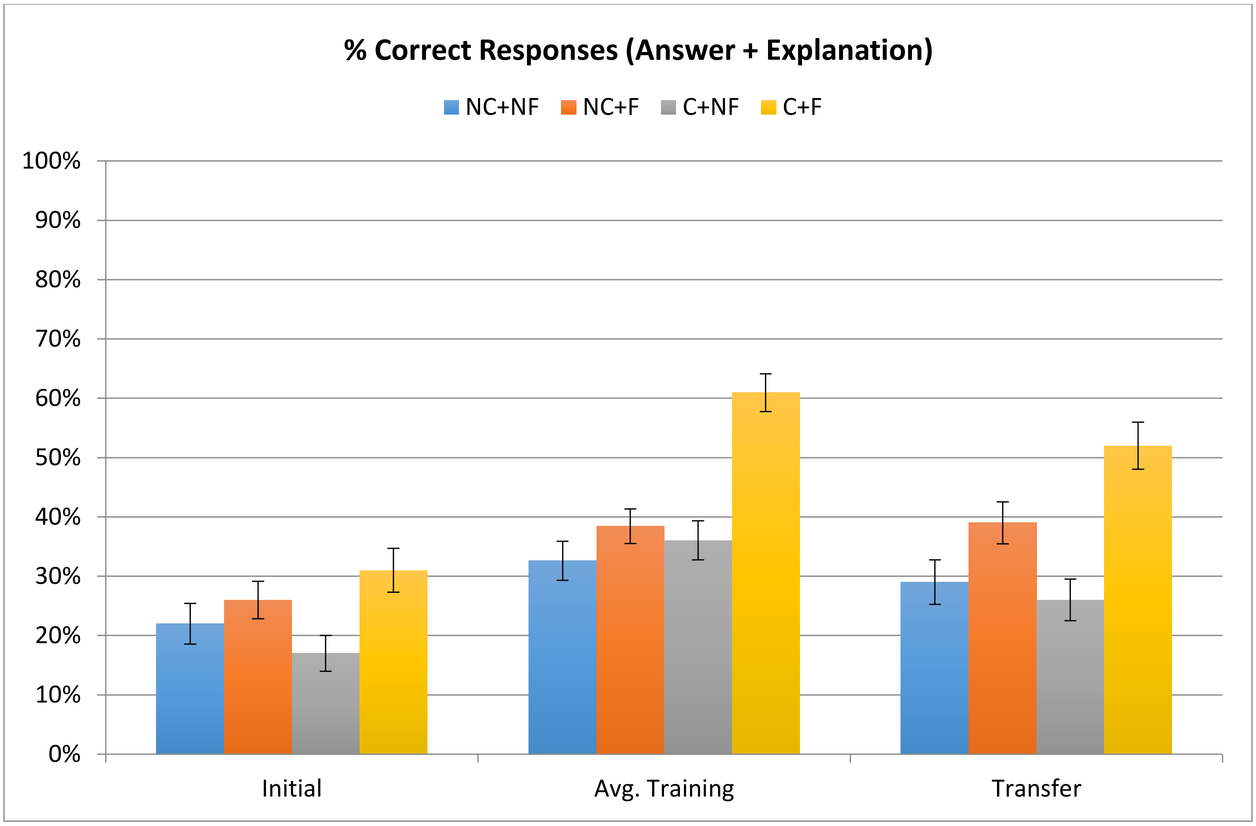


Figure 3-2 Average percentages of students correctly solved each problem across initial, training and transfer problems

Training Problem Performance by Problem Set

Problem by problem analysis shows that, when the initial problem correctness is taken into account the *Ball* problem set follows the same trend as the omnibus ANCOVA above.

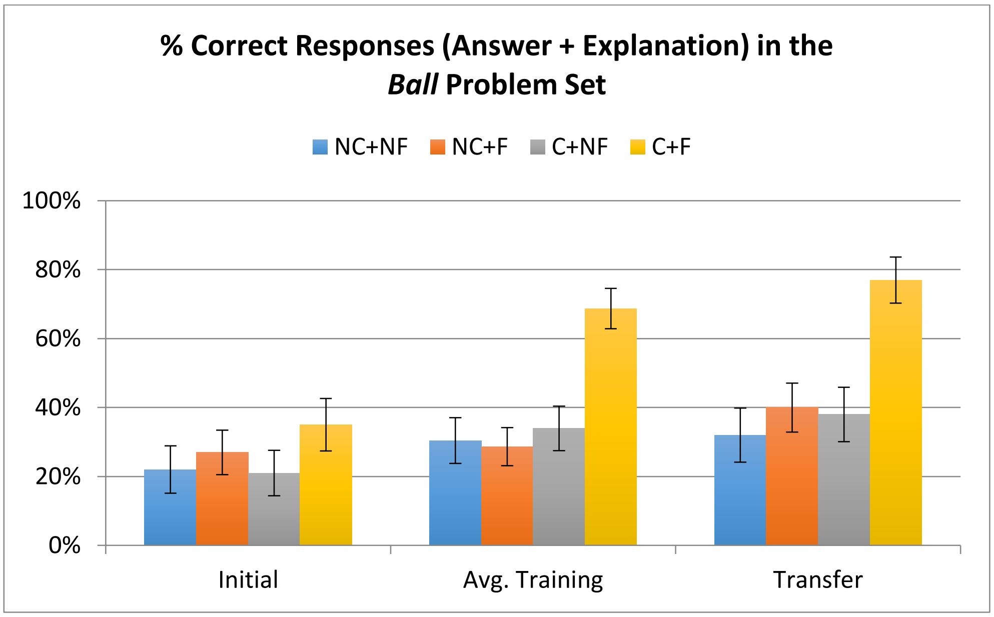


Figure 3-3 Average percentages of students correctly solved each problem across initial, training and transfer problems in *Ball* problem set.

In the *Graph* problem set, there is a significant main effect of feedback such that participants who received outcome feedback had a significantly higher percentage of training problems solved correctly than participants who did not receive correctness feedback. No other effects are significant.

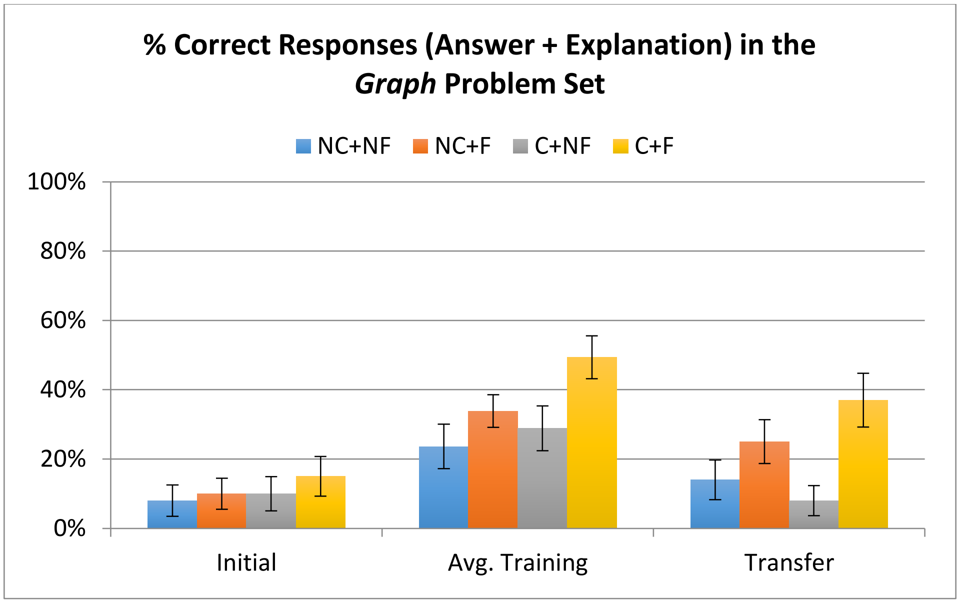


Figure 3-4 Average percentages of students correctly solved each problem across initial, training and transfer problems in *Graph* problem set.

For the *Roller Coaster* problem set, there is a significant main effect of cue such that participants who saw cues on the training problems correctly solved a higher percentage of training problems than participants who did not view cues on the training problems, regardless of whether they were in the feedback or no feedback condition. There is also a significant main effect of feedback such that regardless of whether they saw visual cues or not, participants who received correctness feedback solved a significantly higher percentage of training problems correctly than participants who did not receive correctness feedback. There is no significant interaction between cue and feedback.

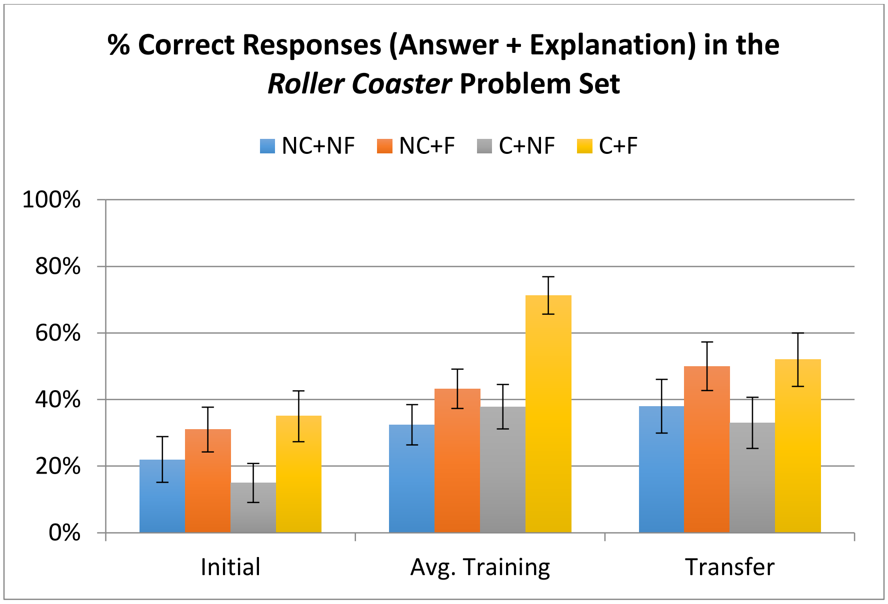


Figure 3-5 Average percentages of students correctly solved each problem across initial, training and transfer problems in *Roller Coaster* problem set.

For the *Skier* problem set, the main effects of cue and feedback, and the interaction between cue and feedback, are not significant.

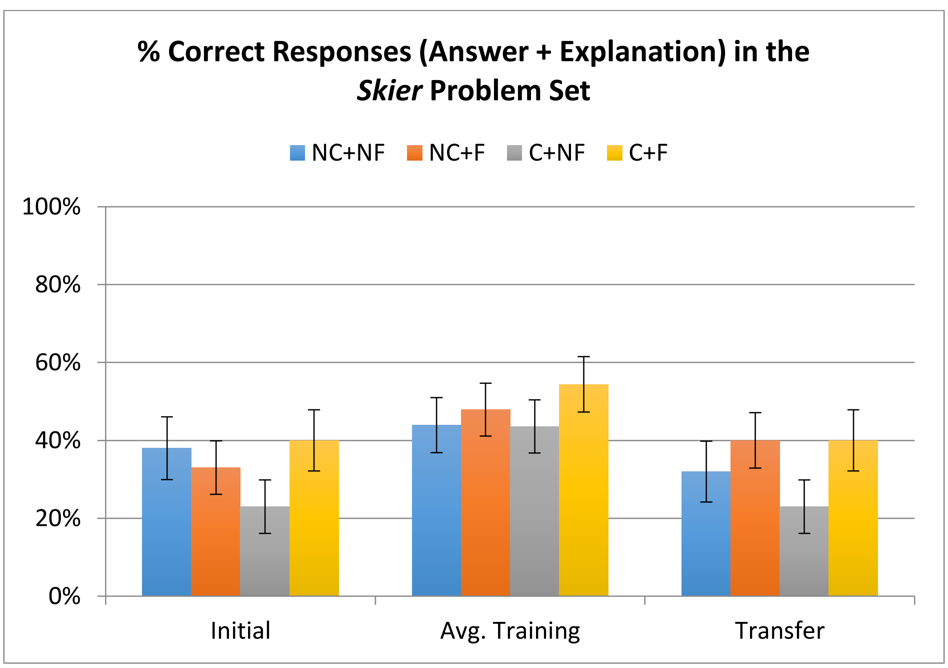


Figure 3-6 Average percentages of students correctly solved each problem across initial, training and transfer problems in *Skier* problem set.

Transfer Problem Performance by Problem Set

For the Transfer problems overall there is no significant difference between the percentage of students who solved the transfer problem correctly in the cued vs. non-cued conditions for students who solve the initial problem correctly (Cue = No Cue if initially correct). Overall, a significantly higher percentage of students solved the transfer problem correctly if they received outcome feedback *after correctly solving the initial problem* (Feedback > No feedback if initially correct). When looked in to problem by problem, we find that there is no significant dependence of the percentage of students who correctly solved the transfer problem on the feedback condition for all problem sets if they solved the initial problem correctly.

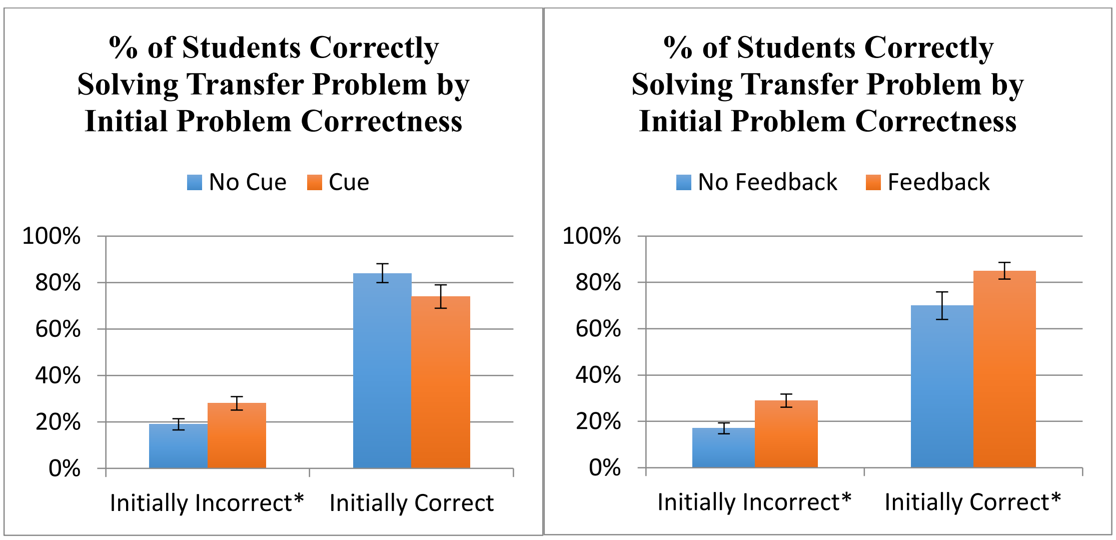


Figure 3-7 Transfer problem correctness with initial problem correctness for cue vs. no cue and feedback vs. no feedback.

Overall, a significantly higher percentage of students solved the transfer problem correctly if they saw cues after incorrectly solving the initial problem (Cue > No Cue if initially incorrect). The same holds for students who received outcome feedback (Feedback > No Feedback if initially incorrect). Looking problem by problem for students who incorrectly solved the initial problem, we find a significantly higher percentage of students correctly solved the transfer problem if they saw cues on the training problems for the *Ball* problem set only. Also a significantly higher percentage of students correctly solved the transfer problem if they received outcome feedback for the *Graph* problem set only.

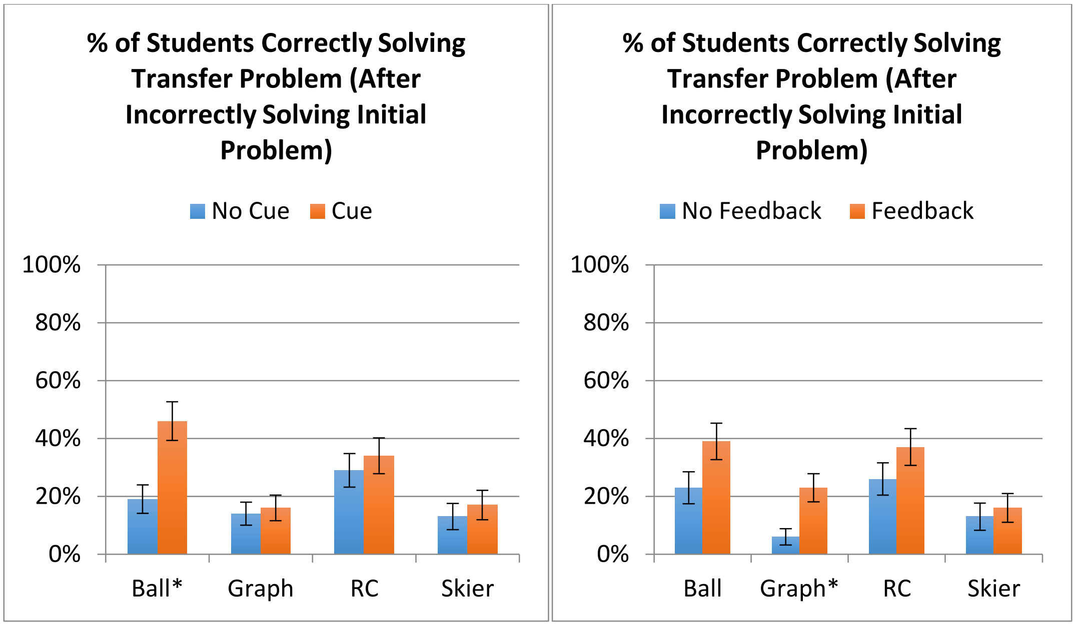


Figure 3-8 Transfer problem correctness with initial problem correctness for all problems sets.

Chapter 4 - Discussion and Conclusions

This study was designed to investigate the effectiveness of visual cues, outcome feedback, and their combination on students' performance on conceptual physics problem solving when the cues and feedback are presented in an online system, with no human intervention, This work built upon a previous study which investigated the effects of visual cues and feedback with participants in an interview environment facilitated by a human interviewer. [2]

Addressing the Research Questions

Research Question 1

The first research question asked how visual cueing, outcome feedback and their combination influenced the students' performance on the training problems on which the cues and/or feedback were provided.

We found evidence to suggest that the combination of visual cueing and outcome feedback is most effective in helping students provide correct answers and reasoning to conceptual physics problems they were previously unable to solve. The students who were in the conditions Cue + Feedback, Cue Only, and Feedback Only, showed improved performance with respect to the initial problem. The Cue + Feedback group showed the best performances, followed by the Feedback only group, and next by the Cue only group. The group that received neither cues not feedback had the lowest performance on the training problems.

Research Question 2

The second research question asked how the practice on the training problems using cues, feedback and their combination, influenced student performance on a transfer problem with different surface features, but based on the same concept, and on which neither cues nor feedback were provided.

We found that significantly higher percentage of students solved the transfer problem correctly if they saw cues after incorrectly solving the initial problem. The same holds for students who received outcome feedback. If we looked in to our results problem by problem, for students who incorrectly solved the initial problem, we found, for the Ball problem set, a significantly higher percentage of students correctly solved the transfer problem if they saw cues on the training problems. In the Graph problem set a significantly higher percentage of students solved the transfer problem correctly if they received outcome feedback. The reason for these differences between problem sets is not yet clear.

Comparison of Results with Previous Study

As in the previous study, we found clear evidence that the combination of visual cues and feedback was the most effective, as we found those who were in the cue + feedback condition had the highest percentage of correct responses. However, unlike the previous study, in this study we found that feedback dominated the cue, such that students in the feedback only condition provided correct answers and reasoning more frequently than students in the cue only condition. We speculate that the reason for this difference with prior results is because the outcome feedback appeared in a separate page while the cue appeared on the same page as the question. Therefore, students attended more carefully to the feedback than the cue. Also it may be the Outcome feedback caused students to realize they had activated inappropriate resources, but lack of cues did not enable them to activate productive resources. Ultimately they used trial & error across multiple trials to activate correct resources to improve performance.

As expected according to what we saw in previous study, students who received neither cues nor feedback had the least performance. These student did not get any help and therefore they activated resources consistent with commonly held misconceptions and rarely reactivated new resources that would have enabled them to correctly solve the problem.

One of the other unexpected findings pertained to the time for completion. We had expected that the survey would take between 30 -40 minutes to complete. This estimate was based on the time taken to complete the interview in the previous study [2]. However, we found that the average time spent by the students was only around 13-15 minutes. It clearly shows that the many of the students were rushing through the problems. Students who were in the cued conditions were supposed to watch the cued video at least one time, but the time spent does not indicate that they watched the videos on subsequent training problems. This too could have resulted in the results that the cues were not as effective as feedback in this study.

Limitations and Future Work

We speculate that one of the reasons outcome feedback was more effective than visual cues in this study, which was a departure from the results from the previous study, is that the outcome feedback was not provided verbally by the interviewer, rather it was provided visually on a separate page. We need to do another study to investigate whether outcome feedback indeed becomes more effective than visual cues because it appears on a separate page. Studying students' eye movements using an eye-tracker would also allow us to determine whether students tend to look at the feedback more carefully than the cues because it appears on a separate page.

Another issue with the survey in its current form pertains to randomization of the question order. Qualtrics – the system used to deliver the survey, does not easily allow for randomizing the problem order within the problem sets or randomizing the order of the problem sets themselves. This would have eliminated any order effects which could have affected our results. For instance, the reason for the performance differences in different problem sets with regard to the effectiveness of cues and feedback is not clear. It could be an artifact of the order in which the problem sets were administered. A future study would use a different survey delivery system that allows for complete randomization of problem set order and also the order of training problems within a problem set.

Finally, it was evident from the time that participants needed to complete the survey, that some of the participants took this survey for the sake of taking it, in order to receive the extra credit. They did not spent as much time looking at the cues. In a future study it might be worthwhile building an extra point giving scale, where students are rewarded for their performance and not just for their participation in the survey.

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