A CONCEPTUAL MODEL FOR FACILITATING LEARNING FROM PHYSICS TASKS USING VISUAL CUEING AND OUTCOME FEEDBACK: THEORY AND EXPERIMENTS

by

ELISE STACEY GARASI AGRA

B.S., University of the Philippines, 2005
M.S., West Virginia University, 2012

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Physics
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2015

Abstract

This dissertation investigates the effects of visual cueing and outcome feedback on students' performance, confidence, and visual attention as they solve conceptual physics problems that contain diagrams.

The research investigation had two parts. In the first part of the study, participants solved four sets of conceptual physics problems that contain diagrams; each set contained an initial problem, four isomorphic training problems, a near transfer problem (with a slightly different surface feature as the training problems), and a far transfer problem (with considerably different surface feature as the training problems). Participants in the cued conditions saw visual cues overlaid on the training problem diagrams, while those in the feedback conditions were told if their responses were correct or incorrect. In the second part of the study, the same students solved the near and far transfer problems from the first study two weeks later.

We found that the combination of visual cueing and outcome feedback improved performance on the near transfer and delayed near transfer problems compared to the initial problem, with no significant difference between them. Thus, the combination of visual cueing and outcome feedback can promote immediate learning and retention.

For students who demonstrated immediate learning and retention on the near and far transfer problems, visual cues improved the automaticity of extracting relevant information from the transfer and delayed transfer problem diagrams, while outcome feedback helped automatize the extraction of problem-relevant information on the delayed far transfer problem diagram only. We also showed that students' reported confidence in solving a problem is positively related to their correctness on the problem, and their visual attention to the relevant information on the problem diagram.

The most interesting thing was how changes in confidence occurred due to outcome feedback, which were also related to changes in accuracy and visual attention. The changes in confidence included both reductions in confidence and increases in confidence due to feedback when the student was wrong (first) and right (later). This seems to have led to learning (change in accuracy), and also changes in attentional allocation (more attention to the thematically relevant area).

A CONCEPTUAL MODEL FOR FACILITATING LEARNING FROM PHYSICS TASKS USING VISUAL CUEING AND OUTCOME FEEDBACK: THEORY AND EXPERIMENTS

by

ELISE STACEY GARASI AGRA

B.S., University of the Philippines, 2005
M.S., West Virginia University, 2012

A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Physics
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2015

Approved by:

Major Professor
N. Sanjay Rebello

Abstract

This dissertation investigates the effects of visual cueing and outcome feedback on students' performance, confidence, and visual attention as they solve conceptual physics problems that contain diagrams.

The research investigation had two parts. In the first part of the study, participants solved four sets of conceptual physics problems that contain diagrams; each set contained an initial problem, four isomorphic training problems, a near transfer problem (with a slightly different surface feature as the training problems), and a far transfer problem (with considerably different surface feature as the training problems). Participants in the cued conditions saw visual cues overlaid on the training problem diagrams, while those in the feedback conditions were told if their responses were correct or incorrect. In the second part of the study, the same students solved the near and far transfer problems from the first study two weeks later.

We found that the combination of visual cueing and outcome feedback improved performance on the near transfer and delayed near transfer problems compared to the initial problem, with no significant difference between them. Thus, the combination of visual cueing and outcome feedback can promote immediate learning and retention.

For students who demonstrated immediate learning and retention on the near and far transfer problems, visual cues improved the automaticity of extracting relevant information from the transfer and delayed transfer problem diagrams, while outcome feedback helped automatize the extraction of problem-relevant information on the delayed far transfer problem diagram only. We also showed that students' reported confidence in solving a problem is positively related to their correctness on the problem, and their visual attention to the relevant information on the problem diagram.

The most interesting thing was how changes in confidence occurred due to outcome feedback, which were also related to changes in accuracy and visual attention. The changes in confidence included both reductions in confidence and increases in confidence due to feedback when the student was wrong (first) and right (later). This seems to have led to learning (change in accuracy), and also changes in attentional allocation (more attention to the thematically relevant area).

Table of Contents

List of Figures

List of Tables

Acknowledgements

I am very fortunate to have the support of many people during my time at K-State. I am grateful to my advisor, Dr. N. Sanjay Rebello, for his tremendous support and guidance during the course of this research study. He provided me with lots of encouragement and sound advice whenever I needed them. I could not have chosen a better advisor.

I am also grateful to Dr. Lester Loschky for his mentorship in the visual cognitive aspects of this research. His contribution to this work is invaluable. I would also like to thank the other members of my committee: Dr. Andrew Bennett, Dr. Brett DePaola, and Dr. Stephen Dyer.

Several people have made this work possible. I would like to thank John Hutson for programming the experiment. Many thanks to Bahar Modir, Tianlong Zu, Drew Johnson and Mitchell Burkett for all the hours spent doing the interviews. My sincere thank you to Dr. Jeremy Schmit, Dr. Vinod Kumarappan, Dr. Omer Farooq, Dr. Deepak Shrestha, and Dr. Richard Zajac, who very generously gave me access to their classes for my interviews.

It was a privilege to work with the KSU Physics Education Research group. I would like to thank Dr. Amy Rouinfar for her mentorship and encouragement. Thanks to Xian Wu for the insightful discussions about the project. I have been fortunate to work with amazing people in the group including Claudia Fracchiolla, Nandana Liyanage, Bahar Modir, Tianlong Zu, and Jeffrey Murray. I also want to thank our administrative assistant Kim Coy for all her help. She has done an amazing job keeping the group sane.

The KSU Philippine Student Association has given me incredible support during my time at K-State. Special thanks to Dr. Ronaldo Maghirang and Elizabeth Maghirang who have been extremely generous in offering me their home when I was writing my dissertation. I would like to thank all the members and affiliates for the dance lessons, the food, and for introducing me to Adopt-a-School. Maraming salamat Barangay PhilSA!

To Mama Pamie and Daddy Boy, my cousins Mg Maila, Mg Ador, Elaine and Gene, my niece Carmela, and my nephews Alex and Eli, thank you for providing me a home away from home. I always look forward to the yearly shopping trips and amusement park visits. Thanks, Mg Ador, for always cooking authentic Ilokano food whenever I visit. Naimpusuan a panagyaman ko iti panagayat ken panangsuporta yo kanyak!

Finally, I would like to thank my sisters, Karla and Elysse, for always being there for me. To my niece Cione, thanks for never failing to cheer me up. Most importantly, I would like to thank my parents, Carlo and Elisa Agra for all their love and support. Thank you for always believing in me. What I have achieved wouldn't have been possible without you in my life.

Financial support was provided in part by the National Science Foundation under awards 1138697and 1348857.

Dedication

To my parents.

In memory of my grandparents:
Trinidad Aglugob Garasi (June 4, 1916 – April 16, 1980)
Presentacion Racho Garasi (November 21, 1921 – April 11, 2009)
Solferino Pascua Agra, Sr. (November 1, 1919 – June 29, 2013)
Victorina Agbayani Agra (November 1, 1926 – May 25, 2013)

Chapter 1 - Introduction

Problem solving has been a considered as an essential part in learning physics (Hsu, *et al.*, 2004; Maloney, 1993). Jonassen (2011) defines a problem as a “question or issue that is uncertain and so must be examined and solved.” Traditionally, problem solvers are categorized as experts and novices, although the distinction between them is not absolute (Singh, 2002). Experts usually solve problems faster and more successfully than novices (Chi, Feltovich & Glaser, 1981; Larkin, McDermott, Simon, & Simon, 1980). Novices tend to categorize problems based on the entities contained in the problem statement, and solve problems using surface features of the problem. Experts on the other hand categorize and solve problems based upon physics principles that will be used in the solution.

Problems in physics make extensive use of diagrams such as kinematics graphs and free-body diagrams. Problems that contain diagrams allow problem solvers to make inferences (Larkin & Simon, 1987). However, it is not guaranteed that these inferences are useful for successful problem solving. Research (Chi, Feltovich & Glaser, 1981; Rosengrant, *et al.*, 2009; Madsen, *et al.*, 2012) has demonstrated that on physics problems that contain diagrams, correct problem solvers focus on the feature of the diagram that is relevant to getting the correct answer, and then apply the correct physics principles to successfully solve the problem. Incorrect solvers focus on the salient but irrelevant features and then associate those features to common naïve conceptions physics problem solving (McCloskey, 1983).

In this chapter of the dissertation I first present the motivation for my research project. The next section discusses the previous studies that were conducted, and how the context of the current study is situated within the NSF project that supports this work. The chapter concludes with the research questions that the research study seeks to address, and a roadmap for the rest of the dissertation.

Motivation

Our research is motivated by the three research studies on problem solving and visual attention (Grant & Spivey, 2003; Thomas & Lleras, 2007; 2009). Grant and Spivey (2003) investigates how eye movements determine the attentional and perceptual processes that accompany Karl Duncker's (1945) radiation problem. Duncker's radiation problem asks solvers how to destroy an inoperable stomach tumor using lasers, if, at sufficient intensity, the lasers can also destroy the healthy organic tissue that surround the tumor (lasers were not invented until the 1960s; Duncker (1945) used "ray" instead of "laser" in the original statement of the problem). The solution to Duncker's radiation problem involves firing multiple low intensity lasers from different angles outside the healthy tissue, which then converge at the tumor with sufficient intensity to destroy it. The results of Grant and Spivey's (2003) study showed that just before successful participants solved the problem, they were spending more time focusing on the skin that separates the healthy tissue (which surrounds the tumor) and the space outside the diagram. Solvers who solved the problem correctly also made more skin-crossing saccades than solvers who solved the problem incorectly; the saccades followed a path from a point outside the skin, inwards to the tumor, and back towards the skin, simulating multiple converging lasers from outside the body.

In a follow-up study, Thomas and Lleras (2007) investigated the hypothesis that guiding the eye movements in in such a way that they embody the solution of the problem can lead to solving the problem successfully. Visual cues were overlaid on the diagram for Duncker's radiation problem, which participants were asked to solve. They found that participants who were moved their eyes in a way that embodied multiple lasers crossing the skin area at different locations and converging at the tumor had a higher success rate in solving the problem than any other groups, including one where participants' eye movements crossed the skin area multiple times but at the same location. The result demonstrated that in spatial reasoning tasks, eye movements could influence thinking. It also supports Grant and Spivey's (2003) proposal that embodied eye movement patterns can guide participants toward the correct solution.

Thomas and Lleras (2009) also investigated whether the triggering of insight comes from the physical movement of the eyes or from an attentional shift in a pattern that also embodies the solution. They found that participants who overtly moved their eyes in an embodied pattern and participants who covertly attended to the stimuli without physically moving their eyes had no significant difference in problem solving performance. This result suggests that solving the problem was not due to the participants physically moving their eyes, but in the shift in participants' attention that occured before they moved their eyes.

Previous Work

In physics problem solving, it may not be possible for embodied eye movement patterns to be applied to a diverse set of problems. Problems in which it is possible to embody the correct answer are ones that contain a diagram. The diagrams contain regions that are related to the correct answer, as well as regions that are associated with well-documented incorrect answers in physics education research literature. In our studies, we use such problems.

Madsen *et al.* (2012) showed in their study that students who looked more closely at the relevant area of the problem diagram tended to correctly solve the problem, while students who attended to the areas that are associated with misconceptions incorrectly solved the problem, with their answers related to those misconceptions. To investigate if directing the students' visual attention to embody the solution could improve problem solving, Madsen *et al.* (2013a; 2013b) used a computational model to modify the saliency of the relevant and irrelevant areas of the diagrams. The way the modified the saliency was by varying the luminance contrast of the diagram elements. They found that correct students' visual attention was directed by their prior knowledge, which often overwhelmed the saliency of the diagram (Madsen, *et al.*, 2013a; 2013b).

To direct students' attention towards the relevant areas of problem diagrams, Madsen *et al.* (2013a; 2013b) provided visual cues on the problems. The visual cues were eye movements of students who solved the problem correctly. They found that in one problem set, students who were cued with the correct eye movements significantly outperformed students who were not cued. Students who were cued also significantly outperformed students who were not cued on a transfer problem, which was presented without cues. Madsen *et al.* (2013a) suggested that the cues be described to the students as to their purpose, and to redesign the cues to be simpler and thus more easily interpreted.

In a follow-up study, we extended the work the work completed in Madsen *et al.* (2013a; 2013b) in two ways. First, visual cues were described to students in the cue conditions as hints that were designed to help them correctly solve the problems. Second, it is possible that students are not aware that they solved a problem incorrectly, so students were given feedback in which they are told whether their response (answer and reasoning) correct or incorrect. Thus, the research condition was similar to an online learning environment in which students may be provided hints to help them solve problems correctly, and feedback to indicate whether their answers are correct or incorrect.

Students solved four sets of related problems covering the areas of speed and conservation of energy. There were eight open-ended problems in each set: an initial problem, six isomorphic training problems, and a transfer problem. In comparing the students' training problem performances, we found that those who received visual cues and feedback were the highest performing, and students who did not receive visual cues or feedback were the lowest performing. Students who saw visual cues but did not receive feedback were more successful than students who received feedback but not visual cues (Rouinfar, 2014a; Rouinfar *et al.*, 2014b). We also found that on the transfer problems, students in the Cue + Feedback condition were the significantly highest performing on three problem sets, while students in the No Cue + No Feedback condition were the significantly lowest performing. Thus, the combination of visual cueing and outcome feedback is effective in helping students solve training and transfer problems.

We also investigated how the students' visual attention changed as a result of being cued on training problems (Rouinfar, 2014a; Rouinfar *et al.*, 2014c). We found that for participants who got the initial problem wrong and then got the transfer problem right, participants in the non-cued group attended to the relevant information of the transfer problem significantly longer than the cued participants. Being cued made the students more efficient in extracting the relevant information, leading to a shorter time looking at the relevant information on the on the transfer problem. This shows that visual cues help in the automatization of extracting problem-relevant information from transfer problem diagrams.

One limitation of the study was that the transfer problems were considered as "near" transfer problems such that the surface features are not changed very much and the problems still looked similar to the initial and training problems. To determine whether visual cues and outcome feedback also influenced performance on problems that have a considerably different surface feature from the training problems, we recommended that far transfer problems be investigated as well. Moreover, to investigate if visual cueing and feedback influence retention, it was also recommended that the students be tested on the transfer problems a few weeks after their initial participation.

Research Questions

In a broad sense, the study investigated the influence of visual cueing and outcome feedback on students' accuracy, confidence, and eye movements as they solved conceptual physics problems. First, I focus on investigating performance as students solve physics problems while they verbalize their reasoning. Second, I study how visual cueing and outcome feedback shift students' visual attention as they solve these problems. Finally, I investigate the effects of visual cueing and outcome feedback on students' reported confidence, and how changes in confidence are related to students' accuracy and visual attention. Specifically, I address the following research questions:

1. What is the effect of training that uses visual cues, outcome feedback, or their combination, on students' performance, after they solved an initial isomorphic problem?
2. After being trained with visual cues and/or outcome feedback on a set of isomorphic training problems, does performance improve on problems …
    - …that are somewhat similar to the initial and training problems (near transfer)?
    - …that test the same concept but that have considerably different features as the initial and training problems (far transfer)?

3. How does the combination of training with visual cues and/or outcome feedback affect performance on somewhat similar and considerably different problems two weeks after training?
    - Is there a difference in students' performance on near transfer problems presented immediately after training, and near transfer problems that are presented two weeks after training (delayed near transfer)?
    - Is there a difference in students' performance on far transfer problems presented immediately after training, and far transfer problems that are presented two weeks after training (delayed far transfer)?
4. What is the effect of training that uses visual cues and/or outcome feedback on students' confidence in solving a problem, after they solved an initial isomorphic problem?
5. How do visual cueing, outcome feedback, and their combination thereof affect visual attention on the thematically relevant area of a problem diagram? Is there a difference …
    - …between correct and incorrect solvers with respect to their visual attention on the thematically relevant area of a diagram?
    - …on the thematically relevant area of the diagram between students who receive and do not receive visual cues on the training problems? For students who received and did not receive outcome feedback?
6. What is the effect of visual cueing and/or outcome feedback on the automaticity of extracting relevant information from a problem diagram?

- For students who incorrectly solve the initial problem and then correctly solve the near/far transfer problem, do those who see visual cues on the training problems spend less time attending to the thematically relevant area of the near/far transfer problem diagrams?
- For students who incorrectly solve the initial problem and then correctly solve the near/far transfer problem, do those who receive outcome feedback spend less time attending to the thematically relevant area of the near/far transfer problem diagrams?

7. Does the automaticity of extracting relevant information from a problem diagram persist?
    - For students who are incorrect on the initial problem but are correct on both the transfer and delayed transfer problems, does the visual attention on the thematically relevant area decrease for students who see visual cues?
    - For students who are incorrect on the initial problem but are correct on both the transfer and delayed transfer problems, does the visual attention on the thematically relevant area decrease for students who receive outcome feedback?
8. Does a student’s confidence in solving a problem relate to his visual attention on the thematically relevant information on the problem diagram?

Overview of Dissertation

Chapter 2 provides a review of relevant studies and literature, which include previous research on problem solving and the cognitive processes involved, and the use of visual cueing and its influence on visual attention. The chapter concludes with a discussion of prior research on visual attention in physics problem solving.

Chapter 3 is focused on a review of the relevant frameworks used in the study – Representational Change Theory and Framework for Attentional Cueing, including a description of how those frameworks are extended and integrated in this research. The role of outcome feedback on learning is also discussed. Chapter 4 discusses the context of this research study, the student population, and data collection processes used in the study. The chapter concludes with a description of the eye tracking technology used in the study. Chapter 5 focuses on the quantitative results describing the influence of visual cueing and outcome feedback on students' problem solving performance. The first four research questions are answered in this chapter. Chapter 6 describes analyses of the eye movement data to address the next four research questions. Chapter 7 provides a summary of the results of the previous chapters, and how the results have addressed the research questions. The chapter concludes with a discussion of the implications of the study, as well as the direction of future research.

Chapter 2 - Review of Relevant Literature

Understanding the processes of learning and problem solving is of great interest to educational researchers. In this chapter, I present a review of studies on problem solving and the cognitive processes involved in problem solving. The problems that we study are physics problems with diagrams that have two distinct features: one associated with the correct answer, and one associated with common incorrect answers. In order to solve the problems correctly, students should pay attention to the relevant information and relate it to physics concepts. The problems are also conceptual and do not require algorithmic calculations. Thus, they are similar to insight problems.

Visual attention has been a relevant topic in contemporary cognitive science. The influence of cognitive processes on visual attention has been studied for a long time. More recently, researchers have been studying the inverse – the influence of eye movements on cognition. In this literature review, I will discuss studies that investigate both the influence of cognitive processes on eye movements and the influence of eye movements on cognition. First, I will discuss insight problem solving. Then, I will discuss visual attention in eye movements, and how visual attention is related to cognitive processing. Next, two different sources of information –bottom-up and top-down information – that guide our visual system, will be studied. Their influence in physics problem solving will be discussed. Previous research on the effect of eye movements on cognitive processing and the effects of cognitive processing on eye movements will also be discussed. Finally, previous studies regarding visual attention in physics problem solving will be presented.

Insight Problem Solving

In problem solving, insight refers to the experience of an “Aha!” moment, which occurs when the correct answer to a problem springs unexpectedly to mind. In insight problem solving, a solver first attempts to solve the problem. Then, after the initial failure to solve the problem, the solver reaches an impasse. During impasse, the solver believes that he has explored all the options, and yet is still not able to correctly solve the problem. Then suddenly, the solution comes to mind in a flash of insight.

An example of an insight problem is Duncker’s (1945) radiation problem, which posed the following question (adapted by Grant & Spivey, 2003):

> “Given a human being with an inoperable stomach tumor, and lasers which destroy organic tissue at sufficient intensity, how can one cure the person with these lasers and, at the same time, avoid harming the healthy tissue that surrounds the tumor?”

The solution relies on the concept of convergence – using multiple laser beams of lower intensity from different directions to converge on the tumor at a sufficient intensity to destroy it without damaging the tissue through which each laser beam travels. The insight required to solve this problem is to realize that multiple lasers may be employed, as long as their intensity is low enough to not damage the surrounding tissue. Upon seeing the solution, most insight problems appear to be fairly simple, and certainly well within the intellectual capability of an average person.

The problems we investigate in the current study are analogous to insight problems. Attending to the areas of the problem diagram that are associated with correct answers allows the solver to retrieve and apply the correct resources and solve the problem correctly. Of course, physics problems are more complex such that solving one may involve several steps. Thus, the problems that we study may require more that one instance of insight.

Eye Movements and Visual Attention

Eye movement methodology has been demonstrated to be useful in the investigation of insight problem solving (Grant & Spivey, 2003; Knoblich, Ohlsson, & Raney, 2001; Litchfield & Ball, 2011; Thomas & Lleras, 2007, 2009). In these studies, an eye tracker recorded fixations (when the eyes are stationary at a single spatial location) and saccades (when the eyes are moving), which were then analyzed to understand the problem solving process.

In reading, adult readers fixate most on nouns, adjectives, verbs, etc. (“content” words) and tend to skip “function” words (articles, conjunctions, etc.) (Just & Carpenter, 1980). Just and Carpenter (1980) suggested that readers fixate on each word until processing has been completed. This was referred to as the “eye-mind assumption.” According to the study, the time it takes to fixate on a word is directly related to the processing of the word. Therefore, the fixation duration provides a useful measure of the cognitive mechanisms that are involved in reading.

There are two types of visual attention. Overt visual attention involves a change in the orientation of our eyes to concentrate on areas of interest. They are called overt because they are visible to other people. On the other hand, covert visual attention is not visible to other people. This allows us to pay attention without changing the location of our gaze.

Studies have demonstrated that overt visual attention can explain the cognitive mechanism of problem solving (Bilalić et al., 2008; Eivazi & Bednarik, 2010, 2011; Epelboim & Suppes, 2001; Grant & Spivey, 2003; Jones, 2003; Knoblich et al., 2001; Knoblich et al., 2005; Lin & Lin, 2014; Madsen et al., 2012, 2013a, 2013b; Susac et al., 2014; Thomas & Lleras, 2007, 2009). Top-down processes, which are based on prior knowledge, have also been shown to direct solvers' attention towards the relevant information (Epelboim & Suppes, 2001; Madsen et al., 2012).

Zhao, Gersch, Schnitzer, Dosher, and Kowler (2012) investigated the effect of pre-saccadic shift of attention on eye movements. In one experiment, participants moved their eyes in a 'V' pattern between two corners of a screen. In between the two saccades, the letter 'T' appeared in different orientations on four corners of the screen. The participants were then asked about the orientation of the 'T' in one specific corner. This was done with and without visual noise or mean luminance. As expected, they found that the participants were most successful in reporting the orientation when the "T" was located where their gaze ended.

In another experiment, participants visually followed a path and then reported the presence or absence of the target at a specific location. They found that the performance was better when the target was at the goal than at a location opposite the goal. They concluded that the increase in performance when the target was at located at the goal of the saccade was not only due the features of the target.

The result of the investigations by Zhao, et al. (2012) parallels those of Hoffman and Subramaniam (1995), who found that covert and overt visual attention are closely linked in guiding behavior. In their study, they showed that eye movements directed to a specific spatial location are preceded by a covert shift of visual attention to the same spatial location (Hoffman & Subramaniam, 1995).

In contrast, Hein and Moore (2009) investigated how explicit (overt) eye movements influenced the precision of covert shifts of attention during an "attentional walk" – the shift in attention from one item to another within an array of items as a response to a series of tones. Eye movements of six participants were recorded as they performed an attentional walk task. At the end of the task, participants reported the color of the last disc in the walk. Twenty percent of the walks were zero-step (only the cued disc was shown), while the majority was multiple-step (in between six and nine discs were shown in addition to the cued disc). Three different densities were used for the display (12, 24 and 36 discs). Two conditions were investigated – fixation condition in which the participants remained fixated on the central fixation dot when the cued disk started blinking, and the saccade condition in which the participants made explicit eye movements to the cued disc.

The researchers found that for the zero step walk type, the performance decreased as the density increases for both conditions, and that at the highest density of 36 discs, the saccade condition performed better than the fixation condition. Interestingly, they found no significant difference in performance between the fixation and saccade conditions in the multiple-step walk type. This contradicted their hypothesis that the explicit eye movement to the initial position of the attentional walk would increase the precision with which subsequent steps of attention could be performed.

In the current study, we investigate the overt visual attention of students as they solve conceptual physics problems that contain diagrams. Specifically, we investigate how students' visual attention shifts as they transition from an incorrect solution to a problem to a correct solution in the next problem.

Bottom-up and Top-down Processes

Our visual attention is guided by two information processes. Bottom-up processing is data-driven in that current stimuli influence what is perceived. That is, bottom-up processing involves the detection of features such as color, orientation, and luminance contrast. Studies have shown that saliency plays an important role in determining the location eyes fixations (Irwin et al., 2000; Itti & Koch, 2000; Mital et al., 2010).

Theeuwes, Kramer, Hahn, and Irwin (1998) investigated the effect of the appearance of a new object on goal-oriented eye movements. They used a visual search task of a color-singleton target, and an irrelevant object appeared abruptly somewhere in the display at the same time as the target. Initially, the screen displayed six equally spaced gray circles in an imaginary circle containing a figure-eight premask. After one second, all the circles except one turned red, and, at the same time, all the premasks changed to letters. The observers made a saccade to the remaining gray circle, and determined whether the letter inside was a ‘c.’ In half the trials, at the same time the colors changed, another red circle appeared at one of four possible locations. The study found that the reaction time to identify the letter was longer with the onset of a new object. Moreover, observers’ eyes tended to move toward the new object, irrespective of where it appeared, paused briefly, then moved to the singleton target. Thus, a new object captures the eyes. The result of this study demonstrates bottom-up processing.

Top-down processing is knowledge-driven such that a person’s prior knowledge influence what is perceived. Top-down processing can be involuntary and automatic, or voluntary and effortful based on prior experience and learning (Baluch & Itti, 2011)

Studies have shown that automatic top-down processes influence overt attentional scene selection (Theeuwes & Godthelp, 1995; Shinoda et al., 2001). In general, mandatory top-down processes have a greater effect (Einhauser et al., 2008; Foulsham & Underwood, 2007; Henderson et al., 2007), and volitional top-down processes have weaker effects (Guitton et al., 1985; Mitchell et al., 2002) than bottom-up saliency. In research done by Madsen, Larson, Loschky, and Rebello (2012), the saccades and fixations were measured as participants solved different conceptual physics problems with diagrams to determine what parts of diagrams are attended to. They showed that participants' physics knowledge directed their knowledge to either the relevant information or the irrelevant information of a problem, depending on how correct their prior knowledge was.

Hegarty, Canham, and Fabrikant (2010) investigated how the saliency of information that is either relevant or irrelevant to a task influenced participants' comprehension and eye fixations. In the first experiment, a weather map of North America with pressure and temperature information was presented to participants, after which they were asked to determine whether an arrow in the map showed the actual direction that the wind would blow in that region. The perceptual salience of the task-irrelevant (temperature) and task-relevant (pressure) information was varied in two conditions, and the participants did the tasks before and after a tutorial on meteorology. They found that after instruction, participants performed significantly better when pressure was the salient information on the map than when temperature was the salient information on the map. They also found that the eye fixations of both groups showed similar patterns after instruction, but the eye fixations of the participants in the pressure-salient group was more accurate. They replicated the methodology in a second experiment in which they redesigned the pressure-salient map to make the centers of the pressure systems more salient. They found that increasing the relative visual salience of the relevant information led to more eye fixations on the task-relevant regions but made did not make a more accurate performance. In the third experiment, the researchers added two conditions to the previous experiment. In addition to getting the same type of weather map before and after the tutorial, participants were also presented with a weather map after the tutorial that is different from the one given before the tutorial. Result showed that while there was no significant effect of the type of map viewed before instruction on the accuracy, performance was significantly better with pressure-salient maps after instruction. This was consistent with the previous experiments and demonstrated that domain knowledge reduced the influence saliency on where learners looked.

Influence of Bottom-up and Top-down Processes in Physics Problem Solving

A consistent pattern of incorrect answers in physics can be described using top-down and bottom-up processes (Heckler, 2011). For example, we have notions about how the physical world works even without instruction (Halloun & Hestenes, 1985; McDermott & Redish, 1999; McCloskey, 1983). These ideas can result in deep-seated stable cognitive structures (called misconceptions) that interfere with the acquisition of scientifically accurate understanding (Docktor & Mestre, 2014). It is also suggested that the patterns of incorrect answers are a result of misappropriation of conceptual resources (Hammer, 2000), which are small pieces of knowledge that a learner may activate alone or in clusters depending on context. Incorrect answers to physics questions occur when inappropriate resources are applied to a given situation. Other research has shown that students systematically answer problems incorrectly because they miscategorize knowledge into inappropriate ontological categories, for example thinking of force as a thing instead of an interaction (Chi, 1992).

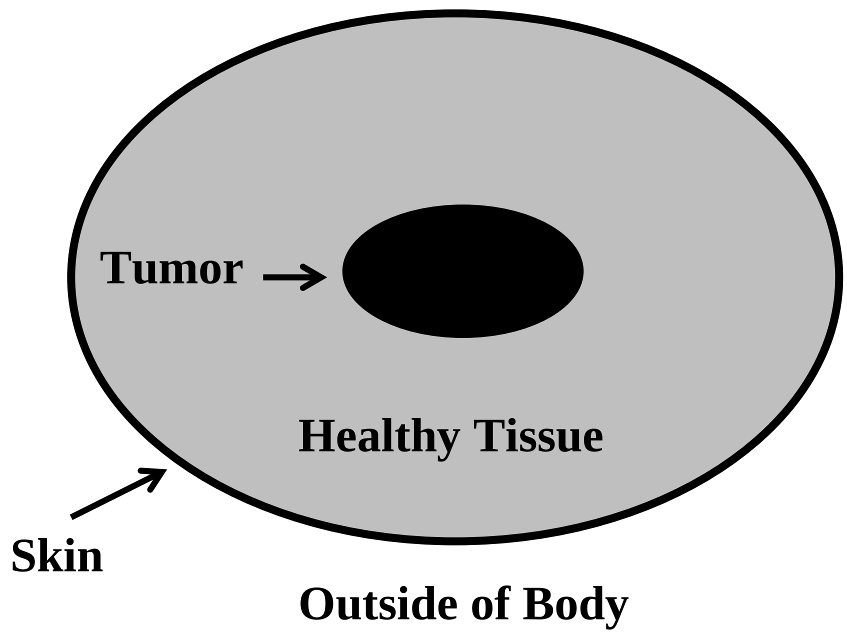
Heckler (2011) suggested an alternative bottom-up explanation for students' consistent incorrect answers to simple physics questions. Instead of being primarily concerned with students' knowledge, he suggested that processes inherent to our visual system might be contributing to systematically incorrect answers. Heckler suggested that, "salient yet scientifically irrelevant features of a question compete for attention with less salient yet relevant features." The most salient feature tends to capture attention easily. Thus, bottom-up processes inherent in students' visual system automatically direct their attention to the most perceptually salient problem elements. Then, as long as the elements suggest a plausible and relevant answer, students' base their answer choices on them. This occurs even if these elements suggest an answer choice that is contrary to the scientifically correct answer, as students have not considered other less salient elements. Heckler provided evidence for his explanation in the form of student response patterns to a set of similar questions in which areas in the problem diagram relevant to the incorrect answer were presumed to have high levels of salience, but he pointed out that eye tracking is needed to observe the allocation of attention and confirm his conjecture.

In the current study, visual hints, in the form of colored shapes that are overlaid on the problem diagrams, are presented. The hints are designed such that they highlight the relevant information in the problem, and suppress the irrelevant but salient information. We investigate whether top-down or bottom-up processing dominates during students' problem solving performance when they are presented with visual hints.

Influence of Visual Attention on Cognitive Processes

Grant and Spivey (2003) were the first to study the effects of eye movements on cognitive processes by attempting to influence problem solvers' visual attention while they solved Duncker's radiation problem. In addition to a verbal description of the problem, a visual schematic of the problem was also presented to the participants (see Figure 2.1). Grant and Spivey (2003) tracked the eye movements of the participants and found that just before successful participants solved the problem, they spent a significant amount of time fixating on the skin area of the diagram. Thus, the relevant feature to solving the problem correctly is the skin area, and directing attention to the skin by increasing its salience might help in correctly solving the problem.

Figure 2.1 A depiction of the diagram that the participants viewed while working on Duncker's radiation problem, as adapted from Grant and Spivey (2003). The labels were not shown, but were presented verbally.



In a second experiment, the diagram was manipulated such that the relevant area (skin) or an irrelevant area (tumor) pulsated, or the diagram remained static. They found that participants who were in the condition in which the skin pulsated performed significantly better than participants in the "animated-tumor" or the static condition. Analysis of the eye movement data also revealed that those who were successful in solving the problem made more skin-crossing saccades than those who were not. They showed that the eye movements started from a point outside the skin, then a saccade towards the tumor, and then back towards the skin, simulating multiple lasers from outside the body converging on the tumor.

In a research study conducted to follow up on Grant and Spivey's (2003) results, Thomas and Lleras (2007) demonstrated that directing participants' eye movements to embody the solution leads to solving Duncker's radiation problem successfully. In their study, they divided their 10-minute experiment into twenty 30-second intervals consisting of a 26-second free viewing period followed by a 4-second digit-tracking task. The visual cues were overlaid on the diagram for Duncker's radiation problem, which the participants were also asked to solve. During the free-viewing period, there were no instructions on how participants should move their eyes; in the digit-tracking task, the participants were asked to find a digit when it is embedded in a string of 7 letters.

For one group, the eight items were presented sequentially at different points inside and outside the skin boundary, therefore requiring many skin-crossing saccades and embodying multiple lasers converging on the tumor. For the second group, the eight items were presented in the same eight locations, but in an order that minimized the number of skin- crossing saccades. For a third group of participants, the eight items were once again alternately presented inside and outside the skin boundary, but always in the same location so the saccades did not converge towards the tumor. In the final group of control participants, all eight items were presented on the "tumor," thus requiring no eye movements at all during the digit identification task.

Thomas and Lleras (2007) found that the embodied-solution group was more successful in solving the problem than the other groups. This is consistent with their hypothesis in that eye movements were able to influence problem solving. This result also supports Grant and Spivey's (2003) proposal that embodied eye movements can help participants arrive at the correct solution.

Interestingly, while the number of skin-crossing saccades made by the different groups were very different during the identification task, these differences did not carry over to the free viewing periods of problem solving, during which participants from all groups had the same number of skin crossing saccades. A post-task questionnaire revealed that participants did not suspect that the digit identification task was related to the problem-solving task, instead believing the identification task to be a distraction. Thus, while physical behaviors embodying the solution seem to induce problem-solving success, it appears that the effect of this phenomenon is implicit in nature.

Thomas and Lleras (2009) examined whether the triggering of insight comes from the physical movement of the eyes or an attentional shift in a pattern that also embodies the solution. They replicated the experiment in their previous (Thomas & Lleras, 2007) study, and had four conditions. The embodied-solution group from the previous paper was retained, and was renamed the eye-movement group. A second group of participants (“attention-shift group”) were told to covertly attend to the stimulus without physically moving their eyes. The third group of participants (“tumor-fixation group”) remained fixated on the tumor during the tracking task, but were allowed to look anywhere on the screen during the free-viewing period. The last group of participants (“no-eye-movement group”) kept their attention on the tumor the entire duration of the session.

As with their previous result, the frequency of skin-crossing saccades made by all groups during the free-viewing period was the same except for the no-eye-movement group, who kept their attention on the display during this time. They also found no significant difference between the performances of participants who were overtly attending to the stimuli and participants who were covertly attending to the stimuli. This suggests that solving the problem correctly was not due to the physical movement of the eyes but in the shift in attention that occurs before eye movements.

Litchfield and Ball (2011) investigated how looking at someone’s eye movement patterns influenced accuracy and visual attention. Participants solved Duncker’s radiation problem (see Fig. 2.1), and the diagram was initially overlaid with another person’s eye movements. The three eye movements shown were: (a) eye movements that focused only on the central tumor; (b) eye movements naturally making skin-crossing saccades from different angles; and (c) didactic eye movements based on the “embodied-solution” in Thomas and Lleras’ (2007) study. Then the scanpaths were removed, and the participants were asked to solve the problem. Participants were given two chances to solve the problem within a given time period, and they were allowed to see scanpaths in between the two attempts. In order to be considered correct, participants should be able to explain that multiple low-intensity lasers coming from different locations in the outside area converge at the tumor.

The authors were able to demonstrate that following the eye movements of a correct solver enabled participants to solve the problem correctly, as participants who saw both embodied eye movements (both natural and didactic) made more skin-crossing saccades significantly more than participants who saw eye movements fixating on the tumor. They found no significant difference in performance between participants in the natural condition and participants in the didactic condition.

In a similar study, van Gog, Jarodzka, Scheiter, Gerjets, and Paas, (2009) investigated the effect of showing an expert’s problem-solving process and eye movements to students’ learning. The problem is known as “frog leap.” At the starting position, three frogs on the right side of an empty stone are facing left, and three frogs on the left side of the empty stone are facing right. The goal is to switch the frogs, that is, the ending position is of three frogs on the left of the empty stone facing left and three frogs on the right of the empty stone facing right. The correct solution to this problem consists of 15 steps, and any error made cannot be corrected.

There are four conditions that the researchers tested – product-oriented example with and without attention guidance, and process-oriented example with and without attention guidance. In the product-oriented example, only the actions of the expert model were shown while in the process-oriented example, this was accompanied by a narration of the thought-process behind the actions. In addition to these example conditions, a problem-solving condition was also implemented to determine if the example study is more effective than problem solving.

For the examples conditions, two worked-out examples were shown, both with the solution starting on the right side. Participants in the problem-solving condition were given two attempts to solve the problem. After viewing the examples or attempting to solve the problems, the participants solved the problem themselves; the first one starting on the right side as in the example, and the second one starting on the left side. Performance was scored as either correct or incorrect.

The results showed that when experts' eye movements were not shown, students in the process-oriented condition significantly outperformed students in the product-oriented condition the first problem. A larger percentage of the process-oriented students were correct on the second problem as well. On the other hand, when experts' eye movements were shown, more students in the product-oriented condition than in the process-oriented condition that were correct on the first problem were also correct on the second problem. Thus, the authors suggested that attention guidance only become apparent on transfer tasks. They also concluded that the expert's didactic eye movements as well as the narration that accompanied the process-oriented example might have interfered with the investigation.

The previous studies presented in this section were all on insight problem solving – the subjective experience of an "Aha!" moment. In insight problem solving, the solution to a problem suddenly and unexpectedly springs to mind. A study by Ellis, Glaholt, and Reingold (2011) investigated the acquisition of knowledge in insight problem solving by applying eye movement measurements during an anagram problem-solving task. Specifically, the study determined whether the knowledge is gradually accumulating prior to insight or suddenly increased at the arrival of insight.

Thirty-two undergraduates were provided with an anagram problem that consisted of a four-word solution (three consonants and a vowel) and a consonant distractor. The addition of the distractor was introduced as a visual baseline of the knowledge of the solution. Two experiments were conducted, which were similar except for the subjects' reporting of their classification of their experience in solving the anagram problem in one experiment.

They found no significant difference between the experiments with respect to the success rates in solving the anagram problems. There were also no significant differences in response times, number of dwells, and dwell duration for both experiments (a dwell is defined as consecutive fixations occurring in the same area). This suggests that the retrospective subjective reports in the second experiment did not influence performance of the anagram task.

The researchers compared the viewing times spent on the consonants at the start of the trials to the viewing times prior to the arrival of insight. They showed that participants were looking at the solution and distractor consonants equivalently at the start of the trials, but they spent a significantly longer time at the solution consonants than the distractor consonant at the end of the trials. This indicates solution knowledge just prior to insight.

In the current study, we investigate students’ problem solving performance when they are presented with visual hints. Specifically, we are interested in whether we can improve problem solving by redirecting students’ visual attention from the salient but irrelevant information towards the relevant information of the problem diagram.

Influence of Cognitive Processes on Visual Attention

The first to employ eye movement methodology to insight problem solving were Knoblich, Ohlsson, and Raney (2001), in which the authors investigated the eye movement patterns of participants while they solved matchstick arithmetic problems to test three predictions from insight theory. Twenty-four participants who were familiar with Roman numerals were asked to solve three incorrect arithmetic equations constructed with matchsticks in Roman numerals by moving one match stick. (e.g., change IV=III+III to VI=III+III; change III=III+III to III=III= III; change XI = III + III to VI = III + III).

Knoblich *et al*. (2001) examined the eye movements of participants to test the predictions of the representational change theory of insight. The authors looked for evidence that participants had created unhelpful initial representations of the problem, and found that participants' eye movements were more fixated on the numerals rather than the operators during the early stages of problem solving. This suggested that participants assumed the constraint that operators are fixed variables. They also found that successful problem solvers dramatically increased their fixation times towards the critical element of the problem in the later stages of problem solving, thus indicating that they were considering relaxing a constraint or decomposing a perceptual chunk. These findings provide support for the representational change theory of insight.

The representational change theory of insight was used by Knoblich *et al*. (2001) to explain the occurrence of impasse as a consequence of an inappropriate initial mental representation of the problem. According to this theory, the presentation of an insight problem is likely to activate unhelpful knowledge elements, which consequently inhibit other knowledge elements that are essential to the solution, thus leading to an impasse. In a matchstick arithmetic example, knowledge elements normally associated with math are activated, such as the assumption that operators are invariant, and that Roman numerals are indivisible entities. In order to solve the problem, the initial problem representation must be revised, through means such as constraint relaxation and chunk decomposition. Once the pattern of activation in memory shifts, previously inactive but essential knowledge elements appear in working memory, leading to the solution and the associated subjective experience of insight.

In the current study, we also investigate how the visual attention of correct problem solvers differs from that of incorrect problem solvers. That is, we are interested in which area of the diagram students focus on when they solve the problem correctly as compared to when they solve the problem incorrectly.

Research on Visual Attention in Physics Problem Solving

It is not common in physics education research (PER) to investigate the cognitive mechanisms involved in physics problem solving, specifically using visual attention. However, there have been a few studies conducted that offer interesting results.. Below we discuss work in PER that deals with differences in attention based on expertise, attention to relevant features, global versus local attention and attention to conceptual text and mathematical steps.

Tai, Loehr, and Brigham (2006) investigated how expertise influenced eye movement patterns as participants solved standardized science assessment problems. The six participants, who were pre-service secondary teachers, self-reported their levels of expertise in physics, chemistry and biology.

The problems contained four components – a diagram, the question, the answer choices, and a link to the next question. They were located on the right, upper left quadrant, lower left quadrant, and lower right corner of the screen, respectively. The location of these elements was fixed to minimize extraneous eye-movements. Participants solved the questions in the same order – 6 questions in biology followed by 6 questions in chemistry and then 6 questions in physics.

They found no correlation between the reported expertises of the participants to their problem solving accuracy. An interesting thing that the researchers did was that they assigned the four elements of the problem to “look zones” and graphed the amount of time spent on each zone and the saccadic shifts to different zones in what they called “zone graphs.” In looking at a zone graph, you can see clearly where the students looked at on the screen from the time the problem appeared until the time they clicked the hyperlink to the next problem, and for how long. Zone graphs of expert observers showed a progression across zones with fewer saccades between them, while zone graphs of novices showed a number of saccades between the image and the answer zones. This study suggests that students with higher expertise can hold important pieces of information in working memory and coordinate those with other important features without looking back at previously attended zones. This work was done with only six subjects, so conclusions remain tentative.

Rosengrant, Thomas, and Mzoughi (2009) used eye tracking to discuss the similarities and differences on how experts and novices focus on graphics used in circuit analysis. Nine novices and two experts were given four different circuit configurations and were asked different questions regarding current flow, net resistance, and potential drop. Eye tracker data showed that when solving a problem, experts often referred back to the circuit diagram. Novices, on the other hand, were less likely to alternate their focus between the circuit diagram and their work. Moreover, while both experts and novices tended to look alternately between two resistors, experts focused more on the entire circuit and not on the components. An interesting finding is that the eye movement pattern of one expert followed the direction of current flow in the circuit.

The novices did not exhibit this gaze pattern – their eye movements followed the shortest path between the resistors. This study showed that experts exhibited a more global attention (i.e. current flow) while novices focused more on the individual components. This is consistent with the result of a previous research regarding experts and novices, in which the authors showed that experts focused more on the underlying physics concepts and novices focused more on the surface features of a diagram (Chi *et al.*, 1981).

Smith, Mestre, and Ross (2010) observed the eye movement patterns of introductory physics students as they worked out examples in mechanics to determine where they looked at and for how long when solving problems. They also investigated the effect of the given instruction about the examples on the attention paid to the conceptual and mathematical information. Undergraduate students were provided with worked-out examples that were presented in a two columns – one column contained the equations and another column contained a conceptual explanation of the equations. Participants in the *Homework* condition were told at the beginning that they would be solving the target problem, while participants in the *Quiz* condition were not immediately presented with the target problem. Participants studied the examples before they solved the target problem, and an assessment to test recall was given. They showed that participants spent most of the time looking on the conceptual columns. Transitions between conceptual and mathematics columns corresponded to the same step in the solution, while transitions among mathematical regions were mostly between adjacent regions. Thus, students were processing both textual and mathematical information at the same time.

They found that participants in the *Homework* and *Quiz* conditions did not significantly differ with respect to their eye movement patterns. There was also no difference on the performance on the first target problem, but the *Homework* condition group performed significantly better on the second target problem. Interestingly, there was no correlation between the memory recall assessment to either the amount of fixation time spent on textual information or the total fixation time. The participants in both conditions performed equally poorly.

This study is important because this is the first time any study has looked into what students focus on when processing worked-out examples, and the result that students spend almost half the time processing textual information is interesting. The result regarding the performance on the target problems is not very encouraging, since on only one target problem were there significant differences. The authors suggest that this may be due to the fact that often, conceptual information is not assessed in physics problem solving, that participants may not understand the role of conceptual information in problem solving or that the text was not used by the students to gain conceptual insight.

Feil and Mestre (2010) investigated whether physics experts (graduate students) and novices (introductory algebra and calculus based physics students) could detect small changes to physics problems containing blocks and ramps or blocks and pulleys using a change blindness paradigm. They found that experts were more likely to notice a change if it altered the underlying physics of the situation. Novices who had stronger relevant content knowledge were also more likely to notice physics-modifying changes. Neither experts nor novices were likely to notice changes to surface features of the problems. This suggests that experts and those with strong physics understanding attend to diagram features that are important to understanding the physics in a diagram.

Rosengrant, Hearrington, Alvarado and Keeble (2011) studied students' visual attention during the lecture for a physical science course for elementary teachers. Eight students from the course volunteered to wear eye-tracking glasses for the duration of a lecture. They found that students spent very little time attending to the professor and instead directed their attention to PowerPoint slides or their notes unless the professor was very animated, drew on the board or offered examples in addition to those on the PowerPoint slides. This implies that if a professor wanted students to attend to him/her, they should not also provide another distractor such as a PowerPoint slide. They also found that students located in the middle and front of the classroom tended to be more on task than those in other areas.

Docktor, Mestre, Gire and Rebello (2012) looked at how graduate physics students and introductory algebra based physics students differed in the way they viewed and interpreted kinematics graphs. The participants were asked to select the region of the graph that matched a text description. The congruence between the text description and the shape of the graph was varied (e.g. the text stated the velocity was increasing and the corresponding region in the displacement vs. time had a negative slope) as well as whether the text represented a direct, derivative or integral quantity. They found that the performance of experts was higher than novices on incongruent items, though they did not find any difference in their eye movements.

Gire, Docktor, Rebello and Mestre (2012) investigated representational fluency of experts and novices in physics. Participants were presented with pairs of a graph, equation or text, and would indicate if the representations were consistent with each other. Experts were significantly more likely to indicate consistency correctly, indicating greater representational fluency than novices. Experts also spent less time fixating on equations and text. This implies that experts required less processing time for the information represented with equations and text, as they were more familiar with this information. It is curious that the same difference was not found on the graphical representation.

Madsen, Larson, Loschky, and Rebello (2012) measured the saccades and fixations as participants solved different conceptual physics problems with diagrams to determine what parts of diagrams are attended to. In the first experiment, 13 introductory psychology students were interviewed regarding ten multiple-choice conceptual physics problems to determine which parts of the diagrams they were looking at when they provided incorrect answers. They found that their results were in agreement with documented student difficulties in literature. In a second experiment, 24 participants consisting of introductory psychology students, physics graduate students, and a postdoctoral candidate in physics were asked to solve six of the problems in the first experiment while their eye movement patterns were recorded. The eye movements were replayed so the participants could report their thought processes while they solved the problems.

To analyze eye movement data, areas-of-interests (AOIs) were created. They found that correct participants looked at the relevant information of the diagram while incorrect participants looked at the novice-like areas. This suggests that participants' accuracy in their physics knowledge direct where they look.

This research was significant because it verified previous research about where students focus on when they are solving problems in physics, and that the student misconceptions influence where they look at in problem solving.

Rouinfar, Agra, Larson, Rebello, and Loschky (2014c) investigated the shifts in students' visual attention before and after seeing visual cues during training. We found the counterintuitive result that for participants who got the initial problem wrong and then the transfer problem right, those who saw visual cues on the training problem diagrams attended to the relevant information of the transfer problem diagram significantly less than those who did not see visual cues. We explained this result by proposing that participants who were cued to look at the relevant areas of the training problem diagrams had had more practice extracting the relevant information than those who were not cued, thus becoming more efficient. This is an example of automaticity.

Automaticity

Automatic processing has been defined by Schneider and Shiffrin (1977) as the "activation of a learned sequence of elements in long-term memory that is initiated by appropriate inputs and then proceeds automatically." For example, in visual search tasks, subjects that are continuously being trained to recognize certain inputs as targets are able to automatize their responses (Schneider & Shiffrin, 1977; Scialfa, Jenkins, Hamaluk, & Skaloud, 2000; Shiffrin & Schneider, 1977). Thus, automaticity is acquired through practice (Bargh & Ferguson, 2000; Kramer, Strayer, & Buckley, 1989; Logan 1978; 1979; 1985; 1988). One important effect of practice on skilled performance is that skill speeds up with practice and reduces the error rate (Anderson, 1992).

In one study by Logan (1978), participants were provided the same list of 1-, 2-, and 4-letter target sets for six days and asked if a specific letter was on the list ("yes" task), and then switched to another list on the seventh day and asked about the letters that were on the previous list but not on the current list ("no" task). It was assumed that visual search would show evidence of automaticity if participants took a longer time to respond on the seventh day, when the list was changed. They found that reaction times decreased over the six days, increased with the set size of the target lists, and was longer for the "no" task than the "yes" task. They also showed that the attention demanded by the search was high on the first few days of practice, but diminished later on. Thus, they showed that automaticity develops with practice. On the seventh day, they found that the reaction times were similar to the reaction times in the first few days of practice. Thus, automaticity develops with *specific* practice. To provide a baseline under which automaticity should not develop, they provided a different set of participants a different list every day. They found that the attention demanded by the search (as measured by the reaction times) remained consistently high. Thus, automaticity had not developed.

In another study, Scialfa, Jenkins, Hamalouk, and Skaloud (2000) asked participants to indicate the absence or presence of a white diagonal line in a 6×6 matrix containing distractors. First, participants were tested on a contrast, (finding the target within black diagonal lines) and then on orientation (finding the target within white diagonally opposite lines). Then, participants were tested on a conjunction task (finding the target within black diagonal lines and white diagonally opposite lines) for seven days. On the last day, participants completed a conjunction reversal task, in which they found a black diagonal line within white diagonal lines and black diagonally opposite lines. Eye movements and fixations were recorded during visual search. They found that on the conjunction task training, first fixation duration for the last session is shorter than the first fixation duration for the first session. Thus, fixation duration decreased with increasing improvement in search. They also found that the average fixation duration increased following reversal. The results suggested that without practice, conjunction search was more demanding than feature search. They also observed that on the conjunction search task, participants would select the white items first, and then search the target within that subset. Thus, the general improvement reflects a more efficient use of the search cues.

In the current study, we extend the previous study (Rouinfar, 2014a; Rouinfar *et al.*, 2014c) such that in addition to the near transfer problem, we also investigate the visual attention of students as they solve the training problems. In the previous study, we found the surprising and counter-intuitive result that among learners who wrong on the initial problem and then were right on the near transfer problem, participants who were visually cued on the training problem diagrams attended to the relevant areas of the transfer problem diagram significantly less than those who were not visually cued. We proposed a *post hoc* hypothesis that participants who were shown cues became more automatic at solving the problems – participants had become more efficient in extracting the relevant information as a result of being cued on the training problems, and so needed less time to extract the relevant information on the near transfer problem. In the current study, we test the automaticity hypothesis that was emergent in the previous study by investigating learners' visual attention to the relevant information on the training problems in both the cue and no-cue conditions. We have not been able to test this hypothesis directly in the previous study, as we did not have eye movement data on the training problems. We also investigate whether students can automatize the extraction of problem relevant-information not just on near transfer problems but also on far transfer problems and delayed transfer problems.

Chapter 3 - Theoretical Background

Introduction

The main goal of this dissertation is to extend existing frameworks in order to interpret student performance in the context of solving conceptual physics problems that contain diagrams. I combined aspects of three theoretical frameworks. The first framework that I will discuss is the Representational Change Theory (Ohlsson, 1992), which is concerned with the cognitive processes that are involved in insight problem solving. The second framework is de Koning et al.'s (2009) framework for attentional cueing used in instructional materials that make use of animations. Lastly, the Cognitive Theory of Multimedia Learning (Mayer, 2001) is concerned with the use of multiple modalities in learning. I also discuss the role of outcome feedback in learning. Finally, I discuss confidence in learning and how it is moderated by outcome feedback.

Representational Change Theory

Representational Change Theory was an attempt by Gestalt (Ohlsson, 1984) psychologists to explain insight problem solving. It explains the cognitive processes involved when learners solve conceptual insight problems. This framework is important to our to our research since the problems that we study require students to recognize and apply the necessary concepts in order to be solved correctly.

Theory of Insight

Traditionally, insight is defined as the sudden appearance of the complete and correct solution to a problem. However, for more complex problems, a series of insights might be needed to completely solve the problem. Insights occur because the problem solver encounters an impasse, but not every impasse sets the stage for insight. Breaking out of impasse can have two different outcomes. First, the problem solver may overcome an impasse, but the solution still eludes him. He does not see the complete solution in his mind's eye, and so his problem solving still features characteristics of stepwise or trial-and-error problem solving. Ohlsson (1992) refers to this as *partial insight*. On the other hand, sometimes overcoming an impasse is followed by the experience of seeing the solution in the mind's eye, after which problem solving is completed without error or false starts. This is referred to as *full insight*.

Ohlsson (1992) raises three questions about the theory of insight. First, why do we encounter an impasse on a problem that we are competent to solve? Second, how is the impasse broken? Finally, what happens after impasse is broken? In order to answer these questions, the mechanism of problem solving is explained.

Problem Solving Principles

In order to explain insight, Ohlsson (1992) discusses some mechanisms involved in problem solving. According to Representational Change Theory, when a learner starts solving a problem, his mental representation of the problem is influenced by his prior knowledge. Long-term memory is searched for concepts that are related the problem representation. If memory search is unsuccessful, learner encounters impasse. Impasse is broken when the representation is changed, and insight occurs when the retrieved knowledge is sufficient to solve the problem.

Overcoming Impasse

The mental representation of a problem can be restructure by one of the following mechanisms: elaboration, re-encoding, and constraint-relaxation.

Elaboration

Elaboration occurs when new information is added to enhance the existing problem representation. For example, problem representation can be extended by becoming aware of features of the problem that the learner was previously unaware of. Information can also be added through long-term memory recall.

Re-Encoding

The initial representation of many insight problems is generally erroneous instead of incomplete. Thus, the problem solver must reject a component of his current representation before going forward to create a different interpretation. Re-encoding occurs when the learner reinterprets an existing representation into a different, more productive representation.

Constraint-Relaxation

Impasse often occurs because the problem solver imposes constraints on the problem solution, which makes the problem unsolvable. In constraint relaxation, the learner removes unnecessary, often self-imposed, constraints.

In summary, impasse is broken when the mental representation that a learner has of a problem is restructured to allow them to retrieve relevant concepts from long-term memory. The retrieval allows the creation of a new way for the problem to be represented. The learner overcomes impasse and achieves insight when the new problem representation is sufficient to correctly solve the problem.

Constraint-relaxation lifts previous unnecessary constraint due to incorrect assumptions by the solvers (Chi, Feltovich, & Glaser, 1981). Thus, problems in which insight is achieved using constraint-relaxation are not amenable to visual cueing. The emphasis of the current study is on problems in which elaboration and re-encoding are used in overcoming impasse and achieve insight.

Cognitive Theory of Multimedia Learning

Cognitive Theory of Multimedia Learning (Mayer, 2001) explains the use of multiple modalities in learning. Physics problem solving lends itself to the use of multiple representations. Many physics problems require students to coordinate information provided in multiple modalities, such as problems with text and diagrams.

Active Processing Assumption

One assumption of Mayer's Cognitive theory of Multimedia Learning is that problem solver engage in cognitive processing actively in order to construct mental representations of the problem. This includes organizing incoming information, and integrating it with other information.

Active learning occurs when a learner applies cognitive processes to make sense of incoming material. This results in the construction of a coherent mental model, which represents the key information in the presented material and how they relate to each other. Examples of how knowledge can be structured include process, which is represented as cause-and-effect chains and consists of explanation of how a system works; comparison involves comparing two or more elements along several dimensions and can be represented as matrices.

There are three processes that are important for active learning to occur. These are: selection of relevant information, organization of information selected, and integration of the selected information with existing prior knowledge.

Selection

Selection occurs when a learner attends to specific pieces of information. For example, selection occurs when the learner pays attention to relevant words and images in a presented material. This process involves bringing the presented material into the working memory component of the cognitive system.

Organization

Organization involves creating a coherent mental representation of the problem by creating connections betwen the selected information. Process and comparison are examples of organizing selected material. This process occurs in the working memory of the cognitive system.

Integration

Integration involves building connections between incoming materials and relevant portions of prior knowledge. This involves activating knowledge from long-term memory and bringing it into working memory.

Framework for Attentional Cueing

Cueing refers to the manipulation of visuospatial characteristics in instructional materials to help learners select the relevant information, and then organize and integrate the selected information into a coherent mental representation (de Koning, *et al.*, 2009). It is intended to draw the learners' attention towards the relevant visual elements of a representation.

de Koning *et al.* (2009) proposed a framework to classify three functions of cueing which are related to the three cognitive processes involved in active learning: (1) guiding learner's attention to facilitate the selection and extraction of relevant information, (2) emphasizing the organization of individual elements and combining them into a coherent structure, and (3) making the relationship of different elements more salient to facilitate their integration.

Guiding Attention

In order to construct a coherent representation, the learner should be able to extract relevant ideas or concepts that can serve as a basis for further processing. Unfortunately, learners frequently cannot discriminate between relevant from irrelevant information, and therefore are at risk of forming misconceptions and drawing inaccurate conclusions by focusing on salient but non-essential information. Therefore, a function of cueing is to emphasize specific information intended to indicate the relevance of the cued content. For example, spotlight cues, which are produced by reducing the luminance of but the relevant parts of a presentation (de Koning *et. al.*, 2007; 2009; 2010) have been shown improve learning. Similarly, Grant and Spivey (2003) showed that emphasizing the critical skin area of Duncker's (1945) tumor problem resulted in better problem solving and longer times spent fixating on the skin area.

Emphasizing Organization

An essential aspect of comprehension is the identification of the individual elements and then combining them into a coherent structure. If learners are not supported with cues that emphasize the structure of different information, then comprehension fails. Therefore, another function of cueing is to emphasize the organization of information to help learners to represent the structure of the presented material, such as recognizing associations and trends between information. Examples of cues that emphasize organization are the use of spreading color cues to represent temporally spaced events (Boucheix & Lowe, 2010).

Integrating Elements

In order for learners to build a coherent and integrated mental representation, it is insufficient to merely attend to the key elements of the material, but also to make causal inferences and be aware of the temporal dimensions of information. Thus the final function of cueing is to construct an integrated mental representation by attending to the relationships between elements. This function of cueing can emphasize the relationship between spatially separated elements within a single representation such as a text or a picture, or to draw attention to connected elements in different representations such graphs and text. Integration cues can aid learners in relating spatially separated elements (Lowe, 1989) or elements across different modalities such as text and graphs using simultaneous flashing (Craig, *et. al.*, 2002), color coding (Kalyuga, *et. al*, 1999), or graphical organizers (Mautone & Mayer, 2007).

In the current study, we investigate how visual cues can help students select and organize relevant information, and how they integrate selected information into their existing mental representation. In most physics problems, organization and integration cues are collapsed. Often, we require students to make comparisons across different representations.

Outcome Feedback

One of the important drivers of learning, including representational change, is feedback. Feedback has been conceptualized in terms of positive or negative reinforcement. The basic idea behind reinforcement is the intuitive notion that a satisfactory outcome following a specific action results in an increased tendency to perform that action (Thorndike, 1911).

The role of feedback has been considered in terms of higher-order cognitive processes involved in self-regulated learning. Feedback can support self-regulation by enabling learners with strategically useful information (Bangert-Drowns *et al.* 1991).

Feedback has evolved from focusing solely on external feedback to also including internal feedback, which is feedback generated by the learner during the process of self-regulation. The notion of internal feedback has been influenced by the works of Meyer (1986) and of Chinn and Brewer (1993), who characterized the ways in which students changed their naïve theories in response to feedback.

In light of this research, Butler and Winne (1995) proposed five functions that feedback could potentially serve in the process of conceptual change. These are confirmation of correct understanding, addition of needed information, overwriting false information, tuning partial understanding, and restructuring schemata. They expanded on the model by Bangert-Drowns *et al.* (1991) to integrate instruction, self-regulation, feedback and knowledge construction.

The role of feedback has also been studied in second language learning. A review by Loschky and Harrington (2013) demonstrates an important distinction between outcome feedback and elaborated feedback. Outcome feedback only provides information on the correctness of an answer, while elaborated feedback also includes follow-up explanations. These studies show that while elaborated feedback is the most effective, outcome feedback is also effective in promoting initial learning (Caroll, Swain & Roberge, 1992; Caroll & Swain, 1993) and long-term retention (Leow, 2000).

Feedback as a Means to Calibrate Confidence

Studies have shown that people are often overconfident in the correctness of their knowledge (Lichtenstein & Fischhoff, 1977; Fischhoff, Slovic, & Lichtenstein, 1977; Lichtenstein, Fischhoff, & Phillips, 1977; Koriat, Lichtenstein, & Fischhoff, 1980; Fischer & Budesco, 2005; Arkes, Christensen, Lai, & Blumer, 1987). For example, people who express 100% certainty of being correct are correct only 85% of the time (Fischhoff, 1982). In eyewitness research, the confidence with which a witness makes an identification is a weak predictor of accuracy of that identification (Kassin, Ellsworth, & Smith, 1989; Perfect & Hunt, 2000; Bornstein & Zickafoose, 1999; Sporer, Penrod, Read, & Cutler, 1995), with witnesses generally being overconfident.

In order to reduce overconfidence, confidence should be calibrated (Lichtenstein & Fischhoff, 1977; Fischhoff, Slovic, & Lichtenstein, 1977; Lichtenstein, Fischhoff, & Phillips, 1977; Koriat, Lichtenstein, & Fischhoff, 1980). A study by Koriat, Lichtenstein, and Fischhoff, (1980) showed that participants who were asked to list their reasons as to why an answer to a question might be incorrect dropped their confidence ratings to a point at which they closely approximated their accuracy levels. Another method to calibrate confidence is through feedback (Arkes, Christensen, Lai, & Blumer, 1987; Gonzalez-Vallejo & Bonham, 2007; Beckmann, Beckmann, & Elliott, 2009). Beckmann, Beckmann, and Elliott (2009) showed that participants who were initially low in confidence benefitted from feedback such that they were able to have the same performance accuracy as participants who did not receive feedback. Arkes, Christensen, Lai, and Blumer, (1987) showed that participants who were asked questions that appeared easy but were actually difficult had relatively high confidence. Receiving negative outcome feedback caused them to adjust their confidence levels downward and, ultimately, they manifested less overconfidence.

In this study we explore the role of outcome feedback on problem performance. We also investigate how outcome feedback moderates problem-solving confidence. Providing outcome feedback is similar to creating a discrepant event, which causes cognitive dissonance (Festinger, 1962) or disequilibrium (Piaget, 1964). This can lead to knowledge restructuring (i.e., representational change), which has been argued to be the most important type of learning (Rumelhart & Norman, 1976), and is most relevant to our project. Outcome feedback has been shown to invoke conceptual change (Posner, et. al., 1982) and facilitate correct problem solving

(Mory, 2004) in computer-aided instruction (Fraij, 2010; Martin, et. al, 2002). A downward change in confidence can potentially increase readiness of students to learn and therefore facilitate conceptual change. Visual cueing can aid in directing students' attention to the relevant areas, and the subsequent outcome feedback can increase their confidence. Thus, outcome feedback can lower overconfidence as well as raise underconfidence. Finally, the combination of outcome feedback with visual cueing can be functionally considered as a form of elaborated feedback.

Conceptual Model

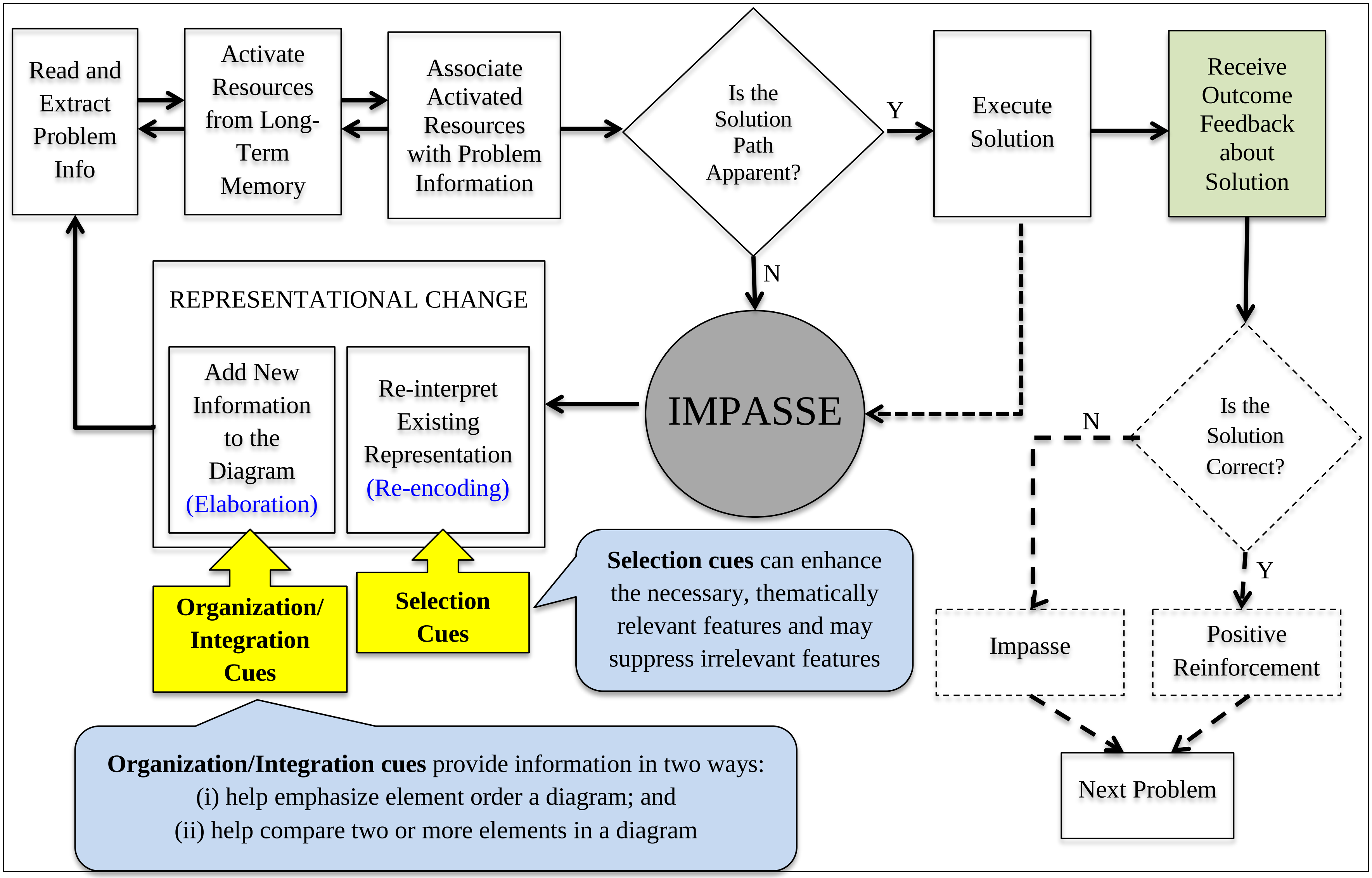
In the previous sections I described the different conceptual theories in our study. In this section I will combine them into the conceptual model that we use to explain how students solve the problems in our study. Figure 3.1 shows the conceptual model.

According to representational change theory, the learner reads the problem, and then uses prior knowledge to create a problem representation. He then probes his long-term memory and activates the resources related to the problem information. If a path to a solution is apparent, then the learner implements the strategy and reports a high confidence rating. If memory search is unsuccessful, the learner encounters an impasse, at which point all problem solving ceases. Impasse may also occur if the learner fails to follow through in his execution of his solution strategy. The confidence levels reported after the learner encounters impasse should be low. In order to overcome impasse, the problem representation in the solver's mind must be modified. One way to overcome impasse is by re-interpreting the information given in the problem (re-encoding). Another way to overcome impasse is by adding new information from inference or long-term memory to extend the existing representation (elaboration). After the learner overcomes impasse and achieves insight, the learner's confidence should increase.

Visual cues can help the learner in problem re-representation, which can help the learner achieve the necessary insight to break impasse. Selection cues help suppress irrelevant or enhance relevant information, which can activate previously inactive relevant resources from long-term memory, creating a new problem representation. Organization or integration cues add new information to the problem. New information can be added by highlighting the order that the information should be attended to, or by emphasizing comparisons between elements of one or more diagrams. Thus, they can help overcome impasse.

In most physics problems, the learner may not know that his solution is incorrect. Therefore, providing feedback is essential. After the learner provides an answer to the problem, he is told if he was correct or incorrect in his answer and explanation; no other information is provided. If, based on the feedback, the learner realizes that he was correct, then he moves on to the next problem with positive reinforcement and no change in confidence (assuming he had high confidence to begin with, which is consistent with the general finding of overconfidence). Conversely, if he realizes that he was incorrect, then his confidence level should decrease (assuming that he was originally over-confident), and he should encounter an impasse when he attempts to solve the next similar problem. This should make him more receptive to the information provided in a cue, which assumedly is inconsistent with his previous incorrect representation of the problem. Thus, the cue should facilitate breaking the learner's impasse. If the learner's next attempt at solving the problem is correct, then a critical first step in learning has occurred, and the feedback to that effect should increase the learner's confidence. At this point, the learner's confidence should be better calibrated.

Figure 3.1 Conceptual model which integrates elements of Representational Change Theory (Ohlsson, 1992), Framework of Attentional Cueing (de Koning, *et al.*, 2009), and Outcome Feedback (Butler & Winne, 1995).



Chapter 4 - Research Methodology

The purpose of this research study is to investigate the influence of visual cueing and outcome feedback on students' accuracy, confidence, and visual attention when solving conceptual physics problems with diagrams. In order to investigate these effects, we conducted individual interviews and done a quantitative analysis of the students' performance, confidence and eye fixations. The participants were 115 students who were enrolled in introductory algebra-based physics courses. Each student was interviewed twice, separated two weeks apart. This chapter explains the research methodology employed in this study, including the context of the study, data collection process, and data sources.

Experiment Design

The study consisted of two experiments, a main experiment and a delayed transfer experiment. The main experiment took 50-60 minutes to complete. The delayed transfer experiment was conducted 2-3 weeks after the main experiment (min = 10 days, max = 40 days, avg. = 15.65 days) and was 20-30 minutes long.

Participants

Participants in the study (N = 115, 72 males, 43 females) were students in first- and second-semester algebra-based physics courses at a large, Midwestern university. The students were invited to participate through an email sent to everyone enrolled in the courses, and were provided with extra credit for participation. The extra credit was such that participation in an interview would replace the participant's lowest homework score with a full score. Since there were two interviews, the participant's two lowest homework scores are replaced with full scores.

In effect, this allowed them to "drop" their two lowest homework scores, which was equivalent to about 2% of the total points on the course.

Initially, there were 130 participants who participated in the main experiment: two were dropped because they did not complete the main experiment; six were dropped because they did not participate in the delayed transfer experiment; and seven were dropped because, though they participated in both experiments, they self-reported that they studied the material covered in the main experiment prior to attending the delayed transfer experiment.

Materials

Problem Design

Participants were presented with four sets of conceptual physics problems that covered the topics of energy conservation and speed. The concepts relevant to the material presented in the study had been covered in class prior to participant recruitment. All problems contain a diagram with two distinct features: an area that contains the information relevant to solve the problem correctly, and a salient novice-like area that contains information that is consistent with naïve conceptions documented in literature. In order to correctly solve the problems, participants had to pay attention to the relevant information in the diagram. A more detailed explanation of the problems is discussed in Madsen, *et al*., 2012.

Problem Sequence

Each problem set in the main experiment consisted an initial problem, four isomorphic training problems, a near transfer problem, and a far transfer problem (see Figure 3.1 for examples of each). The visual cues are overlaid on the training problem diagrams, and feedback was provided before each training problem. In the delayed transfer experiment, participants solved the near transfer and far transfer problems from the main experiment. Appendix B presents all the problems presented in the study.

In the previous study (Rouinfar, 2014a), each problem set contained an initial problem, six isomorphic training problems, and a near transfer problem. In the current study we were interested the cognitive processes involved in the students' problem solving, so we required participants to verbalize their thought process as they were solving the problems (i.e., think-aloud, Ericsson & Simon, 1980). Before each interview, we had the participants practice thinking-aloud by solving two practice problems, after observing the interviewer solve another practice problem using a think-aloud process. With the addition of the practice problems, and a far transfer problem in each problem set, the main experiment took longer than one hour during our pilot study. In order to keep the interview to under an hour, we decided to remove some training problems in each problem set. We conducted a mixed factorial ANOVA on the results of the previous study (Rouinfar, 2014a) and the pilot study, with cue and feedback as the between-subjects factors, problem as the within-subjects factor, and performance as the dependent variable. We found that in both studies, for participants in the feedback conditions, there was no statistically significant difference in the performance on a training problem and the next training problem. For participants in the cued conditions, we found that after the third training problem, there was no significant difference in performance on a training problem and the next training problem. Based on these results, we reduced the number of training problems from six to four.

The physics concept tested on each problem within a set is the same. For example, in order to correctly solve all the problems on Figure 4.1, participants have to use conservation of energy and pay attention to the change in height from the initial to the final position for each section of the track (for the initial, training, and near transfer problems) or for each slide (for the far transfer problem).

The problem statement on the training problems is the same as the initial problem. The context of the problem is also identical for the initial and training problems. The problem diagrams on the training problems differed from the initial problem diagram and from each other in such a way that the same method can be used to arrive at the correct solution, but the correct responses could change.

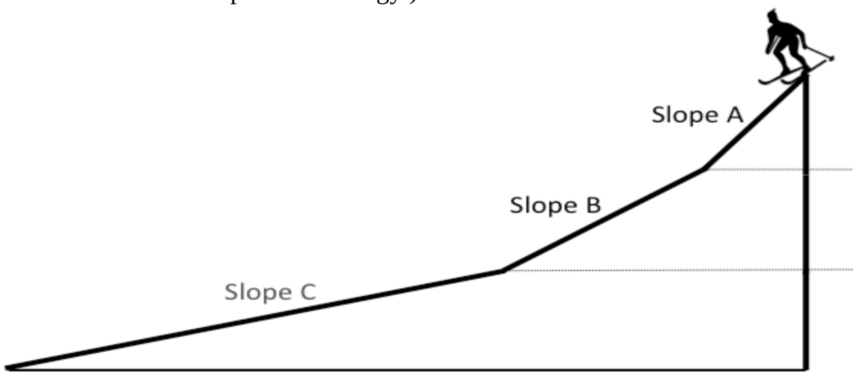
In the Skier problem set in Figure 4.1, the difference on the initial and training problem diagrams can be seen on the steepness and the length of the slopes. The explanations provided by participants who solved the problem correctly involved comparing and ranking the change in height of the sections. On the other hand, participants who incorrectly solved the problems explained their solutions as depending on the slope of the sections, either by the steepness or the length.

The near transfer problem in each problem set had a slightly different problem statement and surface feature, but still tested the same concept, as the initial and training problems. In the example on Figure 4.1, the near transfer problem diagram had a track that had curves as compared to straight tracks on the initial and training problems, and one section of the track goes back up as opposed to just going down the slope. One of the sections also had a net potential energy lost of zero, which has not been encountered by the participants in the previous problems.

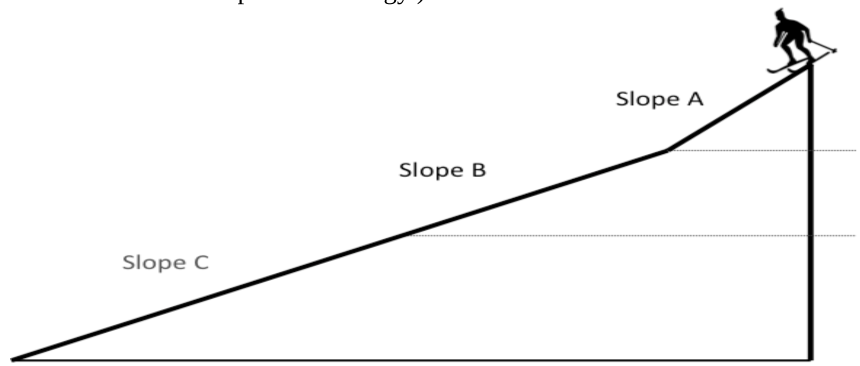
The far transfer problems tested the same concept as the initial and training problems, but had a considerably different surface feature. In the Skier problem set in Figure 4.1, the participants were asked to rank the potential energy lost in each slide. The difference between the far transfer problem from the other problems in the Skier problem set is that to solve the far transfer problem, students have to compare the potential energy lost across four different diagrams. On the other hand, students had to compare the potential energy lost across different sections of a single diagram in the other problems.

Figure 4.1 An example of an initial (top left), training (top right), near transfer (bottom left), and far transfer (bottom right) problem from the Skier problem set.

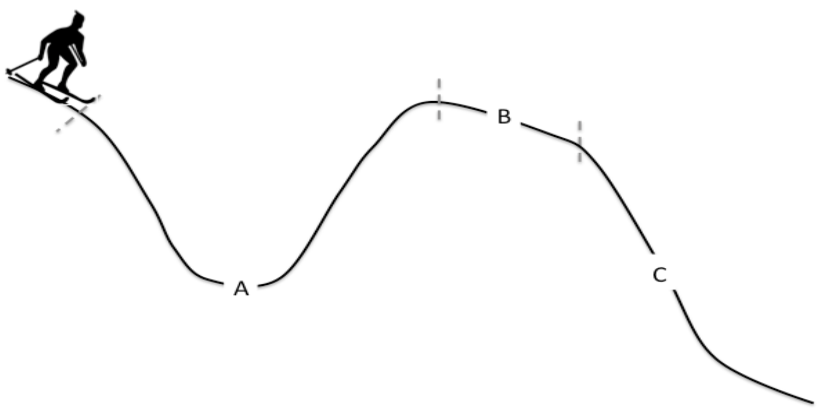
Rank the potential energy lost during the skier's descent down each slope from greatest to least. (That is, rank the potential energy lost from the start of A to the end of A vs. the start of B to the end of B vs. the start of C to the end of C; not the total value of potential energy.)



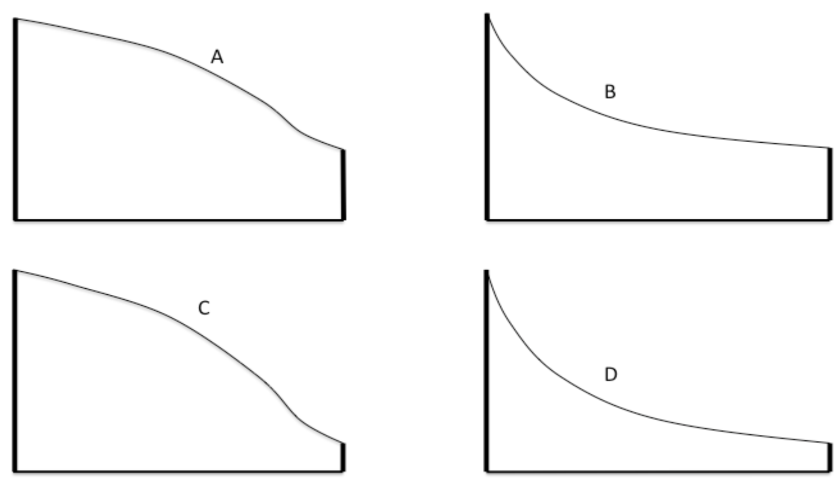
Rank the potential energy lost during the skier's descent down each slope from greatest to least. (That is, rank the potential energy lost from the start of A to the end of A vs. the start of B to the end of B vs. the start of C to the end of C; not the total value of potential energy.)



A skier moves down a track. Rank the potential energy <u>lost</u> by the skier in each section of the track from greatest to least. The dotted lines indicate the beginning and ending of each section of the track. (Rank the potential energy <u>lost</u>, not the total value of the potential energy.)



A young girl slid down four frictionless playground slides as shown below. Compare the potential energy <u>lost</u> by the girl in each slide.



Cue Design

Visual cues that were overlaid on the diagrams of the training problems were shown to participants in the cued conditions (Cue + No Feedback and Cue + Feedback). The participants were told that the cues were hints that were meant to help them correctly solve the problem.

Participants in the cued conditions had to see the cues for each training problem at least one time, but the cues could be played repeatedly. Each cue lasted for a total of eight seconds, which was the shortest amount of time needed to display the animated cues at a rate of one colored shape per second. To view the cues, participants pressed a button on a Cedrus RB-844 Response Pad. Examples of the cues are provided in Figure 4.2.

For the Ball training problem in Figure 4.2, the spaces between the subsequent snapshots of the ball was highlighted in the order shown. Each yellow rectangle was visible for one second before the next in the sequence was shown. The cue was designed to help the participants compare the distance between subsequent snapshots of the ball (integration) since it is necessary to determine when the two balls travelled the same speed. The cue may serve in the process of elaboration by guiding the learner to attend to the information provided in the diagram in a specific order, thereby enriching the existing representation.

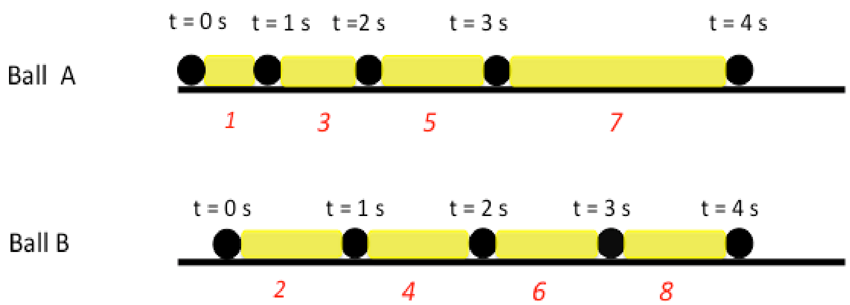
The cue for the Graph training problems was a set of red lines that were tangent to the non-linear curve at different points, and lasted for the full duration of the cue (8 seconds), as shown in Figure 4.2. The tangent lines were meant to help the participants to visualize the non-constant slope of the curved line, which they could then compare to the constant slope of the straight line. This is an integration cue since it aids participants in comparing the slopes of the curved and straight lines. The cue may also serve in elaboration, as the tangent lines add information to and extend the representation by explicitly representing the slope of the line.

In order to correctly solve the Roller Coaster training problems, participants must compare the change in height of the two carts from the initial position to the final position. In the example provided in Figure 4.2, the cue successively highlighted the initial and final positions of cart A and then repeated the same for cart B, aiding in the selection of the relevant information. By explicitly highlighting the positions, the cue can help in elaboration, since the changing positions in the cue could represent the change in height of each cart.

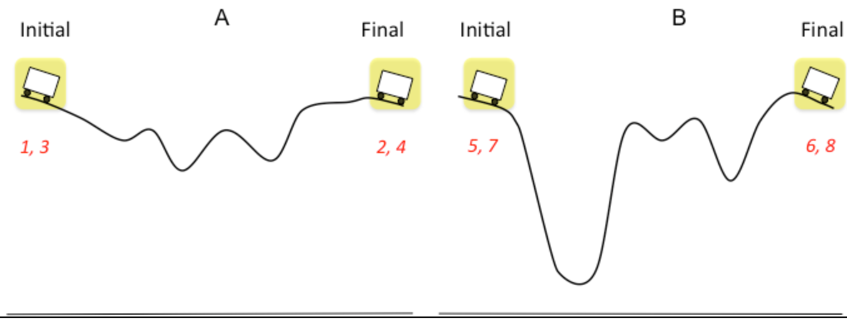
To solve the Skier training problems correctly, participants had to recall that the change in potential energy of each slope is directly related to the height of each slope. The cue for the Skier training problems therefore highlighted the change in heights of each slope. The color of the slopes was also changed to the lightest gray that was still visible to de-emphasize the steepness of the slope. This cue aided in the selection of the relevant information (change in height) by enhancing the heights and suppressing the steepness of the slopes. This could help in re-encoding the problem by replacing the incorrect representation (steepness of the slopes) with the correct one (change in heights).

Figure 4.2 Examples of training problems with the cues superimposed from the Ball (top left), Graph (bottom left), Roller Coaster (top right), and Skier (bottom right) problem sets. All cues appeared on screen for a total of 8s at a time.

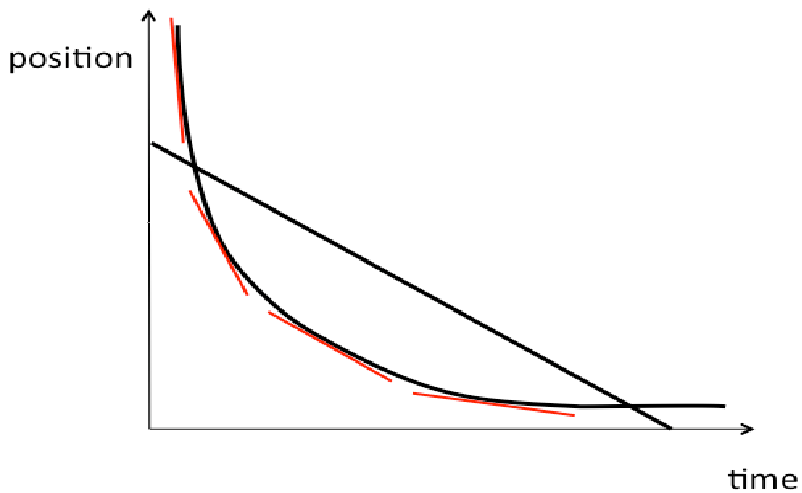
Two balls roll along the paths shown. A snapshot of the position of the balls is taken every second. At what point in time does Ball B have the same speed as Ball A?



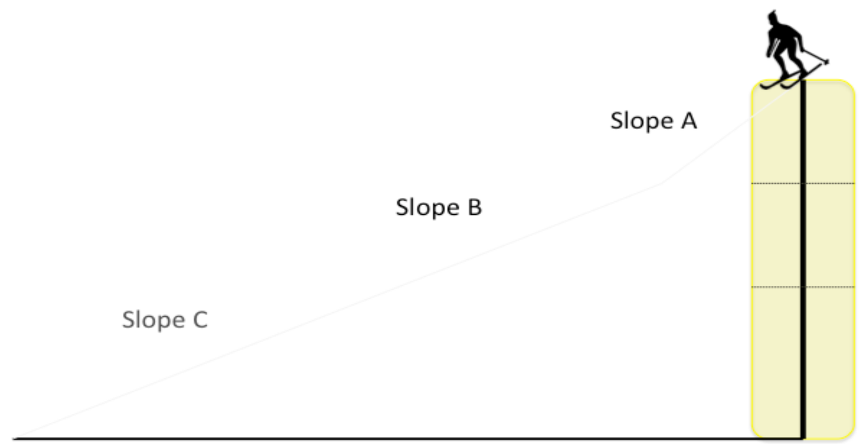
How does the final speed of cart A compare to the final speed of cart B, if the mass of the carts is the same and they both start at rest? (Frictional effects can be ignored)



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



Rank the potential energy lost during the skier's descent down each slope from greatest to least. (That is, rank the potential energy lost 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.)



Design and Procedure

At the beginning of the main experiment, participants were required to sign up for the delayed transfer experiment. After scheduling the second interview, participants were provided with a short explanation regarding the goal of the interview, and were given instructions. Participants were required to verbalize their thought process while solving the problems, hence they were given time to practice thinking out loud before the first problem set was presented. Participants observed as the experimenter solved one practice problem while thinking aloud, and then solved two practice problems while thinking out loud.

Participants were randomly assigned to one of four conditions: Cue + Feedback (N=28), Cue + No Feedback (N=33), No Cue + Feedback (N=27), or No Cue + No Feedback (N=27). All participants solved four problem sets, each containing an initial problem, four isomorphic training problems, a near transfer problem, and a far transfer problem. The order that the problem sets were presented to the participants, as well as the order of the training problems within each set, was randomized.

The problems were shown on a computer screen, and participants were allowed to point on the screen when explaining their answers. Participants were instructed to think out loud as they solved the problems. When the responses were not clear, participants were asked to clarify their answer or explanation. A pre-defined rubric was used to assess the correctness of the responses. In order to be considered correct, the participants had to have provided the correct answer as well as a correct explanation.

Participants in the cued conditions (Cue + Feedback and Cue + No Feedback) saw colored shapes overlaid on the training problem diagrams for eight seconds at a time. Those in the feedback conditions (Cue + Feedback and No Cue + Feedback) received feedback regarding the correctness of their responses, but were given no additional information. The feedback was provided before each training problem. After solving each problem, participants reported their confidence level in their answer and explanation/reasoning. We used a 7-point confidence scale, with 1 being the lowest confidence rating and 7 being the highest confidence rating. A 7-point Likert-type scale was used since there was no significant difference with other Likert-type scales in terms of the proportion of the scale used and the average response time, but that neutral response categories are used more often on 3-and 5-point scales and less often on 7- to 19-point scales (Matell & Jacoby, 1972).

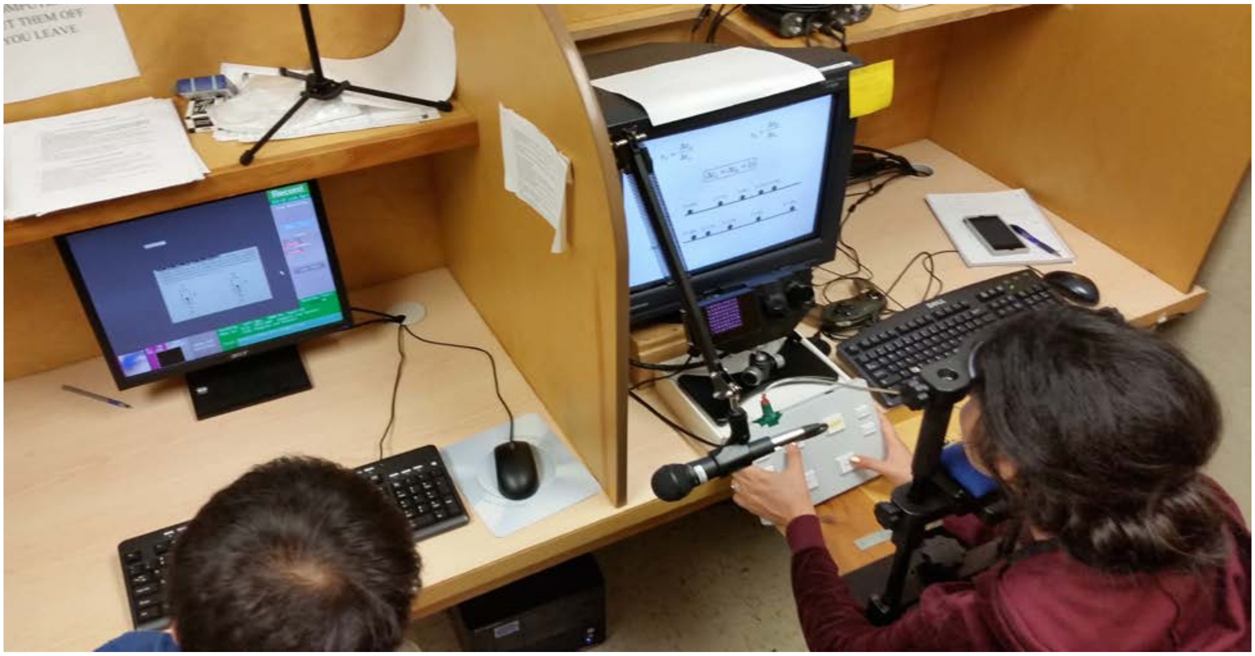
Before starting with the delayed transfer interview, participants were asked to report if they studied the material that was presented in the main interview. Participants who reported that they studied before the second interview were still interviewed, but were dropped from the analyses. Participants were then reminded to verbalize their thought process during the interview, and were given a practice problem to solve while thinking out loud. The problem provided was the same problem as the practice problem solved by the experimenter in the main experiment.

The near and far transfer problems from the main interview were then presented on the computer screen. The order of the problem sets was randomized. After each problem, the participants reported their answer and explanation confidence ratings. After solving all the problems, the participants were debriefed and were offered to discuss the solutions to all the problems in study. The main experiment lasted 50-60 minutes, while the delayed transfer experiment lasted 20-30 minutes, on average.

Interview Set-up

The setup of the interview is pictured in Figure 3.3. The participant is on the right, using a chin and forehead rest. An EyeLink 1000 desktop eye tracker is located below the monitor to record eye movements. The participant is also holding a Cedrus RB-844 response pad, which is used to view visual cues. The response pad is also used to signal when the participant is finished thinking-out loud, and to move on to the next problem. A microphone (not pictured) is used to record the interview, and the audio is synced to the eye tracker. The interviewer sits in front of another monitor. The participant's display is mirrored on the experimenter's display, so the interviewer can monitor the participant's eye movements. The interviewer's follow up questions are recorded using a microphone that is also synced to the eye tracker. A Kodak PlayTouch video camera with a desktop microphone attachment (both not pictured) is also used to record the entire interview.

Figure 4.3 Interview setup. The participant is using a chin and forehead rest, and is in front of the monitor. An EyeLink 1000 desktop eye tracker is used to record eye movements, and a Cedrus RB-844 response pad is used to record participant's button presses. The interviewer is seated in front of another monitor, which mirrors the participant's display monitor.



Eye Tracking Technology

We used an EyeLink 1000 desktop mounted eye-tracking system (http://www.sr-research.com), which has an accuracy of less than 0.50° of visual angle, to record participants' eye movements. Problems were presented on a computer screen with a resolution of 1024 by 768 pixels and a refresh rate of 85 Hz. The images subtended 33.3° × 25.5° of visual angle. In order to minimize extraneous hand movements and increase the accuracy of measurements, participants used a chin and forehead rest that was 24 inches from the screen. An eye movement was considered to be a saccade (i.e., in motion) if the eye's acceleration exceeded $8{,}500°/s^2$ and the velocity exceeded 30°/s. Otherwise, the eye was considered to be in a fixation (i.e., stationary at a specific spatial location). A nine-point calibration and validation procedure was used at the beginning of the experiment.

Chapter 5 - Influence of Visual Cueing and Outcome Feedback on Transfer, Delayed Transfer, and Confidence in Think-Aloud Conceptual Physics Problem Solving

Introduction

In this chapter we discuss the results of the study in terms of participants' performance on the training, transfer, and delayed transfer problems. The study differs from Rouinfar's study (2014b) in that participants were asked to verbalize their thought process as they solved the problems. The number of training problems was also reduced from six to four. To determine this number, we conducted a mixed factorial ANOVA on the Rouinfar's results. Using repeated contrast analysis, we found that after solving three training problems, there is no significant increase in the participants' performance. Another difference is that participants were asked to rate their confidence on their answer and explanation after solving each problem.

The results extend the result of Rouinfar (2014b) in several ways. First, we added a far transfer problem to each problem set. The far transfer problem tested the same concept as the initial and the training problems, but had a considerably different surface feature (e.g. comparing four diagrams instead of within a single diagram). To test the long-term effects of visual cueing and outcome feedback, the transfer problems were presented after two weeks. Thus, the research conditions in the current study resembles a physics course in the following ways: the training problems are similar to an online homework system in which students are given immediate feedback to indicate the correctness of their answers and hints to help them answer problems; the transfer problems resemble a written homework that does not contain hints or feedback; and the delayed transfer problems are similar to exam problems in that they are given weeks after the concept has been discussed (and the online and written homework has been submitted).

Number of Times the Cue was Played

Participants in the Cue + Feedback and Cue + No Feedback conditions were required to view the cues at least once on each training problem. However, the cues could be played as many times as the participants liked. Results showed that a majority of the participants viewed the cues only once, accounting for 91.45% of the total number of training problems solved. The cues were rarely viewed twice (6.58% of total number of cases) or more (1.97% of total number of cases).

Of the multiple viewings of the cue, 51.28% of occurrences were on the first training problem (40 cases), 21.79% occurred during the second training problem (17 cases), 15.38% during the third training problem (12 cases), and 11.54% during the last training problem (9 cases). The high percentage of multiple viewings on the first training problem is most likely due to the participants' first interaction with the cue, since the order that the training problems were presented within a set was randomized.

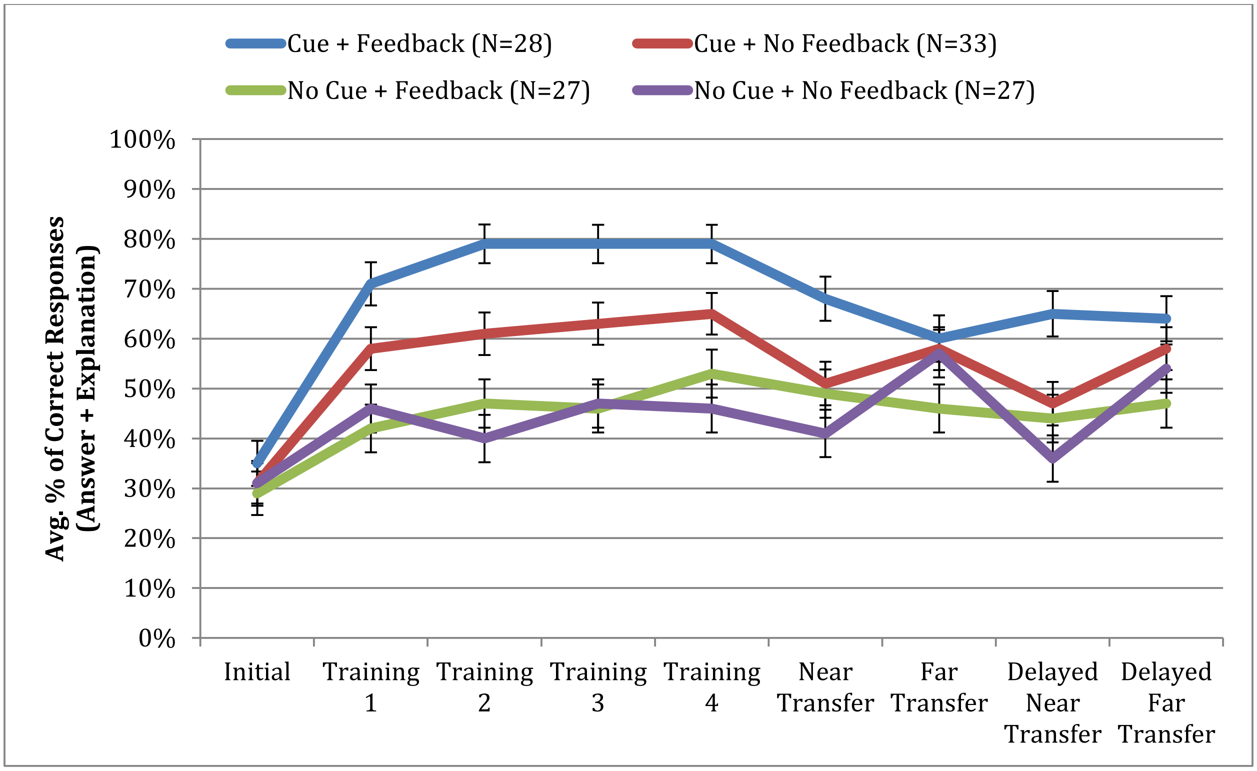
Correctness Results

Overall Problem Solving Performance

We investigated the overall problem solving performance of participants as they solved the initial, training, and transfer problems in the main experiment, and the delayed transfer problems in the delayed transfer experiment. We did this by averaging the participants' performance for each problem across the four problem sets. The average performance of participants in each condition is shown in Fig. 5.1.

The percentage of problems solved correctly by participants in the Cue + Feedback condition increased from 35% in the initial problem to 71% in the first training problems. The performance further increased to 79% on the second training problem, which remained constant until the last training problem. Participants were able to solve 68% of the near transfer problems and 60% of the far transfer problems in the main experiment. Two weeks later in the delayed transfer experiment, they solved an average of 65% of the near transfer problems and 64% of the far transfer problems.

Figure 5.1 Average overall performance across all problem sets. Error bars represent ±1 std. error of the mean.



Participants in the Cue + No Feedback condition were able to solve 31% of the initial problems on average. After viewing the cues on the first training problem, their performance increased to 58%, and continued to increase as they solved the training problems, having able to solve 65% of the fourth training problem. Performance on the near and far transfer problems were at 51% and 58%, respectively, and participants were able to solve 47% and 58% of the delayed near and far transfer problems two weeks later.

In the No Cue + Feedback condition, participants were able to solve, on average, 29% of the initial problems. Performance gradually increased on the training problems, with performance at 42%, 47%, 46%, and 53% for the four training problems. Participants were able to solve 49% of the near transfer problems and 46% of the far transfer problems, and then two weeks later, they were able to solve 44% of the delayed near transfer problems and 47% of the delayed far transfer problems.

For the No Cue + No Feedback condition, participants solved on average 31% of the initial problems, and their performance on the training problems was between 40% and 47% on the four training problems. The average percentage of near and far transfer problems solved correctly were 41% and 57% in the main experiment, and 36% and 54% in the delayed far transfer experiment.

A Chi-square test was used to analyze the differences in the four conditions on each problem. Table 5.1 summarizes the results.

Table 5.1 Summary of the results of a Chi-square test comparing the number of problems solved correctly by participants in the four conditions. The significance level is α = .05. Cells marked with * have adjusted residuals that represent lack of independence.

Problem	Condition	# Solved Correctly	# Solved Incorrectly	Chi-square Result
Initial	Cue + Feedback (*N* = 28)	39	73	$\chi^2(3) = 0.98$, p=.809, V=.046
	Cue + No Feedback (*N* = 33)	41	91	
	No Cue + Feedback (*N* = 27)	31	77	
	No Cue + No Feedback (*N* = 27)	34	74	
Training 1	Cue + Feedback (*N* = 28)*	79	33	$\chi^2(3) = 22.21$ p<.001, V=.220
	Cue + No Feedback (*N* = 33)	76	56	
	No Cue + Feedback (*N* = 27)*	45	63	
	No Cue + No Feedback (*N* = 27)	50	58	
Training 2	Cue + Feedback (*N* = 28)*	88	24	$\chi^2(3) = 39.18$, p<.001, V=.292
	Cue + No Feedback (*N* = 33)	80	52	
	No Cue + Feedback (*N* = 27)*	51	57	
	No Cue + No Feedback (*N* = 27)*	43	65	
Training 3	Cue + Feedback (*N* = 28)*	89	23	$\chi^2(3) = 33.68$, p<.001, V=.271
	Cue + No Feedback (*N* = 33)	83	49	
	No Cue + Feedback (*N* = 27)*	50	58	
	No Cue + No Feedback (*N* = 27)*	51	57	
Training 4	Cue + Feedback (*N* = 28)*	89	23	$\chi^2(3) = 29.96$, p<.001, V=.255
	Cue + No Feedback (*N* = 33)	86	46	
	No Cue + Feedback (*N* = 27)*	57	51	
	No Cue + No Feedback (*N* = 27)*	50	58	
Near Transfer	Cue + Feedback (*N* = 28)*	76	36	$\chi^2(3) = 17.22$, p=.001, V=.193
	Cue + No Feedback (*N* = 33)	67	65	
	No Cue + Feedback (*N* = 27)	53	55	
	No Cue + No Feedback (*N* = 27)*	44	64	
Far Transfer	Cue + Feedback (*N* = 28)	67	45	$\chi^2(3) = 5.14$, p=.161, V=.106
	Cue + No Feedback (*N* = 33)	77	55	
	No Cue + Feedback (*N* = 27)*	50	58	
	No Cue + No Feedback (*N* = 27)	62	46	

Delayed Near Transfer	Cue + Feedback (*N* = 28)*	73	39	$\chi^2(3) = 20.28$, $p<.001$, $V=.210$
	Cue + No Feedback (*N* = 33)	62	79	
	No Cue + Feedback (*N* = 27)	47	61	
	No Cue + No Feedback (*N* = 27)*	39	69	
Delayed Far Transfer	Cue + Feedback (*N* = 28)*	72	40	$\chi^2(3) = 6.85$, $p=.077$, $V=.122$
	Cue + No Feedback (*N* = 33)	76	56	
	No Cue + Feedback (*N* = 27)*	51	57	
	No Cue + No Feedback (*N* = 27)	58	50	

We found no significant differences in the four conditions with respect to the initial problem performance. Thus, we may consider the participants assigned to the four conditions as equivalent for further analyses. For the performance on the first training problem, the Chi-square result showed that there were significant differences in the four conditions. Looking at the adjusted residuals, we found that the Cue + Feedback and No Cue + Feedback conditions contributed to the significant differences. We also found significant differences in the four conditions on the other training problems, with the Cue + Feedback, No Cue + Feedback, and No Cue + Feedback conditions contributing to the significant differences. There was also significant differences on the near transfer and delayed near transfer problems, with Cue + Feedback and No Cue + No Feedback contributing to the significant differences. We found no significant differences in the four conditions on the far transfer and delayed far transfer problems. Thus, the effects of cueing and feedback on the near transfer problem wash out on the far transfer problem, and that the results of the near and far transfer problems are retained on the delayed transfer problems.

One possible reason of the non-significant differences in the four conditions is that by considerably changing the surface features of these problems, we inadvertently made the far transfer problem easier than the near transfer problem, such that the participants were able to solve the problem correctly regardless of whether they saw cues or not, or whether they received outcome feedback or not. This can be observed by comparing the percentage of participants who solved the far transfer problem correctly to the percentage of participants who solved the near transfer problem correctly in Table 5.1. We found that 56% of responses on the far transfer problem were correct, while only 52% of responses on the near transfer problem were correct.

To compare the performance on each group, we also performed a 2×2×9 mixed factorial ANOVA with performance as the dependent variable, Cue and Feedback as the between-subjects factors, and problem as the within-subjects factor. Table 5.2 shows the results. The Greenhouse-Geisser correction was used as a result of Mauchly's test of sphericity being violated.

Table 5.2 Summary of the results of a mixed factorial ANOVA comparing the effects of visual cueing and outcome feedback on participants' performance from the initial problem to the far transfer problem in the main experiment, then the delayed near and far transfer problems in the delayed transfer experiment. The Greenhouse-Geisser correction was applied to the degrees of freedom because Mauchly's assumption of sphericity was violated. The significance level is α = .05.

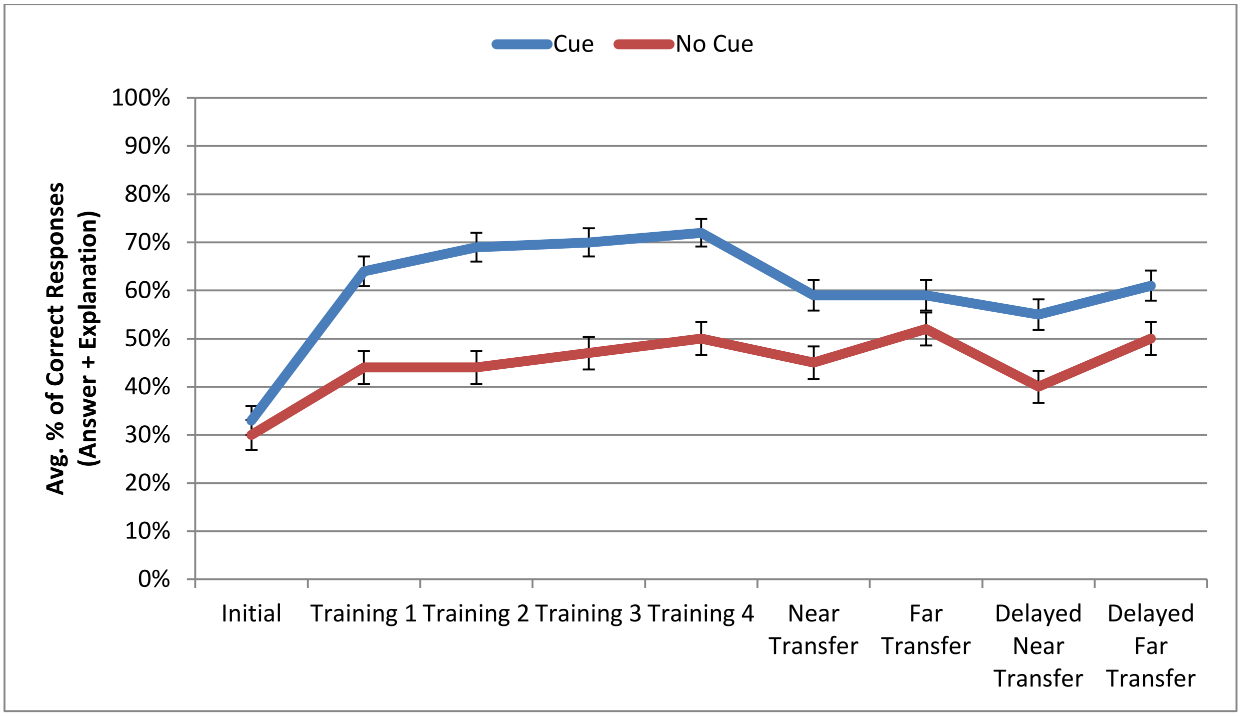
Effect	ANOVA Result	p	η_p^2
Cue	$F(1, 456) = 21.91$	<.001	.046
Feedback	$F(1, 456) = 3.34$	.068	.007
Problem	$F(6.1, 2782.3) = 31.20$	<.001	.064
Cue*Feedback	$F(1, 456) = 2.91$	.089	.006
Cue*Problem	$F(6.1, 2782.3) = 6.61$	<.001	.014
Feedback*Problem	$F(6.1, 2782.3) = 4.38$	<.001	.010
Cue*Feedback*Problem	$F(18.3, 2782.3) = 0.40$	.885	.001

We found a significant main effect of Cue, such that participants who saw visual cues performed better. There was no significant main effect of Feedback, suggesting that the average performance of participants who received feedback does not differ from the overall performance of participants who did not receive feedback regardless of the cue condition, and the problem. We also found a significant main effect of Problem, such that participants did better on the later problems than the initial problem regardless of condition. These significant main effects are qualified by a significant interaction between Cue and Problem, and between Feedback and Problem, which suggests that the participants' performance as they progressed from the initial problem to the delayed far transfer problem differed depending on the whether they saw visual cues on the training problems, or whether they received outcome feedback before each training problem.

To probe the Cue*Problem interaction, and to investigate the differences in the participants' performance as they progressed through the nine problems, we conducted a Mixed factorial ANOVA for the Cue and No Cue conditions with problem as the within-subjects factor. Figure 5.2 shows the average percentage of correct responses in each problem for the Cue and No Cue conditions.

In each condition, we found a significant main effect of Problem, suggesting that learning occurred regardless of participants saw cues on the training problems or not. In order to investigate the learning trajectories further, we looked at the simple and repeated contrasts for each condition. Simple contrast analysis compares the performance on the initial problem to the performance on each of the other problems (e.g., the initial problem vs. the third training problem). This was done in order to determine how much participants' performance improved with respect to the first problem they solved. On the other hand, repeated contrast analysis compares the performance on a problem to the performance of the problem following it (e.g., the second training problem vs. the third training problem). This analysis was performed to determine how much the participants' performance improved after each problem.

Figure 5.2 Average overall performance across all problem sets for the Cue and No Cue conditions. Error bars represent ±1 std. error of the mean.



The simple contrasts show that participants in both the Cue and the No Cue conditions performed significantly better on the training, transfer and delayed transfer problems compared to the initial problem. Looking at the effect sizes, however, we find that the effect sizes in the Cue condition are much higher then the effect sizes in the No Cue condition. For example, comparing the gains from the initial problem to the first training problem, the effect size for the Cue condition is three times larger than the effect size for the No Cue condition. Comparing the gains from the initial problem to the near transfer, far transfer, delayed near transfer, and delayed far transfer problems, we find that the effect size for the Cue condition is 2.1, 1.3, 3.6, and 1.6 times larger than the effect size for the No Cue condition, respectively. These results suggest that although performance significantly improved for both conditions, participants in the Cue condition showed a stronger improvement over the initial problem.

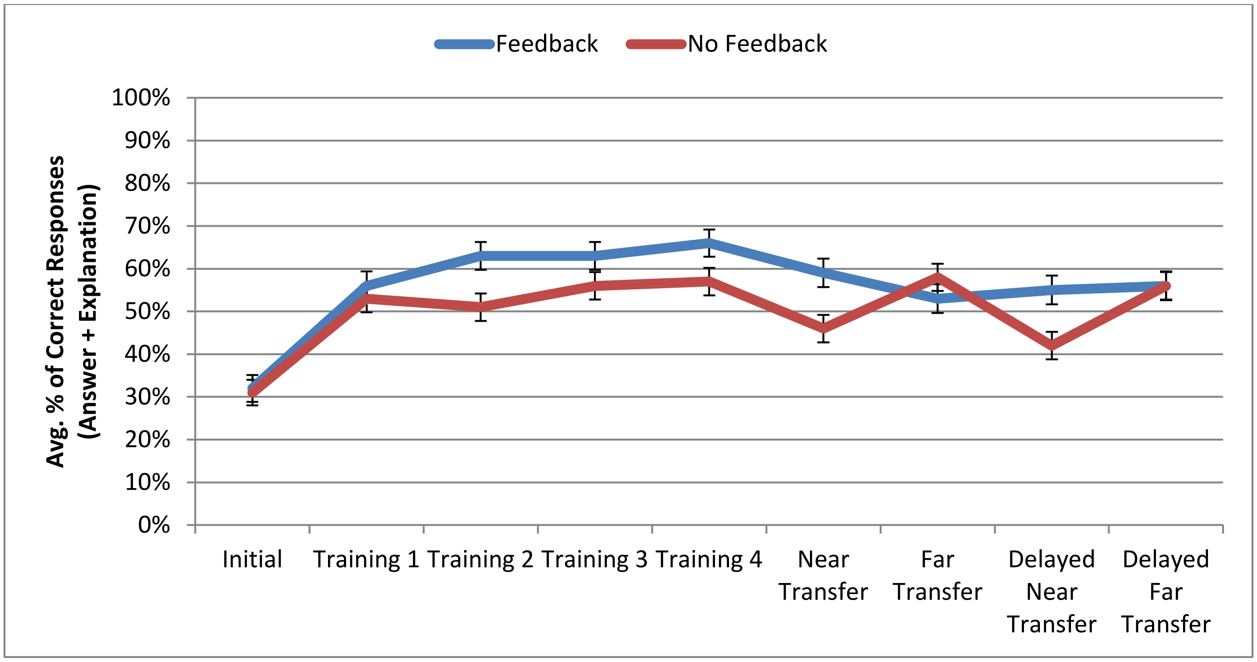
In examining the repeated contrasts, we found no significant differences in the performance from one training problem to the next for both the Cue and No Cue conditions. For participants in the Cue condition, performance significantly decreased from the fourth training problem to the near training problem, and then there was no significant differences between the near and far transfer problems, the far transfer and the delayed near transfer problems, and the delayed near and far transfer problems. On the other hand, for participants in the No Cue condition, we found a significant decrease in performance from the far transfer problem to the delayed near transfer problem, and a significant increase in performance from the delayed near transfer problem to the delayed far transfer problem. The results of the simple and repeated contrasts are reported in Table 5.3.

Table 5.3 Summary of the results of a mixed factorial ANOVA probing the Cue*Problem Interaction. The significance level is α = .003 after applying a Bonferroni correction for the 15 comparisons made below. Cells marked with * are statistically significant using the Bonferroni correction. Mauchly's assumption of sphericity was violated, so a Greenhouse-Geisser correction has been applied to the degrees of freedom for the simple main effects.

Effect	Cue			No Cue		
	Main: $F(6.1, 2782.3) = 30.59$, $p<.001$			Main: $F(5.8, 2782.3) = 8.96$, $p<.001$		
	$F(1, 242)$	p	η_p^2	$F(1, 214)$	p	η_p^2
Initial vs. Training 1	102.43	<.001*	.297	23.58	<.001*	.099
Initial vs. Training 2	124.96	<.001*	.341	21.62	<.001*	.092
Initial vs. Training 3	125.48	<.001*	.341	33.81	<.001*	.136
Initial vs. Training 4	139.12	<.001*	.365	40.30	<.001*	.158
Initial vs. Near Transfer	62.10	<.001*	.204	22.75	<.001*	.096
Initial vs. Far Transfer	57.91	<.001*	.193	32.81	<.001*	.153
Initial vs. Delayed Near Transfer	51.17	<.001*	.175	10.82	.001*	.048
Initial vs. Delayed Far Transfer	64.72	<.001*	.211	32.53	<.001*	.132
Training 1 vs. Training 2	4.07	.045	.017	0.03	.856	.000
Training 2 vs. Training 3	0.53	.469	.002	1.99	.160	.009
Training 3 vs. Training 4	0.40	.528	.002	1.66	.200	.008
Training 4 vs. Near Transfer	22.66	.001*	.086	2.64	.106	.012
Near Transfer vs. Far Transfer	0.01	.937	.000	3.99	.047	.018
Far Transfer vs. Delayed Near Transfer	0.87	.353	.004	11.75	.001*	.052
Delayed Near Transfer vs. Delayed Far Transfer	2.18	.141	.009	9.44	.002*	.042

To probe the Feedback*Problem interaction, and to investigate the differences in the participants' performance as they progressed through the nine problems, we conducted a mixed factorial ANOVA for the Feedback and No Feedback conditions with problem as the within-subjects factor. Figure 5.3 shows the average percentage of correct responses in each problem for the Feedback and No Feedback conditions.

Figure 5.3 Average overall performance across all problem sets for the Feedback and No Feedback conditions. Error bars represent ±1 std. error of the mean.



In each condition, we found a significant main effect of problem, suggesting that learning occurred regardless of participants received outcome feedback or not. In order to investigate the learning trajectories further, we again looked at the simple and repeated contrasts for each condition.

The simple contrasts show that participants in both the Feedback and the No Feedback conditions performed significantly better on the training, transfer and delayed transfer problems compared to the initial problem. Looking at the effect sizes, we find that in general, the effect sizes in the Feedback condition are much higher then the effect sizes in the No Feedback condition. For example, comparing the gains from the initial problem to the first training problem, the effect size for the Feedback condition is a factor of 1.3 times larger than the effect size for the No Feedback condition. Comparing the gains from the initial problem to the near transfer and delayed near transfer problems, we find that the effect size for the Feedback condition is 2.9 and 4.0 times larger than the effect size for the No Feedback condition, respectively. These results suggest that although performance significantly improved for both conditions, participants in the Feedback condition showed a stronger improvement over the initial problem.

In examining the repeated contrasts, we found no significant differences in the performance from one training problem to the next for both the Feedback and No Feedback conditions. We also found that participants in the Feedback condition showed no significant differences in performances between the fourth training problem and the near transfer problem, as well as between one transfer problem and the next. On the other hand, for participants in the No Feedback condition, we found a significant increase in performance from the near transfer problem to the far transfer problem, followed by a significant decrease in performance from the far transfer problem to the delayed near transfer problem, and then a significant increase in performance from the delayed near transfer problem to the delayed far transfer problem. The results of the simple and repeated contrasts are reported in Table 5.4.

Table 5.4 Summary of the results of a mixed factorial ANOVA probing the Feedback*Problem Interaction. The significance level is α = .003 after applying a Bonferroni correction for the 15 comparisons made below. Cells marked with * are statistically significant using the Bonferroni correction. Mauchly's assumption of sphericity was violated, so a Greenhouse-Geisser correction has been applied to the degrees of freedom for the simple main effects.

Effect	Feedback			No Feedback		
	Main: $F(6.2, 2782.3) = 19.35$, p<.001			Main: $F(5.8, 2782.3) = 16.46$, p<.001		
	$F(1, 218)$	p	η_p^2	$F(1, 238)$	p	η_p^2
Initial vs. Training 1	64.70	<.001*	.229	48.93	<.001*	.171
Initial vs. Training 2	89.62	<.001*	.291	40.79	<.001*	.146
Initial vs. Training 3	90.43	<.001*	.293	58.18	<.001*	.196
Initial vs. Training 4	110.07	<.001*	.336	59.02	<.001*	.199
Initial vs. Near Transfer	65.37	<.001*	.231	20.45	<.001*	.079
Initial vs. Far Transfer	37.07	<.001*	.145	59.79	<.001*	.201
Initial vs. Delayed Near Transfer	49.60	<.001*	.185	11.38	.001*	.046
Initial vs. Delayed Far Transfer	47.93	<.001*	.180	46.39	<.001*	.163
Training 1 vs. Training 2	7.92	.005	.035	0.36	.548	.002
Training 2 vs. Training 3	0.00	.994	.000	5.03	.026	.021
Training 3 vs. Training 4	2.72	.101	.012	0.12	.733	.000
Training 4 vs. Near Transfer	8.43	.004	.037	11.74	.001	.047
Near Transfer vs. Far Transfer	2.74	.099	.012	15.32	<.001*	.060
Far Transfer vs. Delayed Near Transfer	0.14	.713	.001	25.39	<.001*	.096
Delayed Near Transfer vs. Delayed Far Transfer	0.19	.666	.001	16.49	<.001*	.065

Performance on Training Problems

We investigated how visual cues and outcome feedback, as well as performance on the initial problem influenced student performance on the training problems. A three-way ANOVA was conducted with the percentage of training problems across all problem sets as the dependent variable, and cue, feedback, and initial problem correctness as the between-subjects factors. The results are reported in Table 5.5.

Table 5.5 Summary of the results of a two-way ANOVA comparing the effects of cue, feedback, and initial problem correctness on the average training problem performance. The significance level is α = .05.

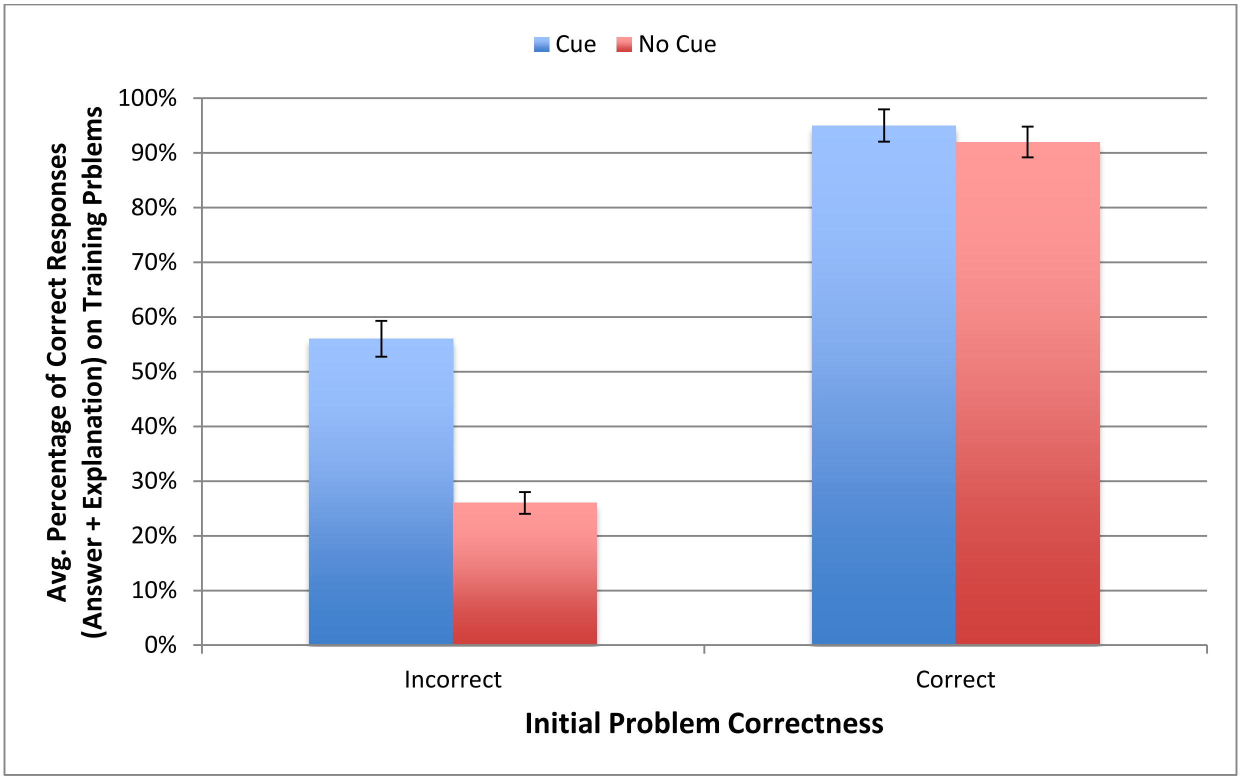
Effect	ANOVA Result $F(1, 452)$	p	η_p^2
Cue	24.39	<.001	.051
Feedback	4.81	.029	.011
Initial Problem Correctness, IPC	226.30	<.001	.334
Cue*Feedback	1.43	.233	.003
Cue*IPC	15.46	<.001	.033
Feedback*IPC	1.37	.243	.003
Cue*Feedback*IPC	0.70	.403	.002

We found that there was a significant main effect of cue, such that participants in the cued conditions significantly outperformed participants in the non-cued conditions in terms of the average percentage of training problems solved correctly. There was also a significant main effect of feedback, such that participants who were told if their response was correct or incorrect had a higher percentage of training problems solved correctly than participants who did not receive any feedback. We also found a significant main effect of initial problem correctness, such that participants who correctly solved the initial problem solved a higher percentage of training problems correctly.

There was no significant interaction between cue and feedback, indicating that each factor had an independent additive effect on the average percentage of training problems solved correctly. There was also no significant interaction between feedback and initial problem correctness, which suggests that the effect of feedback on the training problem performance does not depend on the performance on the initial problem. The three-way interaction of cue, feedback, and initial problem correctness was not significant.

We found a significant interaction between cue and initial problem correctness, indicating that the influence of visual cueing on the average training problem performance depends on whether participants were correct or incorrect on the initial problem. Probing the interaction, we found that for participants who incorrectly solved the initial problem, those who were provided with visual cues on the training problems correctly solved a higher percentage of training problems, on average, then those who did not see cues, $F(1, 452) = 62.80$, $p<.001$, $\eta_p^2=.122$. We found no significant difference between participants in the Cue and No Cue conditions if the initial problem was solved correctly, $F(1, 452) <1$. Figure 5.4 shows the average performance of participants in the Cue and No Cue conditions on the training problems, depending on their performance on the initial problem.

Figure 5.4 Average performance on the training problems of cued and non-cued students moderated by their correctness on the initial problem. Error bars represent ±1 std. error of the mean.



Performance on Transfer and Delayed Transfer Problems

We have shown that visual cueing and outcome feedback can improve performance on problems that students were previously unable to solve. However, after going through the training problems wherein cues or feedback were presented, the influence of cueing and feedback could be better gauged by investigating how students solve a conceptually similar problem but with different surface features without cues or feedback.

Performance on Near and Far Transfer Problems

First, we analyzed the students' near transfer problem performance across all problem sets by performing a Chi-Square test. The results on Table 5.1 show that there is a significant difference on the performance of the students on the near transfer problem in the four conditions when all problem sets are collapsed, $\chi^2(3, N=460) = 17.22$, $p=.001$, $V=.193$. We found that participants in the Cue + Feedback condition were the highest performing, and participants in the No Cue + No Feedback were the lowest performing.

Looking at the performance on each problem set, we found that there was a significant difference in the four conditions for the Ball and Graph problem sets. The Cue + Feedback and No Cue + No Feedback conditions contributing to the significant difference in the both problem sets while the No Cue + Feedback condition also contributed to the significant difference in the Graph problem set. In the Ball problem set in particular, 100% of the participants in the Cue + Feedback condition were able to provide a correct answer and explanation on the Near Transfer Problem. No significant differences in the four conditions were found for the Skier and Roller Coaster problem sets. Table 5.6 summarizes the problem-by-problem results.

Next, we compared the performance of participants in each condition on the far transfer problem. We found that on the far transfer problem, there was no significant difference in the four conditions, $\chi^2(3, N=460) = 5.14$, $p = .161$, $V = .106$. Thus, participants in the four conditions are considered equivalent. This suggests that the differences in the four conditions found on the near transfer problem are washed out on the far transfer problem.

Table 5.6 Summary of the results of a Chi-square test comparing the numbers of students who did and did not correctly solve each near transfer problem set in the four conditions. The significance level is α = .05. Cells contributing to the significant difference, as determined by the adjusted residuals, are marked with *.

Problem Set	Condition	Correctly Solved Near Transfer Problem	Incorrectly Solved Near Transfer Problem	Chi-Square Result
Ball	Cue + Feedback*	28	0	$\chi^2(3) = 17.46$, $p<.001$, $V=.390$
	Cue + No Feedback	29	4	
	No Cue + Feedback*	17	10	
	No Cue + No Feedback*	17	10	
Graph	Cue + Feedback*	19	9	$\chi^2(3) = 10.19$, $p=.017$, $V=.298$
	Cue + No Feedback	16	17	
	No Cue + Feedback	15	12	
	No Cue + No Feedback*	7	20	
Roller Coaster	Cue + Feedback	11	17	$\chi^2(3) = 0.75$, $p=.896$, $V=.081$
	Cue + No Feedback	10	23	
	No Cue + Feedback	9	18	
	No Cue + No Feedback	8	19	
Skier	Cue + Feedback	18	10	$\chi^2(3) = 5.00$, $p=.179$, $V=.209$
	Cue + No Feedback	12	21	
	No Cue + Feedback	12	15	
	No Cue + No Feedback	12	15	

Performance on the Delayed Near and Far Transfer Problems

To investigate whether the effects of visual cues and outcome feedback persist after training, we conducted the delayed transfer experiment two to three weeks later with the same participants. The near and far transfer problems of each set were presented without cues or feedback.

We found that the participants' performance on the delayed near transfer problem has a significant dependence on the four conditions, $\chi^2(3, N=460) = 20.28$, $p<.001$, $V=.210$ such that participants who were provided with visual cues and outcome feedback had the highest percentage of delayed near transfer problems solved correctly, while participants who received neither cues nor feedback were the lowest performing.

Looking at the performance in each condition by problem set, we find that overall the results follow the trend in the near transfer problem results. The results are shown in Table 5.7. In both the Ball and the Graph problem sets, we found significant dependence of the delayed near transfer problem performance on condition, such that participants in the Cue + Feedback condition were the highest performing and participants in the No Cue + No Feedback condition were the lowest performing. There was no significant dependence of the delayed near transfer problem performance on condition for the Roller Coaster and Skier problem sets.

For the delayed far transfer problem, we found from Table 5.1 that performance does not significantly depend on the condition, $\chi^2(3, N=460) = 6.85$ $p=.077$, $V=.122$. This result is again similar to the results of the far transfer problem.

Table 5.7 Summary of the results of a Chi-square test comparing the numbers of students who did and did not correctly solve each delayed near transfer problem set in the four conditions. The significance level is α = .05. Cells contributing to the significant difference, as determined by the adjusted residuals, are marked with *.

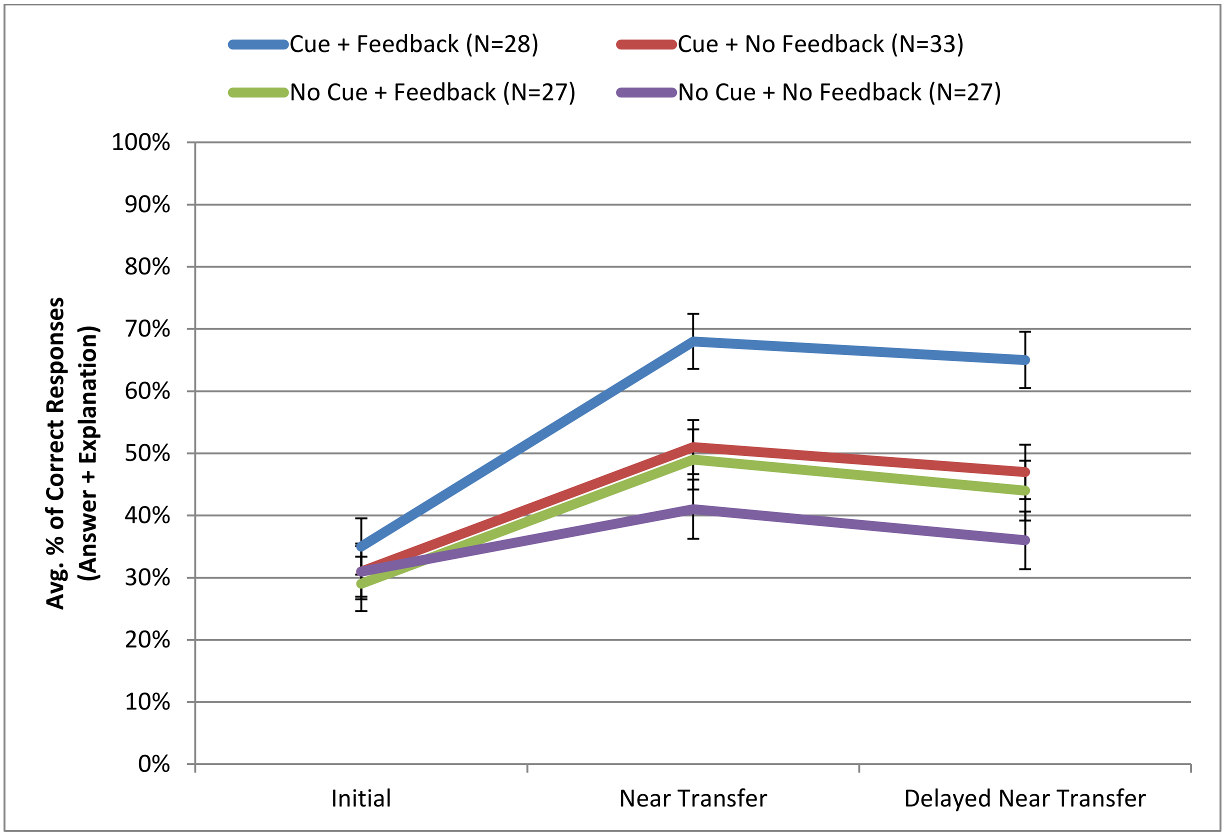
Problem Set	Condition	Correctly Solved Near Transfer Problem	Incorrectly Solved Near Transfer Problem	Chi-Square Result
Ball	Cue + Feedback*	24	4	$\chi^2(3) = 8.25$, p=.042, V=.268
	Cue + No Feedback	25	8	
	No Cue + Feedback	18	9	
	No Cue + No Feedback*	14	13	
Graph	Cue + Feedback*	18	10	$\chi^2(3) = 11.17$, p=.011, V=.312
	Cue + No Feedback	12	21	
	No Cue + Feedback	9	18	
	No Cue + No Feedback*	6	21	
Roller Coaster	Cue + Feedback	14	14	$\chi^2(3) = 4.14$, p=.252, V=.190
	Cue + No Feedback	11	22	
	No Cue + Feedback	8	19	
	No Cue + No Feedback	7	20	
Skier	Cue + Feedback	17	11	$\chi^2(3) = 2.50$, p=.478, V=.147
	Cue + No Feedback	14	19	
	No Cue + Feedback	12	15	
	No Cue + No Feedback	12	15	

To investigate whether the improvement in near and far transfer problem performance persisted after two weeks, we need to compare the average performances on transfer problems to the average performances on the delayed transfer problem.

Performance on the Near and Delayed Near Transfer Problems

Figure 5.5 shows the performance on the initial, near transfer, and delayed near transfer problems in the four conditions. We conducted a 2×2×3 mixed factorial ANOVA with performance as the dependent variable, Cue (Cue vs. No Cue) and Feedback (Feedback vs. No Feedback) as the between-subjects factors, and the initial, near transfer, and delayed near transfer problems as the within-subjects factor.

Figure 5.5 Average performance on the initial, near transfer, and delayed near transfer problems in the four conditions. Error bars represent ±1 std. error of the mean.



We found significant main effects of Cue and Feedback such that participants did better when they were provided with visual cues and they did better when they received correctness feedback. We also found a significant main effect of Problem such that participants performed differently on all three problems. The significant main effects of Cue and Feedback are qualified by their interaction with Problem. No other interactions are significant. The results are shown in Table 5.8.

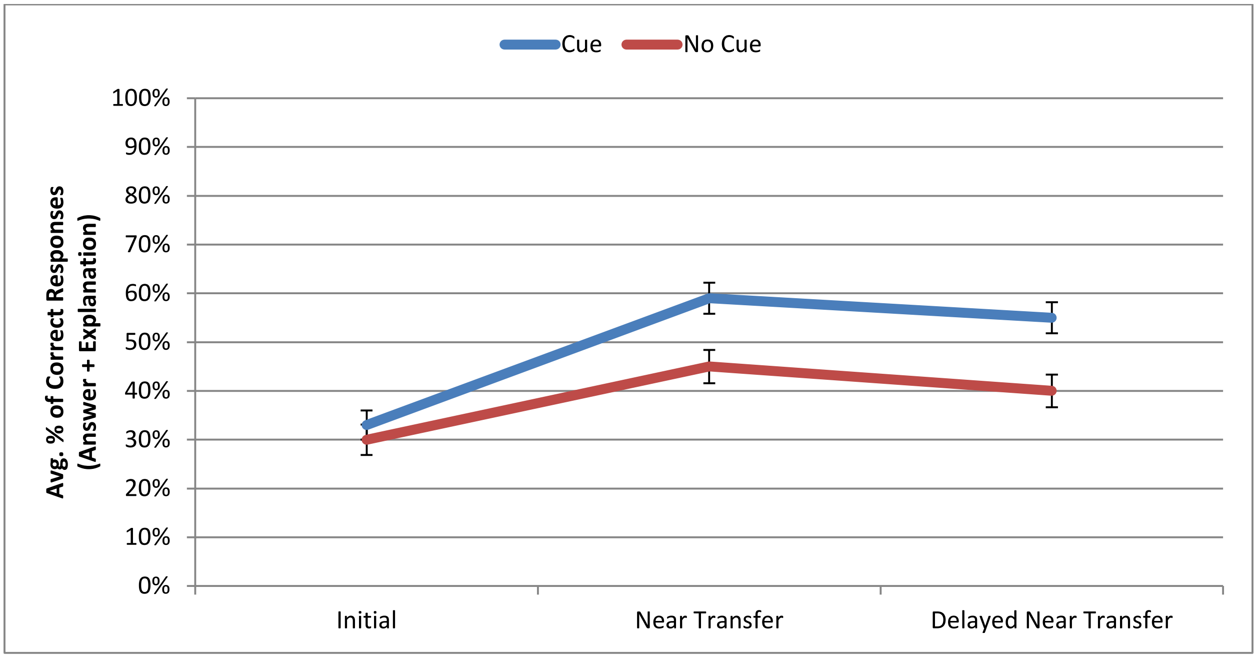
Table 5.8 Summary of the results of a mixed factorial ANOVA comparing the effects of cue and feedback on participants' performance on the initial, near transfer, and delayed near transfer problems. The Greenhouse-Geisser correction was applied to the degrees of freedom because Mauchly's assumption of sphericity was violated. The significance level is α = .05.

Effect	ANOVA Result	p	η_p^2
Cue	$F(1, 456)=8.76$	.003	.019
Feedback	$F(1, 456)=5.28$	.022	.011
Problem	$F(1.9, 877.5)=51.06$	<.001	.101
Cue*Feedback	$F(1, 456)=1.33$	.250	.003
Cue*Problem	$F(1.9, 877.5)=5.69$	.004	.012
Feedback*Problem	$F(1.9, 877.5)=5.41$	.005	.012
Cue*Feedback*Problem	$F(1.9, 877.5)=0.12$	.878	.000

To probe the Cue*Problem interaction, we conducted a 2×3 mixed factorial ANOVA comparing the performance of participants in the Cue and No Cue conditions on the initial, near transfer, and delayed near transfer problems.

We found a significant main effect of Problem for both conditions, suggesting that participants showed learning on the near transfer and delayed near transfer problems regardless of whether they saw visual cues on the training problems or not. Figure 5.6 shows the average percentage of initial, near transfer, and delayed near transfer problems solved correctly by participants in the Cue and No Cue conditions.

Figure 5.6 Average performance on the initial, near transfer, and delayed near transfer problems in the Cue and No Cue conditions. Error bars represent ±1 std. error of the mean.



To further probe the interaction, we conducted simple and repeated contrasts. Analysis of the simple contrasts showed that for both conditions, performance on the near transfer problem and the delayed near transfer problems significantly improved over the initial problem. However, participants in the Cue condition showed a stronger improvement, as shown by the effect sizes from the initial to the near transfer and delayed near transfer problems being 2.1 and 3.5 times larger on the Cue condition than the No Cue Condition. In examining the repeated contrasts, we found no significant difference on the performances between the near transfer and delayed near transfer problems for both conditions.

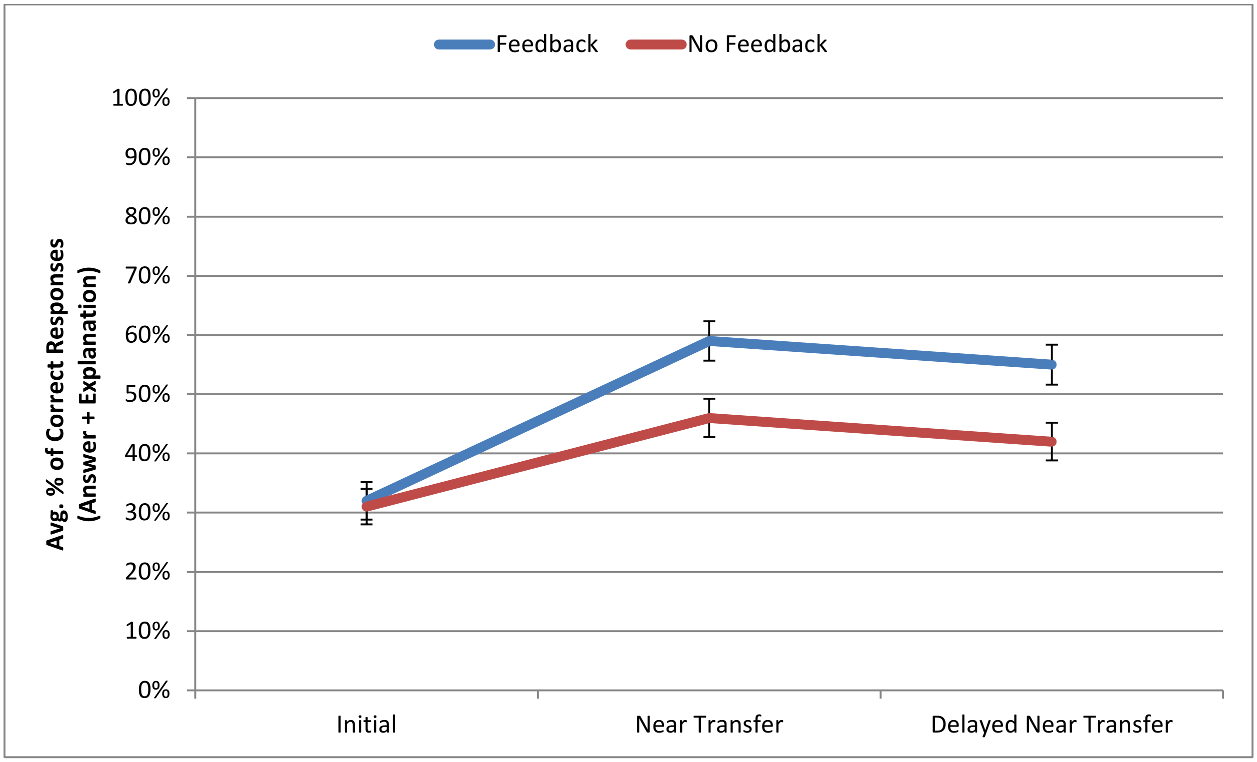
Table 5.9 Summary of the results of a mixed factorial ANOVA probing the Cue*Problem Interaction. The significance level is $\alpha = .017$ after applying a Bonferroni correction for the 3 comparisons made below. Cells marked with * are statistically significant using the Bonferroni correction. Mauchly's assumption of sphericity was violated for the cells marked with †, so a Greenhouse-Geisser correction has been applied to the degrees of freedom for the simple main effects.

Effect	Cue† Main: $F(1.9, 887.5) = 47.05$, $p<.001$			No Cue Main: $F(2, 887.5) = 11.13$, $p<.001$		
	$F(1, 243)$	p	η_p^2	$F(1, 215)$	p	η_p^2
Initial vs. Near Transfer	59.23	<.001*	.196	22.52	<.001*	.095
Initial vs. Delayed Near Transfer	48.12	<.001*	.165	10.72	.001*	.047
Near Transfer vs. Delayed Near Transfer	1.53	.218	.006	3.31	.070	.015

In order to probe the Feedback*Problem interaction, we conducted a second 2×3 mixed factorial ANOVA comparing the performance of participants in the Feedback and No Feedback conditions on the initial, near transfer, and delayed near transfer problems.

We found a significant main effect of Problem for both conditions, which suggests that participants showed learning on the near transfer and delayed near transfer problems regardless of whether they outcome feedback or not or not. Figure 5.7 compares the average percentage of initial, near transfer, and delayed near transfer problems solved correctly by participants in the Feedback and No Feedback conditions.

Figure 5.7 Average performance on the initial, near transfer, and delayed near transfer problems in the Feedback and No Feedback conditions. Error bars represent ±1 std. error of the mean.



To further probe the interaction, we conducted simple and repeated contrasts. Analysis of the simple contrasts showed that for both conditions, performance on the near transfer problem and the delayed near transfer problems significantly improved over the initial problem. However, the effect sizes from the initial to the near transfer and delayed near transfer problems on the Feedback condition are 2.9 and 4.0 times larger than the No Feedback Condition. This suggests that although participants in both conditions showed significant gains on the near transfer and delayed near transfer problems over the initial problem, participants in the Feedback condition exhibited a stronger improvement. In examining the repeated contrasts, we found no significant difference on the performances between the near transfer and delayed near transfer problems for both conditions.

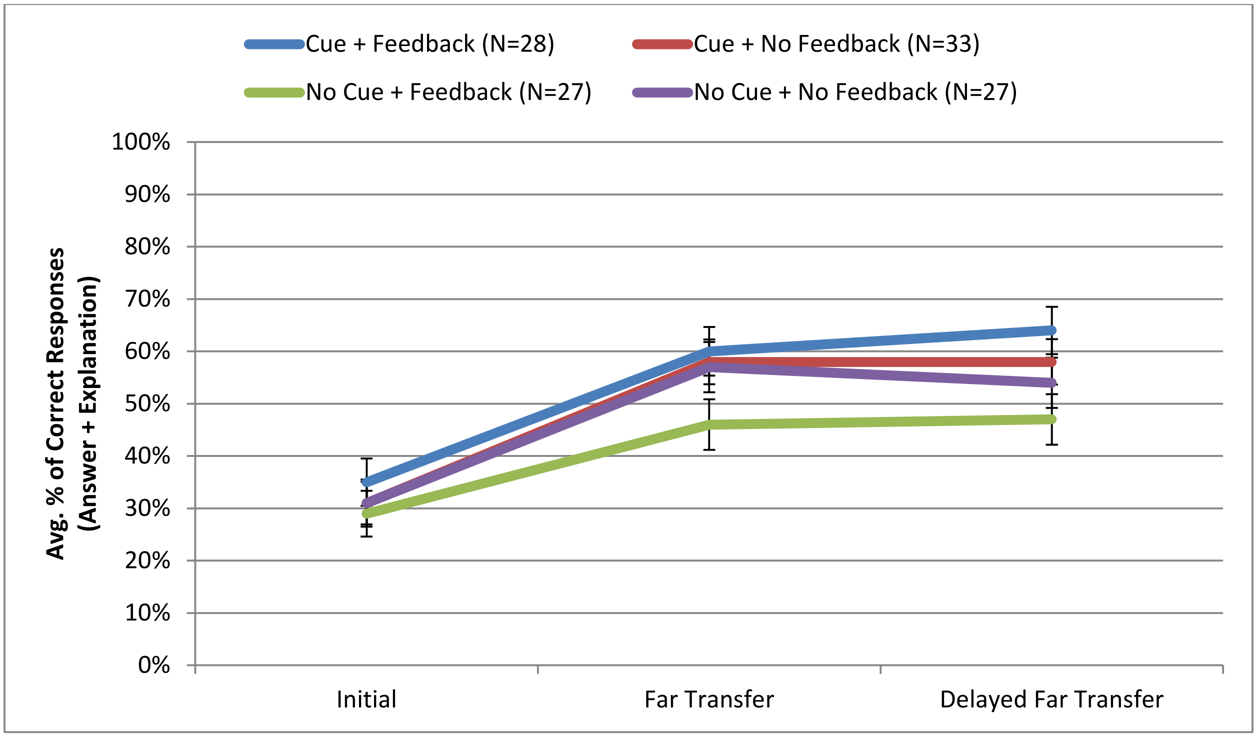
Table 5.10 Summary of the results of a mixed factorial ANOVA probing the Cue*Problem Interaction. The significance level is α = .017 after applying a Bonferroni correction for the 3 comparisons made below. Cells marked with * are statistically significant using the Bonferroni correction. Mauchly's assumption of sphericity was violated, so a Greenhouse-Geisser correction has been applied to the degrees of freedom for the simple main effects.

Effect	Feedback			No Feedback		
	Main: $F(1.9, 887.5) = 43.13$, $p<.001$			Main: $F(1.9, 887.5) = 12.41$, $p<.001$		
	$F(1, 218)$	p	η_p^2	$F(1, 238)$	p	η_p^2
Initial vs. Near Transfer	65.37	<.001*	.231	20.45	<.001*	.079
Initial vs. Delayed Near Transfer	49.60	<.001*	.185	11.38	.001*	.046
Near Transfer vs. Delayed Near Transfer	1.53	.218	.006	3.31	.070	.015

Performance on the Far and Delayed Far Transfer Problems

In order to compare the performance on the initial, far transfer, and delayed far transfer problems, we conducted a 2×2×3 mixed factorial ANOVA with the average percentage of correct responses as the dependent variable, Cue (Cue vs. No Cue) and Feedback (Feedback vs. No Feedback) as the between-subjects factors, and the initial, far transfer, and delayed far transfer problems as the within-subjects factor. Figure 5.8 compares the four conditions with respect to the performances on the initial, far transfer, and delayed far transfer problems.

Figure 5.8 Average performance on the initial, far transfer, and delayed far transfer problems in all four conditions. Error bars represent ±1 std. error of the mean.



We found no significant main effect of Cue, which suggests that average performance overall did not depend on whether participants saw cues on the training problems regardless of the Feedback condition and the problem solved. There was also no significant main effect of Feedback, suggesting that regardless of whether participants in received visual cues or not, average performance on all three problems did not depend on whether or not participants received outcome feedback. However, we found a significant main effect of Problem, which suggests that participants demonstrated learning on the later problems regardless of whether they saw visual cues or received outcome feedback. All interactions were found to be not significant.

Table 5.11 Summary of the results of a mixed factorial ANOVA comparing the effects of cue and feedback on participants' performance on the initial, far transfer, and delayed far transfer problems. The Greenhouse-Geisser correction was applied to the degrees of freedom because Mauchly's assumption of sphericity was violated. The significance level is α = .05.

Effect	ANOVA Result	p	η_p^2
Cue	$F(1, 456)=3.46$	.063	.008
Feedback	$F(1, 456)=0.15$	.703	.000
Problem	$F(1.8, 838.9)=72.21$	<.001	.137
Cue*Feedback	$F(1, 456)=2.14$	.144	.005
Cue*Problem	$F(1.8, 838.9)=1.37$	.255	.003
Feedback*Problem	$F(1.8, 838.9)=0.82$	.433	.002
Cue*Feedback*Problem	$F(1.8, 838.9)=0.32$	.710	.001

Looking at the simple contrasts for Problem, we found that participants overall had a significantly higher percentage of far transfer and delayed far transfer problems solved correctly than initial problem, $F(1, 456) = 95.14$, $p < .001$, $\eta_p^2 = .173$ for the comparison between the initial and far transfer problems, and $F(1, 456) = 93.72$, $p < .001$, $\eta_p^2 = .170$ for the comparison between the initial and delayed far transfer problems. We found no significant difference when comparing the performance between the far transfer and delayed far transfer problems, $F(1, 456) < 1$.

Confidence Results

In this section, we investigate how visual cueing and outcome feedback influence confidence on students' answer and explanation when solving a problem. We also examine the relationship between confidence and problem correctness. Based on our conceptual model, feedback changes accuracy in such a way that confidence is being calibrated. If a student is incorrect on the initial problem and receives feedback, then the student encounters impasse on the next problem and the student's confidence decreases. If the student overcomes impasse and answers the next problem correctly, then the student shows learning, along with an increase in confidence. At this point, the learner's confidence should be better calibrated.

To compare the confidence ratings in the four conditions, we calculated the median and Inter-Quartile Range (IQR) for the answer and reasoning confidence in the initial, training, transfer, and delayed transfer problems. The median is a measure of central tendency; it shows what the likeliest response is. On the other hand, the IQR, which is the difference between the first and the third quartile, is a measure of dispersion; it shows whether the responses are clustered together or scattered. A small IQR is an indication of consensus; while a larger IQR suggests that the ratings are polarized. Since we used a 7-point scale, the possible values of IQR are 1 to 6. In the following analyses, we will consider an IQR of 1-2 to be a small IQR, 3-4 as intermediate IQR, and 5-6 as large IQR.

Table 5.12 shows the median and IQR confidence ratings in the four conditions as they solved the initial, training, transfer, and delayed transfer problems. We found that participants in the No Cue + No Feedback condition had a constant high confidence rating and low IQR. This suggests that participants, who received neither visual cues nor outcome feedback, did not change their confidence substantially across sequence of training problems. We also found that participants in the feedback (Cue + Feedback and No Cue + Feedback) conditions have higher inter-quartile ranges than participants in the no feedback (Cue + No Feedback and No Cue + No Feedback) conditions. This suggests that outcome feedback caused the reported confidence levels to have a wider range of values, indicating that there were larger changes in confidence levels from one problem to the next in the feedback conditions.

Thus, receiving feedback changes the learner's confidence. If a student answered correctly and received feedback, he should have a higher confidence on the next problem.

Conversely, if a student received a negative outcome feedback, it is more likely that the student will have a lower confidence on the next problem. If a student received a positive feedback and was provided with visual cues on the next problem, then the student's confidence is more likely to increase because the student receives reinforcement that what she or he is doing is correct. If the student receives a negative feedback and was provided with visual cues on the next problem, their confidence may increase or decrease depending on the effect of the cue. If the visual cues made the student activate the appropriate resources, the student's confidence level may increase; if the visual cues made the student encounter an impasse, then the student's confidence level may decrease.

Table 5.12 Median and Inter-Quartile Range of answer and reasoning confidence ratings on the initial, training, transfer, and delayed transfer problems in the four conditions.

Confidence	Problem	Cue + Feedback		Cue + No Feedback		No Cue+ Feedback		No Cue + No Feedback	
		Mdn	IQR	Mdn	IQR	Mdn	IQR	Mdn	IQR
Answer	Initial	5	3	5	2	4	3	5	2
	Training 1	5	3	5	2	4	2	5	2
	Training 2	5	3	5	2	4	4	5	2
	Training 3	6	3	5	2	4	4	5	2
	Training 4	6	3	5	2	4	4	5	2
	Near Transfer	5	3	5	2	4	4	5	2
	Far Transfer	5	3	5	2	4	4	5	2
	Delayed Near Transfer	5	2	5	2	4	3	5	2
	Delayed Far Transfer	5	3	5	2	4	3	5	2
Reasoning	Initial	5	3	5	2	4	2	4	2
	Training 1	4	3	5	2	4	3	4	3
	Training 2	5	4	5	2	4	4	4	3
	Training 3	6	4	5	2	4	4	5	3

Training 4	6	3	5	2	4	4	5	2
Near Transfer	5	4	5	2	3	4	4	2
Far Transfer	5	3	5	2	4	4	5	2
Delayed Near Transfer	5	2	5	2	4	3	5	2
Delayed Far Transfer	5	4	5	2	4	3	5	2

To investigate how the answer confidence is related to the correctness on the problem, we conducted chi-square analyses on each problem comparing the number of correctly solved problems to the confidence in the answer. Before doing the analyses, we created four subgroups for the confidence levels: very low (1-2), low (3-4), high (5-6), and very high (7). Table 5.13 summarizes the results.

We found that overall, participants who had high and very high confidence in their answer tended to solve the problems correctly. Participants who had low and very low confidence in their answer, on the other hand, tended to solve the problems incorrectly. Nevertheless, an interesting result is that for participants who had reported high confidence levels on the initial problem, more participants solved the problem incorrectly than correctly. Thus, participants showed overconfidence on the initial problem, consistent with many previous studies (Lichtenstein & Fischhoff, 1977; Fischhoff, Slovic, & Lichtenstein, 1977; Lichtenstein, Fischhoff, & Phillips, 1977; Koriat, Lichtenstein, & Fischhoff, 1980; Arkes, Christensen, Lai, & Blumer, 1987; Gonzalez-Vallejo & Bonham, 2007; Beckmann, Beckmann, & Elliott, 2009). On the first training problem, for learners who received cueing or feedback, the trend reversed, such that there were more participants who solved the problem correctly than incorrectly. For those in the feedback conditions, assumedly their confidence was being calibrated. Analyses of reasoning confidence on each problem show similar trends as the answer confidence.

Table 5.13 Summary of the results of a Chi-square test comparing the number of problems solved correctly by participants with different levels of confidence. The significance level is α = .05.

Problem	Confidence	# Solved Correctly	# Solved Incorrectly	Chi-square Result
Initial	Very High	20	19	$\chi^2(3) = 26.67$, $p<.001$, $V=.274$
	High	55	94	
	Low	28	104	
	Very Low	2	33	
Training 1	Very High	43	4	$\chi^2(3) = 76.19$, $p<.001$, $V=.463$
	High	91	48	
	Low	44	82	
	Very Low	7	36	
Training 2	Very High	50	4	$\chi^2(3) = 107.88$, $p<.001$, $V=.551$
	High	113	41	
	Low	24	81	
	Very Low	12	30	
Training 3	Very High	70	5	$\chi^2(3) = 115.14$, $p<.001$, $V=.570$
	High	98	31	
	Low	28	77	
	Very Low	13	33	
Training 4	Very High	78	2	$\chi^2(3) = 134.36$, $p<.001$, $V=.615$
	High	100	32	
	Low	30	65	
	Very Low	7	41	
Near Transfer	Very High	46	5	$\chi^2(3) = 81.82$, $p<.001$, $V=.480$
	High	95	52	
	Low	28	70	
	Very Low	13	46	
Far Transfer	Very High	52	7	$\chi^2(3) = 86.50$, $p<.001$, $V=.494$
	High	101	50	
	Low	28	68	
	Very Low	9	40	

Delayed Near Transfer	Very High	48	6	$\chi^2(3) = 84.04$, $p<.001$, $V=.487$
	High	93	70	
	Low	20	77	
	Very Low	8	33	
Delayed Far Transfer	Very High	63	6	$\chi^2(3) = 88.53$, $p<.001$, $V=.499$
	High	95	60	
	Low	31	67	
	Very Low	3	30	

To investigate the influence of visual cues, outcome feedback, and correctness on the previous problem on the confidence, we averaged each participant's answer and reasoning confidence in each problem. Because visual cues are presented only on the training problems, and outcome feedback are provided before each training problem, we only considered the initial, and the four training problems in this analysis.

A 2×2×2 between-subjects ANOVA was conducted with the average confidence as the dependent variable and cue, feedback, and previous problem correctness as the categorical independent variables. The results are summarized in Table 5.14.

Table 5.14 Results of the three-way ANOVA comparing the effects of visual cueing, outcome feedback, and previous problem correctness on the average confidence. Significance level is $\alpha = .05$.

Effect	ANOVA Result $F(1, 1832)$	p	η_p^2
Cue	5.62	.018	.003
Feedback	13.11	< .001	.007
Previous Problem Correctness, PPC	701.96	< .001	.277
Cue*Feedback	5.91	.015	.003
Cue*PPC	0.04	.835	.000
Feedback*PPC	80.04	< .001	.042
Cue*Feedback*PPC	0.10	.758	.000

We found a significant main effect of Cue, such that participants who receive visual cues on a training problem have a significantly higher average confidence on that problem. There was also a significant main effect of Feedback, such that participants who are told whether they were correct or incorrect have a significantly lower average confidence than participants who were not told. We also found a significant main effect of Previous Problem Correctness, such that participants who were correct on the previous problem have a significantly higher average confidence than participants who incorrectly solved the previous problem. The main effects of Cue and Previous Problem Correctness are qualified by their interaction with Feedback.

Figure 5.9 depicts the Cue*Feedback interaction. Probing the Cue*Feedback interaction, we found that for participants who received outcome feedback, participants who saw visual cues on the training problems had a significantly higher average confidence than participants who did not see visual cues, $F(1, 1832) = 10.84$, $p = .001$, $\eta_p^2 = .006$. For participants who did not receive outcome feedback, there was no significant difference in the average confidence between participants in the Cue and No Cue conditions, $F(1, 1832) < 1$.

On the other hand, for participants who received visual cues on the training problems, there was no significant difference in the average confidence between participants who did and did not receive outcome feedback, $F(1, 1832) < 1$. For participants who did not receive visual cues, outcome feedback significantly reduced the average confidence, $F(1, 1832) = 17.54$, $p < .001$, $\eta_p^2 = .009$.

Figure 5.9 Graph probing the interaction between Cue and Feedback. Error bars denote ±1 standard error of the mean.

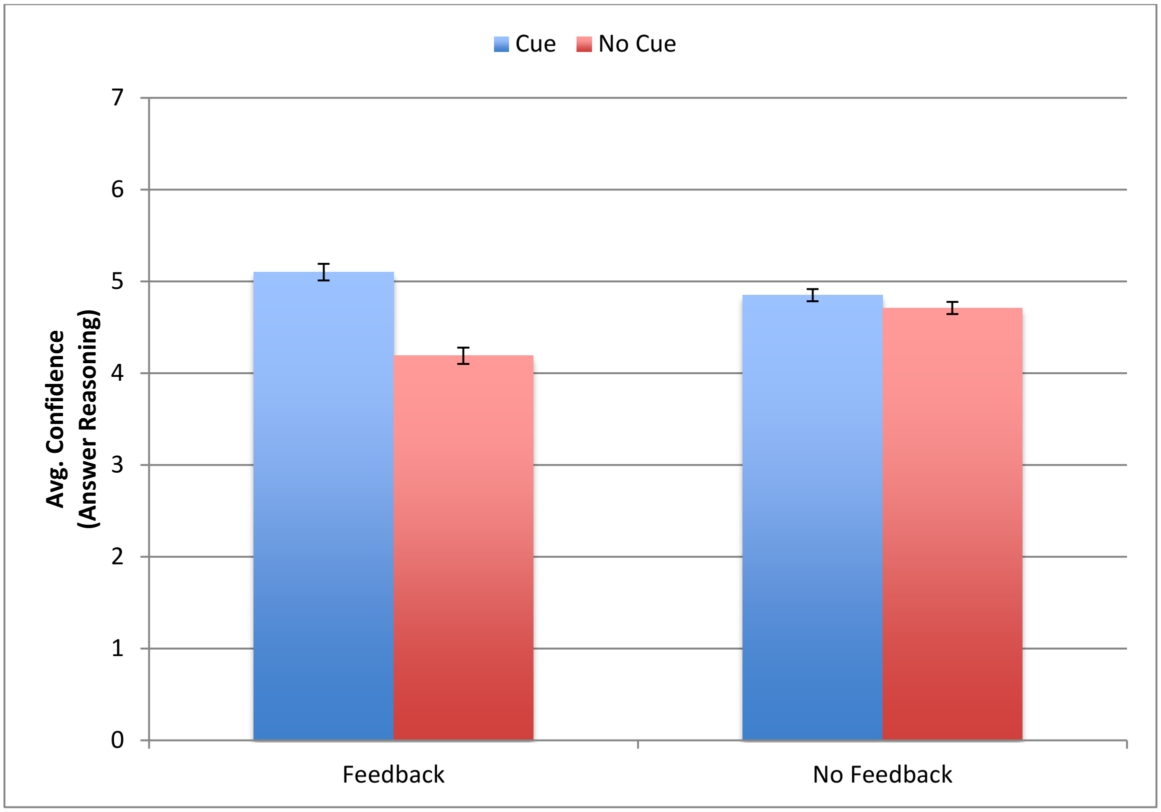
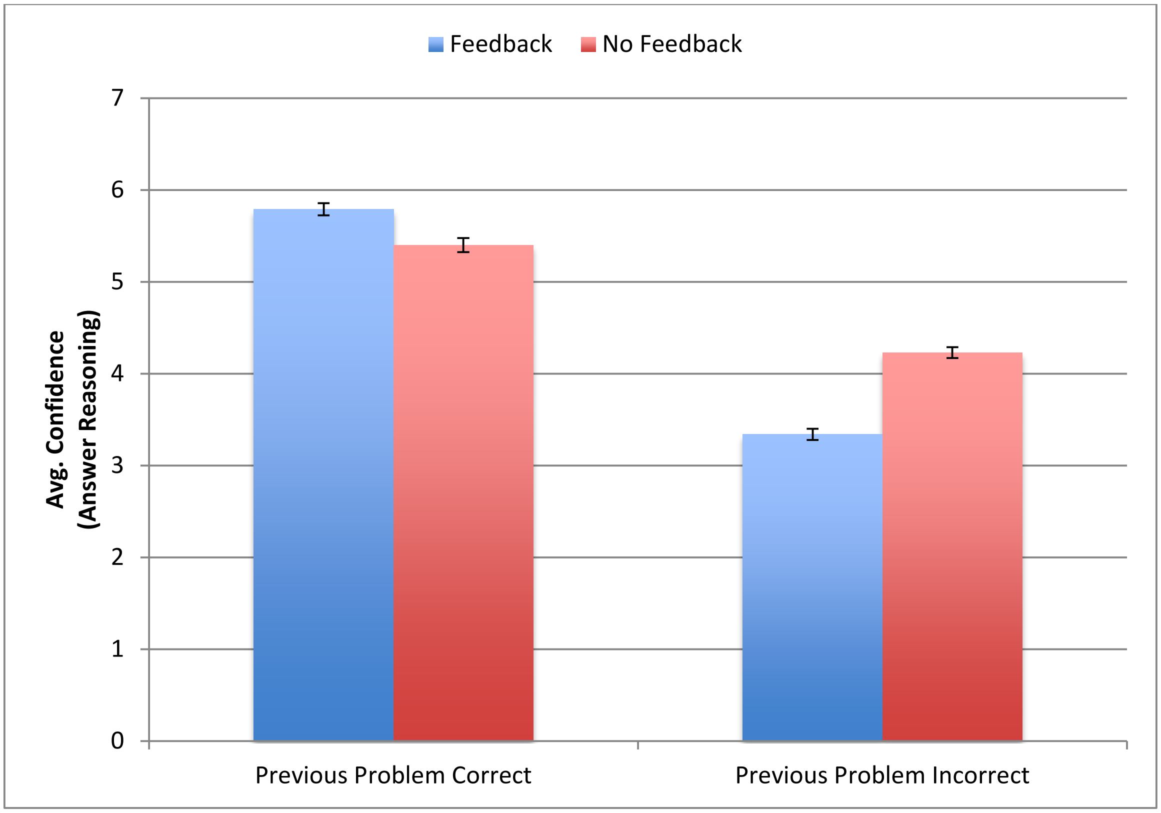


Figure 5.10 depicts the Feedback*Previous Problem Correctness interaction. Probing the Feedback*PPC interaction, we found that for participants in both the Feedback and No Feedback conditions, participants who correctly solved the previous problem had significantly higher average confidence than participants who solved the previous problem incorrectly, $F(1, 1832) = 590.47$, $p < .001$, $\eta_p^2 = .244$ and $F(1, 1832) = 164.49$, $p < .001$, $\eta_p^2 = .082$, respectively. Thus, there is a positive correlation between problem correctness and confidence. We found that previous problem correctness and average confidence are significantly positively correlated such that participants who were correct in the previous problem had a higher average confidence in the current problem for both the Feedback ($r = .64$, $p < .001$) and No Feedback ($r = .41$, $p < .001$) conditions.

We also found that for participants who solved the previous problem correctly, those who received outcome feedback had a significantly higher average confidence than those who did not receive outcome feedback, $F(1, 1832) = 14.26$, $p < .001$, $\eta_p^2 = .008$. On the other hand, if the previous problem was incorrectly solved, participants who received outcome feedback had a significantly lower average confidence than those who received outcome feedback, $F(1, 1832) = 78.55$, $p < .001$, $\eta_p^2 = .041$. Therefore, outcome feedback amplified the correlation. This is confirmed by the higher correlation value for the Feedback condition than the No Feedback condition.

Figure 5.10 Graph probing the interaction between Feedback and Previous Problem Correctness. Error bars denote ±1 standard error of the mean.



Summary and Discussion

In this study we investigated the effects of visual cueing and outcome feedback on performance in think-aloud conceptual physics problem solving. We found that the combination of visual cueing and outcome feedback was effective in helping students provide correct answers and explanations to training problems, transfer problems, and delayed transfer problems. We also that found significantly more students who were shown visual cues correctly solved the training problems than students who did not see visual cues when they incorrectly solved the initial problem.

From an educational standpoint, it is not only necessary for students to correctly solve problems that they have been trained to solve, they should also be able to solve problems that have different surface features from the training problems. We therefore had students solve near and far transfer problems at the end of each problem set. We found that students who received visual cues and outcome feedback were significantly more successful than students in the other conditions in solving problems that had a slightly different surface feature than the training problems (near transfer problems), but not on problems that had a considerably different surface feature (far transfer problems).

From the results on the delayed transfer problems, we found that the performance on the delayed near transfer problems are significantly better than performance on the initial problem, with the effects of both cueing and feedback showing stronger improvement. This shows that the effects of cueing and feedback can be observed on the near transfer problem, and it persists up to two weeks later on the delayed near transfer problem.

From the results on confidence, we found that participants who have a higher confidence in their solution of the problem tend to solve the problem correctly. We also found that visual cues can significantly increase confidence in solving the problem only if participants also receive outcome feedback. Finally, the effect of feedback on the average confidence depends on whether or not participants were correct or incorrect on the previous problem. For participants who solved a previous problem correctly, those who were told that they were correct had a significantly higher confidence in solving the next problem than those who were not told that they were correct. Conversely, for participants who incorrectly solved a previous problem correctly, those who were told they were incorrect had a significantly lower average confidence in solving the next problem than those who were told they were incorrect.

Chapter 6 - Influence of Visual Cueing and Outcome Feedback on Visual Attention in Transfer and Delayed Transfer in Conceptual Physics Problem Solving

Introduction

In this chapter we discuss the results eye tracking study in terms of the visual attention on the training, transfer, and delayed transfer problems. The results extend the result of Rouinfar et al. (2014c) in several ways. First, we have eye movement results for the training problem, which we were not able to collect in the previous study. Thus, we can investigate how the participants' visual attention shifts as they progress from the initial problem, the four training problems, then to the near transfer problem. This is important because in the previous study (Rouinfar et al., 2014c), we did a *post hoc* analysis to try to explain the seemingly counter-intuitive result that the participants who had been cued during the training were looking *less* at the relevant area on the transfer problem, and the participants who had not been cued were looking *more* at the relevant area. We proposed a post-hoc hypothesis that the result could be explained by automaticity, which could be evidenced by participants' needing less time looking at the relevant area to answer the problem correctly, and therefore more efficient at solving the transfer problem due to practice on the training problems. Research has shown that automaticity increases with practice (Bargh & Ferguson, 2000; Kramer, Strayer, & Buckley, 1989; Logan 1978; 1979; 1985), and in the previous study we assumed that participants were getting practice in extracting information from the relevant areas during the training problems. In this study, we can directly test this hypothesis by measuring whether the learners in the cued condition actually spend more time looking at the relevant areas of the training problems than those who are not cued. If so, this would satisfy a primary necessary condition for developing automaticity, which is practice—in this case, greater time spent time extracting information from the relevant areas of diagrams in the training problems. Then, we can test whether this leads learners in the cued conditions to subsequently spend *less* time looking at the relevant areas of the near transfer problems in order to correctly solve them than the uncued learners. If so, this would be evidence for increased efficiency of processing, which is a primary indicator of having developed automaticity. We also have eye movement results for the far transfer problem, as well as the delayed near and far transfer problems. Analyses of the visual attention on these problems can show whether automaticity is also observed on the far transfer problems, and if automaticity persists two weeks after the training.

Methodology

Fourteen participants who did not participate in the eye tracking study and twelve participants who had unusable eye movement data files were eliminated from further analysis in this chapter. Of the remaining 89 participants, 21 were in the No Cue + No Feedback condition (11 males, 10 females), 20 were in the No Cue + Feedback condition (11 males, 9 females), 26 were in the Cue + No Feedback Condition (16 males, 10 females), and 22 were in the Cue + Feedback condition (15 males, 7 females).

To analyze the eye movement data, we drew areas of interest (AOI) around the thematically relevant and novice-like areas associated with each initial, training, transfer, and delayed transfer problem. In order to take into account the physical size of each AOI, we divided the percentage of total dwell time in the AOI with respect to the total dwell time in the entire diagram, by the percentage of total area of the AOI with respect to the total area of the diagram. We will refer to the percentage of total dwell time divided by the percentage of total area as

PT/PA, although it is also known as the domain-relative ratio (Fletcher-Watson, Findlay, Leekam, and Benson, 2008).

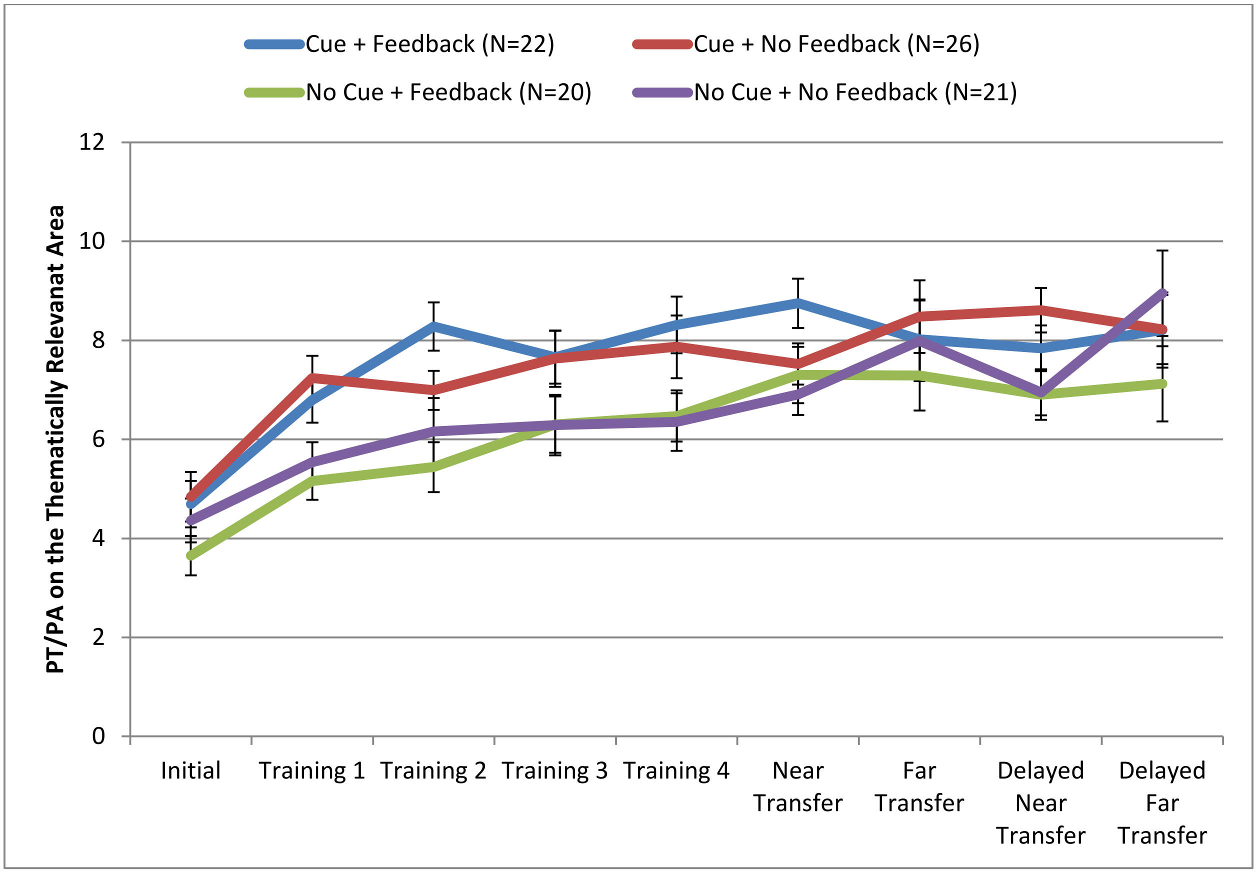
Participants were provided with visual cues on the training problems. In order to analyze the eye movement data on the training problems, we removed the eye fixations resulting from viewing the cues. Thus, the eye movement data for the four training problems presented in this chapter do not include attention to the thematically relevant information as a result of viewing the cues.

Overall Visual Attention

First, we investigate the participants' overall visual attention on the thematically relevant area of the diagram as they solved the initial, training, transfer, and delayed transfer problems. Figure 6.1 summarizes the results.

We conducted a one-way ANOVA on the PT/PA on the thematically relevant area of the initial problem to investigate its dependence on condition. We found that there was no significant dependence of the thematically relevant PT/PA on the four conditions, $F(3, 351) = 1.26$, $p = .287$, $\eta_p^2 = .011$. This means that participants were equivalently attending to the thematically relevant area of the initial problem diagram. Thus, we may consider the participants assigned to each condition to be equivalent for further analyses.

Figure 6.1 Mean PT/PA of participants on the thematically relevant area of the diagram on the initial, training, transfer, and delayed transfer problems. Error bars denote ±1 standard error of the mean.



To investigate how the overall visual attention on the thematically relevant area of the diagram shifted as students went through all nine problems, we conducted a 2×2×9 mixed factorial ANOVA with the PT/PA on the thematically relevant area of the diagram as the dependent variable, cue and feedback as the between-subjects factors, and problem as the within-subjects factor. Table 6.1 summarizes the results.

Table 6.1 Results of the mixed factorial ANOVA comparing the effects of cue and feedback on participants' visual attention on the thematically relevant area of diagram on the initial, training, transfer, and delayed transfer problems. The Greenhouse-Geisser correction was applied to the degrees of freedom because Mauchly's assumption of sphericity was violated. The significance level is α = .05.

Effect	ANOVA Result	p	η_p^2
Cue	$F(1, 351)=11.51$	.001	.032
Feedback	$F(1, 351)=0.20$	.657	.001
Problem	$F(4.4, 1544.7)=21.65$	<.001	.058
Cue*Feedback	$F(1, 351)=0.68$	.411	.002
Cue*Problem	$F(4.4, 1544.7)=1.28$	.273	.004
Feedback*Problem	$F(4.4, 1544.7)=1.19$	.311	.003
Cue*Feedback*Problem	$F(4.4, 1544.7)=0.81$	.532	.002

We found a significant main effect of Cue, such that participants who saw visual cues overlaid on the training problem diagrams have, on average, a significantly higher PT/PA on the thematically relevant area of a problem diagram. There was also a significant main effect of Problem, such that participants had a higher PT/PA on later problems. To investigate the main effect of Problem further, we analyze the simple and repeated contrasts. Table 6.2 summarizes the results.

Table 6.2 Summary of the results of a mixed factorial ANOVA probing the main effect of Problem on the thematically relevant PT/PA. The significance level is α = .003 after applying a Bonferroni correction for the 15 comparisons made below. Cells marked with * are statistically significant using the Bonferroni correction. Mauchly's assumption of sphericity was violated, so a Greenhouse-Geisser correction has been applied to the degrees of freedom for the simple main effects.

Effect	$F(1, 351)$	p	η_p^2
Initial vs. Training 1	62.24	< .001*	.151
Initial vs. Training 2	63.76	< .001*	.164
Initial vs. Training 3	66.68	< .001*	.160
Initial vs. Training 4	74.05	< .001*	.174
Initial vs. Near Transfer	160.14	< .001*	.313
Initial vs. Far Transfer	64.87	< .001*	.156
Initial vs. Delayed Near Transfer	152.76	< .001*	.303
Initial vs. Delayed Far Transfer	69.76	< .001*	.166
Training 1 vs. Training 2	4.42	.036	.012
Training 2 vs. Training 3	0.74	.392	.002
Training 3 vs. Training 4	0.85	.358	.002
Training 4 vs. Near Transfer	1.20	.274	.003
Near Transfer vs. Far Transfer	0.54	.463	.002
Far Transfer vs. Delayed Near Transfer	0.64	.423	.002
Delayed Near Transfer vs. Delayed Far Transfer	1.41	235	.004

Analysis of the simple contrasts reveals that the PT/PA on the thematically relevant area of the diagram on each training, transfer and delayed transfer problem is significantly higher than the PT/PA on the thematically relevant area of the initial problem diagram. There was no significant difference between the PT/PA on the thematically relevant area of diagram of one problem and the next problem.

Visual Attention on the Training Problems

In this section we discuss the influence of visual cueing and outcome feedback on participants' visual attention on the thematically relevant information of the training problem diagrams. We conducted a 2×2 ANOVA with the thematically relevant PTPA in each training problem diagram as the dependent variable, and cue and feedback as the categorical independent variables.

In all four training problems, we found a significant main effect of visual cueing, such that participants who saw cues on a training problem attended to the thematically relevant information of the training problem diagram significantly more than participants who did not see cues ($F(1, 351) = 15.04$, $p < .001$, $\eta_p^2 = .041$ for training problem 1; $F(1, 351) = 12.64$, $p < .001$, $\eta_p^2 = .035$ for training problem 2; $F(1, 351) = 5.51$, $p = .019$, $\eta_p^2 = .015$ for training problem 3; and $F(1, 351) = 8.14$, $p = .005$, $\eta_p^2 = .023$ for training problem 4). Since the eye fixations during the participant's viewing of the cues were removed, these significant differences are not due to the increase in participants' attention on the relevant information while the cues were being played. Thus, visual cues can help redirect students' visual attention to the relevant information of a problem diagram.

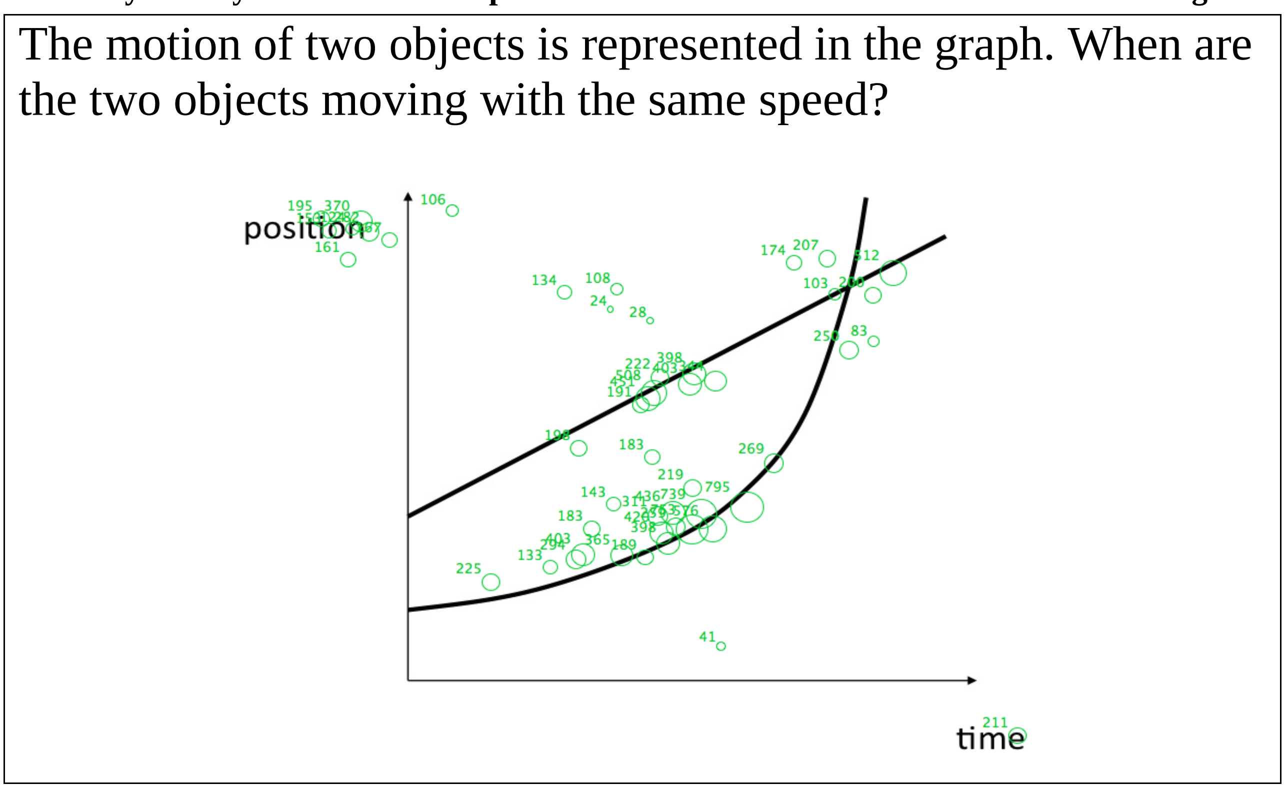
We did not find any significant main effects of feedback, which suggests that participants' visual attention on the relevant information of a diagram did not depend on whether they were told if they solved the previous problem correctly or incorrectly. This is surprising, since participants who received outcome feedback had higher performance on the training problems than participants who did not receive outcome feedback (see Fig. 5.3). There was also no significant interaction between cue and feedback, indicating that the effects of visual cueing on participants' visual attention on the thematically relevant information of a training problem diagram did not depend on whether or not they received outcome feedback on the previous problem.

Difference in Visual Attention Between Correct and Incorrect Solvers

We then compare the visual attention between participants who solved a problem correctly and participants who solved it incorrectly. Examples of the fixations made by a correct and an incorrect solver on a problem are shown in Figures 6.2 and 6.3.

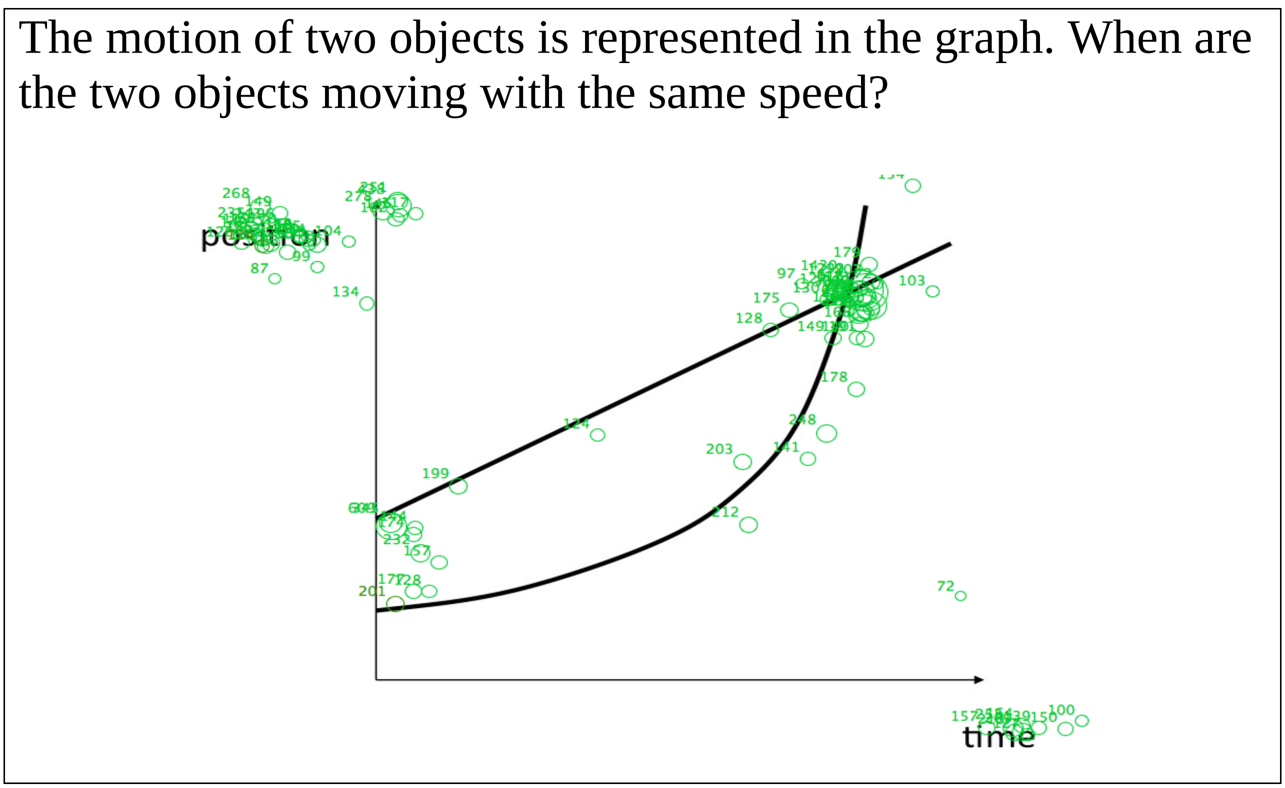
For the Graph problem in Figures 6.2 and 6.3, the students are asked when the speeds of two objects are the same using a position vs. time graph of the two objects. In order to solve this problem correctly, students should realize that slope of the tangent line of a position vs. time graph represents the instantaneous velocity. Thus, students should compare the slopes of the two graphs. The area of the diagram that is relevant to solving the problem correctly is therefore the area where the slopes of the two graphs are the same. The salient but irrelevant information is the intersection of the two graphs, where the two objects are at the same position at the same time (Madsen, *et al.*, 2013a).

Figure 6.2 An example of eye fixations made by a participant who solved a Graph problem correctly. The eye fixations on the problem statement were removed for ease of reading.



Looking at how a correct student attended to the Graph problem in Figure 6.2, we can see that the student has more eye fixations on the area of the diagram where the two graphs have the same slope than the intersection of the two graphs. Thus, the student was paying more attention to the relevant information of the diagram than the salient but irrelevant information. There is also a considerable number of eye fixations on y-axis label of the graph, which, when combined with the few number of eye fixations on the x-axis label of the graph, indicates that the student was paying more attention to the position and less to the time when he was figuring how to solve the problem.

Figure 6.3 An example of eye fixations made by a participant who solved a Graph problem incorrectly. The eye fixations on the problem statement were removed for ease of reading.

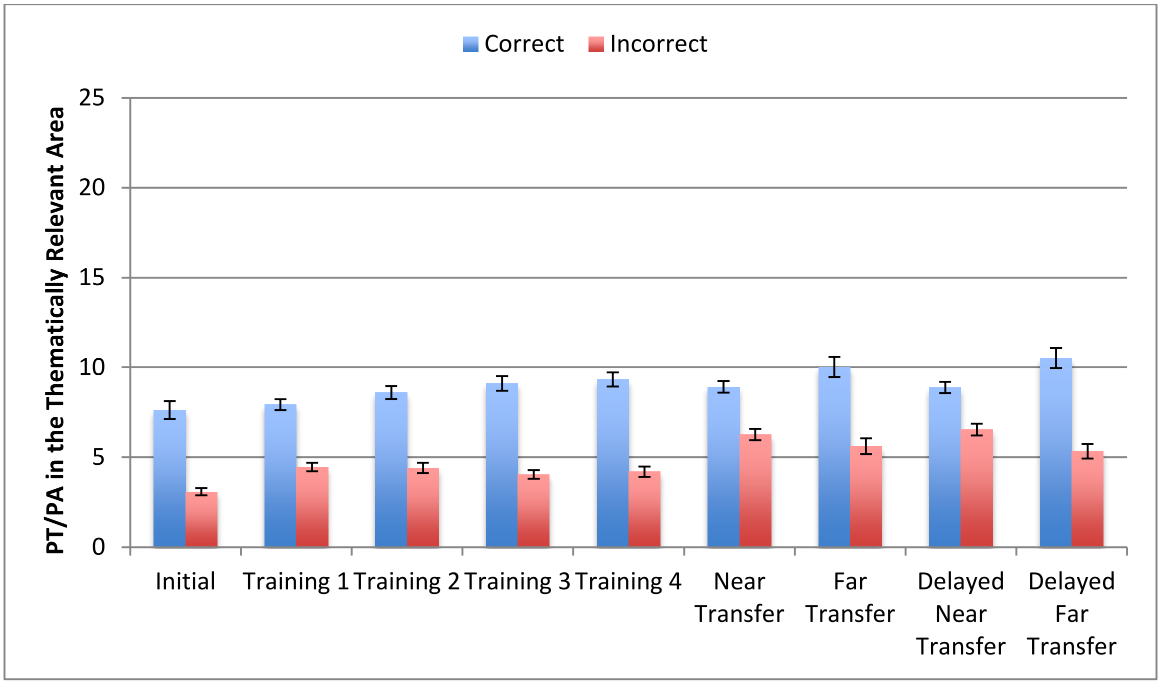


On the other hand, Figure 6.3 shows where an incorrect student looked at when he solved the Graph problem. We can see that the student did not pay attention to the relevant information of the diagram, as evidence by a single fixation on the area where the slopes are the same. However, the student made a lot of eye fixations on the intersection of the two graphs, which indicates that he used the common misconception two objects are moving with the same speed when they are at the same position at the same time when he solved the problem

We also find eye fixations at the start of the graphs, which is consistent with the answer that the two objects are moving with the same speed at time t=0 s because they are both at rest. Finally, we find a considerable number of eye fixations on both the x- and y-axis labels. This indicates that when a solver does not know how to correctly solve a problem that involves graphs, he tries to make connections between what are given in the graph (as indicated by the labels on the axes) and what is required.

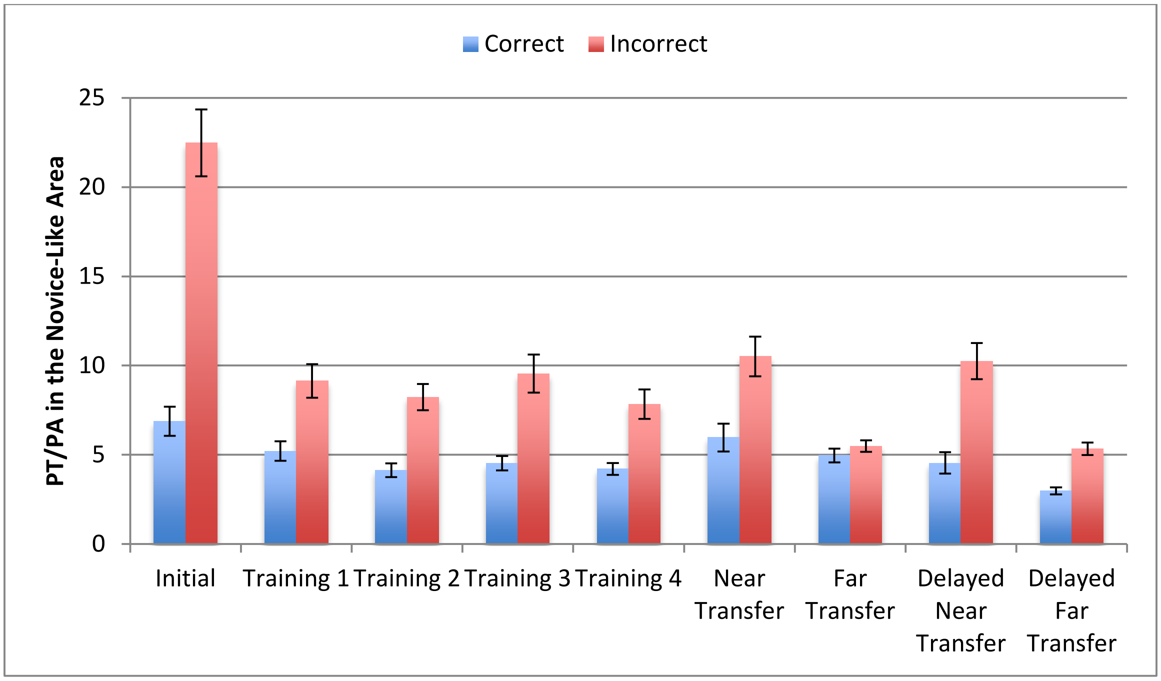
The PTPA on the thematically relevant and novice-like areas for correct and incorrect solvers on each problem are shown in Figures 6.4 and 6.5. For each problem, we conducted a one-way ANOVA with the PT/PA on the thematically relevant or novice-like area as the dependent variable, and problem correctness as the categorical independent variable. Results of the one-way ANOVAs for the two types of AOI are reported in Table 6.3.

Figure 6.4 Difference in visual attention on the thematically relevant area of the diagram between correct and incorrect solvers. Error bars denote ±1 standard error of the mean.



We found that on all problems, there was a significant main effect of problem correctness on the PT/PA in the thematically relevant area (Table 6.3), such that participants who solve a problem correctly attend to the thematically relevant area of the diagram significantly more than participants who solve the same problem incorrectly (Figure 6.4). This result is consistent with previous findings in which those with higher domain knowledge in a discipline spend more time looking at diagrams and pictures that are relevant to solving a task within the discipline (Van Gog, *et al.*, 2010; Antes and Kristjanson, 1991; Reingold, *et al.*, 2001; Madsen, *et al.*, 2013a; Rouinfar, *et al.*, 2014c). Thus, those who correctly solved the problem had the domain knowledge needed to solve the problem, and therefore spent more time attending to the relevant information on the diagram.

Figure 6.5 Difference in visual attention on the novice-like area of the diagram between correct and incorrect solvers. Error bars denote ±1 standard error of the mean.



We also found that on eight out of the nine problems, participants who incorrectly solve a problem have a significantly higher PT/PA on the novice-like area of the diagram than participants who correctly solve the same problem (Figure 6.5). On the far transfer problem, in which we found no significant difference between the correct and incorrect solvers, the PT/PA on the novice-like area for the incorrect solvers is a little bit higher than the PT/PA on the novice-like area for the correct solvers, indicating that the effect is in the same direction as the other problems.

Table 6.3 Results of one-way ANOVA for the thematically relevant and novice-like areas of interest for participants who solved the problem correctly and incorrectly. An asterisk indicates a significant difference at the α=.05 level.

AOI Type	Problem	ANOVA Result $F(1, 353)$	p	η_p^2
Thematically-Relevant	Initial	103.41	< .001*	.227
	Training 1	76.69	< .001*	.178
	Training 2	76.97	< .001*	.179
	Training 3	95.68	< .001*	.213
	Training 4	89.25	< .001*	.202
	Near Transfer	33.98	< .001*	.088
	Far Transfer	36.07	< .001*	.093
	Delayed Near Transfer	25.04	< .001*	.066
	Delayed Far Transfer	51.63	< .001*	.128
Novice-Like	Initial	27.99	< .001*	.073
	Training 1	13.68	< .001*	.037
	Training 2	27.76	< .001*	.073
	Training 3	24.68	< .001*	.065
	Training 4	21.56	< .001*	.058
	Near Transfer	11.31	.001*	.031
	Far Transfer	1.06	.304	.003
	Delayed Near Transfer	22.04	< .001*	.059
	Delayed Far Transfer	36.34	< .001*	.093

These results show that when solving physics problems, top-down processing plays a crucial role in guiding visual attention to thematically relevant or novice-like areas, depending on the scientific correctness of a student's physics knowledge.

Visual Attention of Participants who Demonstrated Immediate Learning and Retention

In this section, we investigate the automaticity of extracting relevant information on the transfer and delayed transfer problem diagrams. Specifically, we test the hypothesis we formulated in our previous study (Rouinfar et al., 2014c) that participants who saw visual cues on the training problems had more practice extracting the relevant information on the training problems, and so became more efficient at extracting the relevant information on the near transfer problem. We also investigate if automaticity is similarly observed on the far transfer and delayed transfer problems. In the following analyses, we consider the subset of participants who incorrectly solved the initial problem and then correctly solved both the transfer and delayed transfer problems.

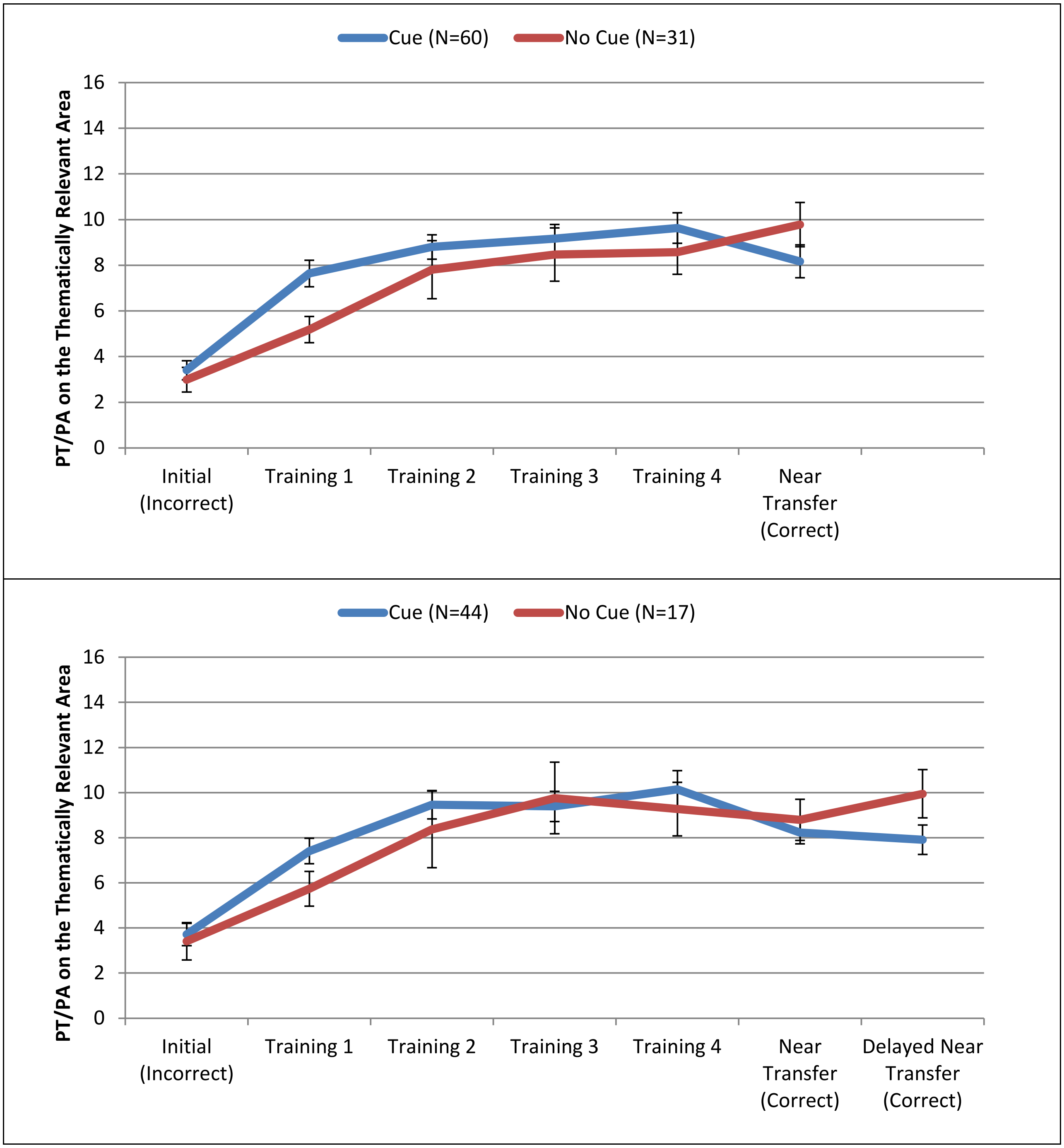
Visual Attention of Participants who Demonstrated Immediate Learning and Retention on the Near Transfer Problem

First, we investigate the changes in the participants' visual attention on the thematically relevant area of the diagram as they solved the initial problem, four training problems, the near transfer problem, and the delayed near transfer problem. We consider only the subset of participants who did not solve the initial problem correctly but were able to correctly solve the near transfer problem and the delayed near transfer problem. Figure 6.6 shows the thematically relevant PT/PA on the initial, training, near transfer, and the delayed near transfer problems for participants who demonstrated learning and retention on the near transfer problem.

We can see that for participants who were incorrect on the initial problem but got the near transfer problem correct (Fig. 6.6, top), participants in the Cue conditions (Cue + Feedback and Cue + No Feedback) had a higher thematically relevant PT/PA on the first training problem after having about the same PT/PA on the initial problem. Recall that before calculating the PT/PA on the training problems, the eye fixations were removed during the viewing of the cues. Thus, the increase in the thematically relevant PT/PA on the first training problems is not due to the participants' attention while they were viewing the cues, but were a result of just having viewed the cues. On the rest of the training problems, the PT/PA on the thematically relevant area of the diagram is about the same for both groups, although the Cue group is slightly higher. What is interesting is that on the near transfer problem, participants in the No Cue conditions had a higher PT/PA than participants in the Cue conditions. This result shows that while the cues make the participants pay more attention to the relevant information on the diagram, when a problem that has a slightly different surface feature is presented, participants who had practice extracting the relevant information of a diagram by being cued to look at the relevant information are able to extract the relevant information more quickly than participants who did not. This is consistent with the result that visual cues can facilitate the automaticity of extracting relevant information from diagrams (Rouinfar, *et al.*, 2014c; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Logan 1978; 1979; 1985; 1988).

For participants who solved both the near transfer and delayed near transfer problems correctly, participants in the No Cue condition had an even higher thematically relevant PT/PA on the delayed near transfer problem than participants in the Cue condition. Thus, automaticity of extracting the relevant information on the near transfer problem diagram was observed even two weeks later.

Figure 6.6 Comparison between the Cue and No Cue conditions with respect to the visual attention on the thematically relevant area of the diagram on the initial, training, near transfer, and delayed near transfer problems for the subset of participants who incorrectly solved the initial problem and then correctly solved the near transfer problem (top), and for the subset of participants who incorrectly solved the initial problem and then correctly solved both the near transfer and delayed near transfer problems (bottom). Error bars denote ±1 standard error of the mean.



A 2×2×7 mixed factorial ANOVA was conducted with cue and feedback as the between-subjects factors and PT/PA on the thematically relevant area of the initial, training, near transfer, and delayed near transfer problem diagrams. The results are reported in Table C.1. We found a significant main effect of Problem, such that participants had significantly higher average PT/PA on the thematically relevant area of the diagram on later problems. This significant main effect is qualified by the Cue*Feedback*Problem interaction.

In order to probe the three-way interaction, we analyzed the PT/PA as a function of Cue*Problem at each level of Feedback We conducted a 2×7 mixed factorial ANOVA with PT/PA on the thematically relevant area of the diagram as the dependent variable, cue as the between-subjects factor, and problem as the within-subjects factor, for the Feedback and No Feedback conditions. Result of the two-way interactions showed that when participants were told if they were correct or incorrect, we found a dependence of the thematically relevant PT/PA on visual cueing, $F(4.0, 281.0) = 3.49$, $p < .01$, $\eta_p^2 = .048$. On the other hand, when participants were not provided with outcome feedback, the PT/PA on the thematically relevant area of the diagram did not vary across problems as a function of whether or not visual cues were presented on the training problems, $F(4.0, 281.0) = 1.46$, $p > .05$. Figure D.1 in the Appendix shows the relationship between Cue and Problem for both the Feedback and No Feedback conditions.

If participants were provided with feedback (Fig. D.1, top), the PT/PA of participants in the Cue condition increases from the initial problem to the second training problem, and then remains constant until the last training problem. Then, the PT/PA decreases from the fourth training problem to the near transfer problem, and further decreases on the delayed near transfer problem. On the other hand, for participants in the No Cue condition, the PT/PA increases from the initial problem until it reaches a maximum on the third training problem, where it matches the PT/PA for the Cue group. The PT/PA slightly decreases on the fourth training problem, and then steadily increases on the near transfer problem and delayed near transfer problem. For participants who did not receive outcome feedback (Fig. D.1, bottom), we see similar trends in the thematically relevant PT/PA from the initial to the delayed near transfer problem, with the exception on the second training problem, where the PT/PA of the No Cue group is higher than the Cue group. I am unable to explain this result for the second training problem.

These results suggest that for students who demonstrate immediate learning and retention, visual cues help automatize the extraction of relevant information of problem diagrams, especially if they are also receiving outcome feedback.

Visual Attention of Participants who Demonstrated Immediate Learning and Retention on the Far Transfer Problem

Next, we investigate the changes in participants' visual attention when they incorrectly solve the initial problem and then correctly solve the far transfer and delayed far transfer problems. Figure 6.7 compares the Cued and No Cue groups as the participants solve the initial, training, far transfer, and delayed far transfer problems.

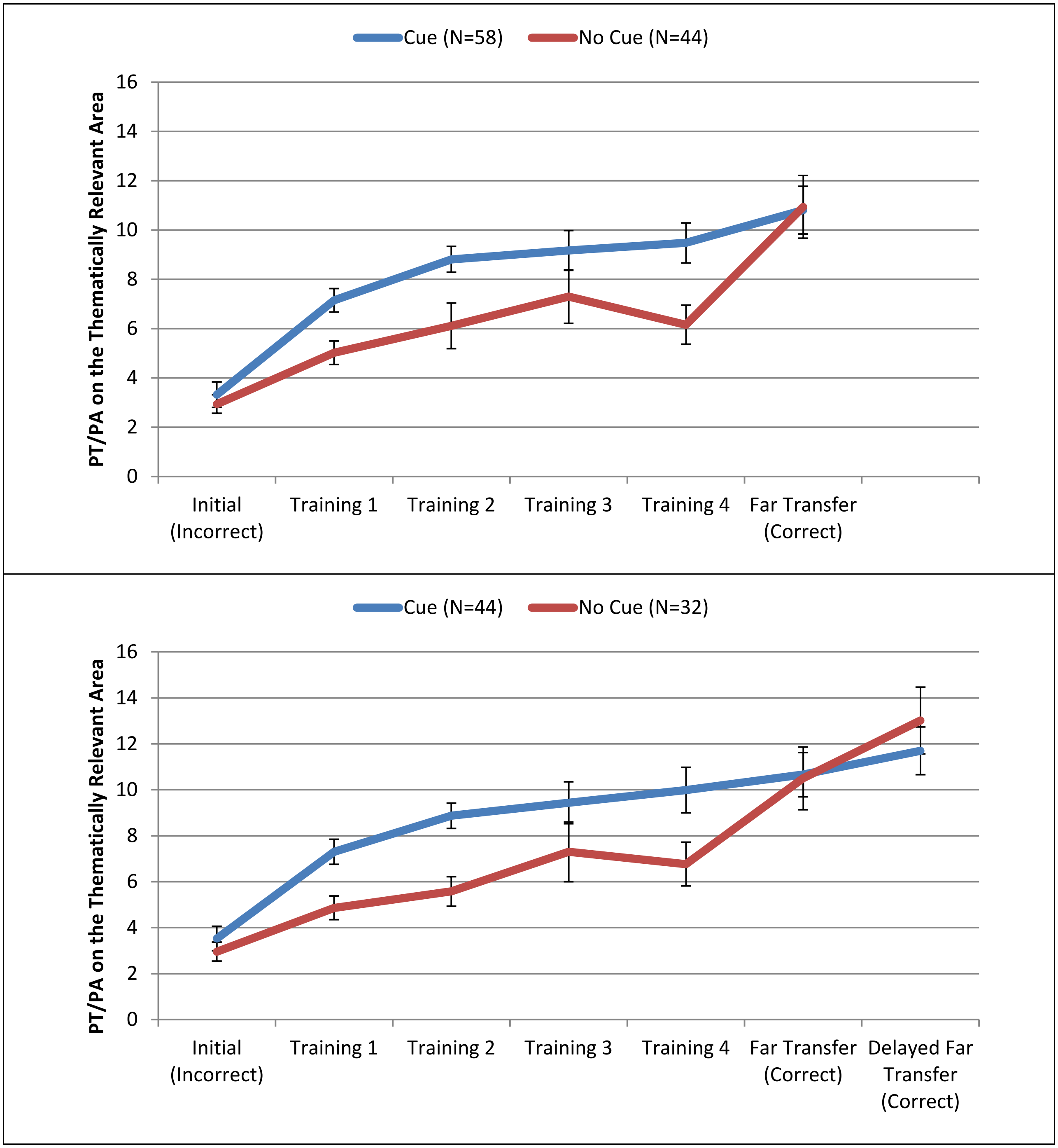
For participants who solved the initial problem incorrectly but were able to solve the far transfer problem correctly (Fig. 6.7, top), participants who were presented with visual cues on the training problems had a higher PT/PA on the training problems than participants who were not presented with visual cues. However, the PT/PA for both groups are the same on the far transfer problem, where the surface features of the diagram are considerably different from the training problems, even though the PT/PA of the Cue group has been consistently higher than the No Cue group on the training problems. Since we considered only the participants who got the initial problem incorrect and the far transfer problem correct, the result is consistent with previous results in our study as well as previous studies (Madsen, *et al.*, 2013) which show that paying attention to the thematically relevant area of the diagram is associated with solving the problem correctly (Fig. 6.4; Rouinfar *et al.*, 2014c; Madsen *et al.*, 2012).

For participants who also solved the delayed far transfer problem correctly (Fig. 6.7, bottom), those in the No Cue condition had a higher thematically relevant PT/PA on the delayed far transfer problem than those in the Cue condition. Thus, visual cueing can automatize the extraction of problem-relevant information on delayed far transfer problem diagrams.

We conducted a 2×2×7 mixed factorial ANOVA with cue and feedback as the between-subjects factors and PT/PA on the thematically relevant area of the initial, training, near transfer, and delayed near transfer problem diagrams. The results are reported in Table E.1. in the Appendix.

We found a significant main effect of Cue, such that participants who received visual cueing had a higher PT/PA, on average, than participants who did not receive visual cueing. We also found a significant main effect of Problem, such that participants had significantly higher average PT/PA on the thematically relevant area of the diagram of later problems. Looking at the simple contrasts, we found that the PT/PA on the each of the training problems, as well as the far transfer and delayed far transfer problems is significantly higher than the PT/PA on the initial problem. Analysis of the repeated contrasts showed that the PT/PA on the delayed far transfer problem is significantly higher than the PT/PA on the far transfer problem, $F(1, 72) = 8.74$, $p = .004$, $\eta_p^2 = .108$.

Figure 6.7 Comparison between the Cue and No Cue conditions with respect to the visual attention on the thematically relevant area of the diagram on the initial, training, far transfer, and delayed far transfer problems for the subset of participants who incorrectly solved the initial problem and then correctly solved the far transfer problem (top), and for the subset of participants who incorrectly solved the initial problem and then correctly solved both the far transfer and delayed far transfer problems (bottom). Error bars denote ±1 standard error of the mean.



Relationship between Visual Attention and Confidence

In the previous chapter we found that participants who had high confidence in solving a problem were significantly more likely to solve the problem correctly. In this section, we investigate the relationship between the PT/PA on the thematically relevant area of a problem diagram and confidence in solving the problem correctly.

In each problem, we conducted a one-way ANOVA with the thematically relevant PT/PA as the dependent variable and answer confidence as the categorical independent variable. In this analysis, we also use the confidence subgroups introduced in the previous chapter. The confidence level subgroups are Very Low (VL, confidence level 1-2), Low (L, confidence level 3-4), High (H, confidence level 5-6), and Very High (VH, confidence level 7). The results are summarized in Table 6.4.

We found no significant difference of thematically relevant PT/PA on the answer confidence in the initial problem. Thus, although significantly more participants with high and very high confidence answered the initial problem correctly (Table 5.13), there was no significant difference in their visual attention on the thematically relevant area of the diagram.

On the training problems, participants with very high confidence (i.e., confidence level of 7) have significantly higher PT/PA on the thematically relevant areas of the problem diagram than participants with Low confidence (confidence level of 3-4) and Very Low confidence (confidence level of 1-2). Participants with High confidence (confidence level 5-6) have significantly higher PT/PA in the thematically relevant area than participants with Very Low confidence. This is consistent with the results in Table 5.13 that participants with higher confidence are significantly more likely to solve a problem correctly, and with the results of Figure 6.4 such that participants who solve a problem correctly have a significantly higher

PT/PA on the thematically relevant area of the problem diagram than participants who solve the problem incorrectly.

For the transfer and delayed far transfer problems, participants with very high confidence level attend to the thematically relevant information of the diagram significantly more than participants with low and very low confidence. Participants with high confidence have a significantly higher thematically relevant PT/PA than participants with low and very low confidence only on the delayed near transfer problem.

Table 6.4 Results of the ANOVA for the PT/PA on the thematically relevant area of the diagram as a function of the answer confidence subgroups. The significance level is α = .05.

Problem	ANOVA Result $F(3, 351)$	p	η_p^2	*Post hoc* Results
Initial	0.83	.477	.007	---
Training 1	7.29	< .001	.059	VH > L, VL; H > VL
Training 2	4.83	.003	.040	VH > L = VL
Training 3	9.21	< .001	.073	H = VH > L = VL
Training 4	7.97	< .001	.064	VH > L, VL; H > VL
Near Transfer	4.36	.005	.036	VH > L = VL
Far Transfer	5.32	.001	.044	VH > L = VL
Delayed Near Transfer	10.60	< .001	.083	VH = H > L = VL
Delayed Far Transfer	7.07	< .001	.057	VH > VL = L

Table 6.5 shows the results of a one-way ANOVA with the thematically relevant PT/PA as the dependent variable and reasoning confidence as the categorical independent variable. Analysis of the dependence of the thematically relevant PT/PA on a problem on the reasoning confidence showed the same trend as dependence of the PT/PA on the thematically relevant area of a problem on the answer confidence.

Table 6.5 Results of the ANOVA for the PT/PA on the thematically relevant area of the diagram as a function of the reasoning confidence subgroups. The significance level is α = .05.

Problem	ANOVA Result $F(3, 351)$	p	η_p^2	*Post hoc* Results
Initial	1.70	.166	.014	---
Training 1	8.47	< .001	.068	VH > L, VL; H > VL
Training 2	4.01	.008	.033	VH > L = VL
Training 3	7.44	< .001	.060	H = VH > L = VL
Training 4	9.01	< .001	.071	VH > L, VL; H > VL
Near Transfer	3.97	.008	.033	VH > L = VL
Far Transfer	6.27	< .001	.051	VH > L = VL
Delayed Near Transfer	9.84	< .001	.078	VH = H = L > VL
Delayed Far Transfer	6.73	< .001	.054	VH > VL = L

Relationship between Performance, Visual Attention, and Confidence

In the previous section, we showed a correlation between confidence and visual attention on the relevant information of a problem diagram. We also showed in the previous chapter a significantly positive correlation between problem performance and confidence. In this section, we investigate the relationship between problem correctness, confidence in solving the problem, and visual attention to the relevant information in the problem diagram.

We showed in the previous chapter that for participants who reported high confidence in their answer for the initial problem, before receiving feedback, more participants solved it incorrectly than correctly. This was evidence of overconfidence. Then, for participants who were given feedback, in the next two problems, more participants solved the problems correctly than incorrectly. Thus, feedback was able to calibrate their confidence such that it was more closely aligned with the performance. We also found that outcome feedback amplified the positive correlation between performance and confidence, which is evidence of the importance of feedback in learning. In this section we investigate whether changes in confidence as an effect of feedback also leads to changes in the visual attention on the relevant information.

Since we wanted to investigate only the effects of feedback, we compared participants in the Cue + Feedback and the Cue + No Feedback conditions, who could use the cue information to help them overcome any impasse engendered by negative outcome feedback. Because the biggest change in performance occurred from the initial to the first and second training problems, we considered only the first three problems in the analysis.

Figure 6.8 compares participants in the Cue + Feedback and Cue + No Feedback conditions on the average accuracy, average confidence, and PT/PA on the thematically relevant areas on the initial, first, and second training problems. As before, we considered only the subset of participants who were incorrect on the initial problem, since they had the greatest opportunity to show effects of learning.

Figure 6.8 (bottom panel) shows that while solving the initial problem, participants in both feedback conditions were no different in how much they attended to the relevant information on the diagram, as shown by identical PT/PA on the relevant information on the initial problem. Figure 6.8 (middle panel) shows that after solving the initial problem, participants in the Feedback condition did not differ from participants in the No Feedback condition in terms of their confidence on the initial problem, $F(1, 129) = 0.55$, $p = .461$, $\eta_p^2 = .004$. Participants in the Feedback condition were then told whether they solved the initial problem correctly or incorrectly.

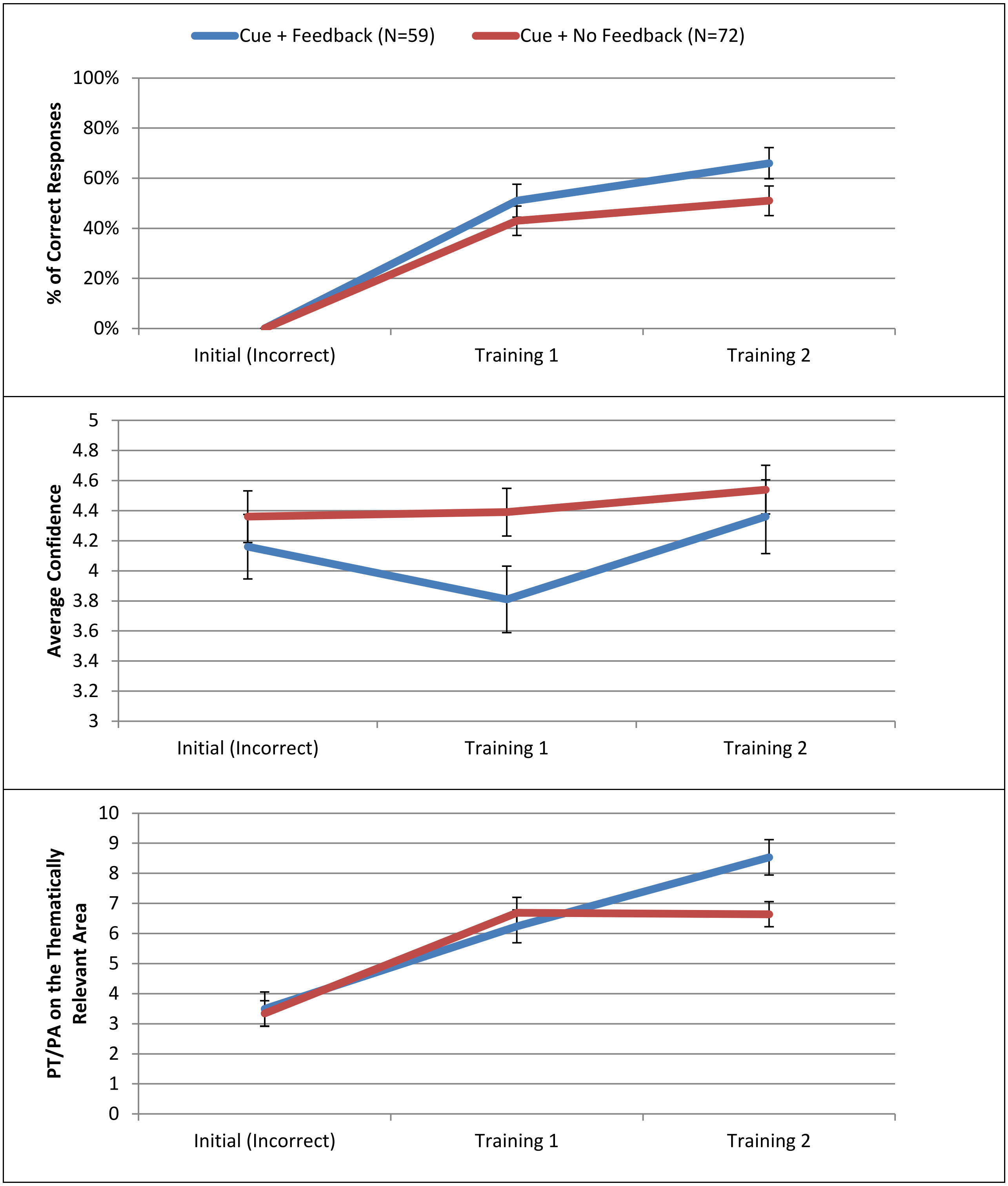
Next, participants in the both conditions solved the first training problem, where they saw visual cues. As shown in Figure 6.8 (middle panel), participants in the Feedback condition reported significantly lower confidence ratings on the first training problem as a result of having been told they were incorrect on the initial problem ($F(1, 129) = 10.73$, $p = .032$, $\eta_p^2 = .035$). This suggests that outcome feedback helped them to calibrate their initial over-confidence; the decrease in confidence is also consistent with the idea that these students would have been in a state of impasse when they attempted to solve the first training problem. Conversely, participants in the No Feedback condition maintained their confidence level ratings. This is interesting, because participants in both feedback conditions increased in accuracy on the first training problem due to being cued (Figure 6.8, top panel). Thus, those in the feedback condition, who had lower confidence, did as well as those in the No Feedback condition, who were more confident.

With respect to the visual attention on the relevant information on the first training problem diagram, Figure 6.8 (bottom panel) shows that there was no difference in the PT/PA between the Feedback and No Feedback conditions. Thus, although cueing increased attention to the relevant area on the first training problem, outcome feedback did not immediately lead to a change in the learners' visual attention.

Learners in both conditions then solved the second training problem. For learners in the feedback condition, this was immediately after getting feedback on the first training problem. Because most of them improved their accuracy on the first training problem, after learning of this through their outcome feedback, they showed a significant jump in confidence ratings on the second training problem, $F(1, 58) = 11.05$, $p = .002$, $\eta_p^2 = .160$ (Fig. 6.8, middle panel). Conversely, those who were not provided correctness feedback reported about the same confidence rating. Here we see how feedback was able to amplify the positive correlation between correctness and confidence, through the process of confidence calibration. Importantly, we see that this seemed to affect learners' degree of attention to the relevant areas of the problem. Specifically, as shown in Figure 6.8 (bottom panel), while solving the second training problem, learners in the Feedback condition spent more time attending to the relevant area of the diagram than they did on the first training problem, while participants in the No Feedback condition showed no such increase in PT/PA from the first to the second training problem ($F(1, 129) = 6.31$, $p = .013$, $\eta_p^2 = .047$). Thus, feedback, and resulting confidence calibration, together with cueing was able to change how participants attended to the relevant area of a diagram.

Finally, and critically importantly, these relationships affected learners' accuracy on the second training problem. Thus, as shown in Figure 6.8 (top panel), there was a nonsignificant trend that learners in the Feedback condition solved a higher percentage of the second training problems correctly than learners who only saw cues on the second training problem, $F(1, 129) = 2.90$, $p = .091$, $\eta_p^2 = .022$. These results are consistent, then, with the ideas represented in our conceptual model (Figure 3.1) of how cues and feedback can facilitate learning through problem solving.

Figure 6.8 Comparison between the Cue + Feedback and Cue + No Feedback conditions with respect to problem performance (top), average confidence (middle), and visual attention on the thematically relevant area of the diagram (bottom) on the initial, first training, and second training problems problems for participants who incorrectly solved the initial problem. Error bars denote ±1 standard error of the mean.



Summary and Discussion

In this study we investigated the effects of visual cueing and outcome feedback on attention to the thematically relevant area of the problem diagram. We also investigated how confidence is related to visual attention on the relevant information of a problem. Finally, we investigated how feedback moderated performance, confidence, and visual attention on the initial and the first two training problems.

We found that consistent with the results of Madsen *et al.* (2013a), participants who solved a problem correctly attended to the thematically relevant area of the problem diagram significantly more than participants who solved the same problem incorrectly. Conversely, participants who solved a problem incorrectly attend to the novice-like area of the problem diagram significantly more than participants who solved the same problem correctly. These results indicate that in conceptual physics problem solving that involve diagrams, top-down processing plays a crucial role in how students direct their visual attention. Students who correctly solved the problem had the domain knowledge needed to solve the problem, and therefore spent more time attending to the relevant information on the diagram. Students who solved the problem incorrectly usually used common misconceptions reported in literature, and so spent more time attending to the areas of the diagram that are consistent with these misconceptions.

For students who incorrectly solved the initial problem and then correctly solved the near transfer problem (i.e., for students who demonstrated immediate learning), we found that those who saw cues on the training problems spent more time attending to the thematically relevant information on the training problems, but spent less time attending to the thematically relevant information on the near transfer problem, than those who did not see cues on the training problems. Among these students, for those who correctly solved the delayed near transfer problem, those who saw cues spent even less time attending to the thematically relevant information on the delayed near transfer problem than those who did not see cues. Thus, for students who demonstrate immediate learning and retention on problems that have a slightly different surface feature from the training problem diagrams, visual cues can automatize the extraction of relevant information from diagrams. This is consistent with literature on automatization which that states that practice is required in order for processes to become automatic (Logan 1978; 1979; 1985; Bargh & Ferguson, 2000; Kramer, Strayer, & Buckley, 1989). We found evidence of practice in information extraction in terms of participants who were cued to the relevant areas of the training problems diagrams spending more time looking at them during training. An outcome of automaticity is that practice speeds up processing (Anderson, 1992). We found evidence of this in the fact that learners in the cue conditions needed to spend less time on the relevant information of the near transfer and delayed near transfer problem diagrams to answer them correctly than did the learners in the No Cue conditions.

For students who incorrectly solved the initial problem and then correctly solved the far transfer problem, we found that those who saw visual cues on the training problem diagrams spent significantly more time attending to the thematically relevant information on the training problems than those who did not see visual cues. However, the students who saw cues and did not see cues spent the same amount of time attending to the relevant information on the far transfer problem. If the students also solve the delayed far transfer problem correctly, participants who did not see cues on the training problems had a higher visual attention on the relevant area of the delayed far transfer problem diagram than those who did not see cues. Thus, for students who demonstrate immediate learning and retention on problems that have a considerably different surface feature than the training problem diagrams, visual cues can automatize extraction of problem-relevant information from the delayed far transfer problem diagram.

In our investigations of the relationship between students' confidence in solving a problem and their visual attention on the problem, we found that on the training, transfer, and delayed transfer problems, those who have higher confidence spend more time attending to the relevant information than those who have lower confidence. This is consistent with our results that students who solve a problem correctly spending more time attending to the relevant information on the problem, and that students who have higher confidence in solving a problem are more likely to correctly solve the problem. On the other hand, students who have higher confidence in solving the initial problem are significantly more likely to solve the problem correctly than those who have lower confidence, but there is no significant difference in their visual attention on the thematically relevant area of the initial problem.

We also looked at how accuracy, confidence, and visual attention were moderated by outcome feedback. We found that for participants who were incorrect on the initial problem and then correct on the first training problem, outcome feedback reduced confidence and then increased confidence. This also led to higher accuracy and visual attention to the thematically relevant area on the second training problem.

Chapter 7 - Conclusions

Overview of Research

Studies in physics education about students' learning and understanding mainly focused on students' misconceptions (McDermott & Redish, 1999). Heckler (2011) suggested that "salient yet scientifically irrelevant features of a question compete for attention with less salient yet relevant features," and this may play an important role in incorrect student answering patterns. Previous studies have shown that on physics problems that contain a diagram, students who solve the problem correctly focus their attention on the relevant information in the diagram, while those who solve the problem incorrectly focus their attention on the salient but irrelevant features of the diagram that are related to common misconceptions from literature (Madsen, *et al.*, 2013a). We have also previously shown that visual cues and outcome feedback can redirect students' visual attention from the irrelevant area to the relevant area of the diagram (Rouinfar, 2014a; Rouinfar *et al.*, 2014c).

In this research study we investigated the influence of visual cueing and outcome feedback on how students solve conceptual physics problems that contain diagrams. Specifically, we investigated the effects of visual cueing and outcome feedback on performance on near transfer and far transfer problems, as well as the effects on retention. We also investigated students' visual attention on the thematically relevant area of a diagram as a result of viewing cues or receiving outcome feedback. We were specifically interested in the visual attention of students who demonstrate immediate learning and retention. Lastly, we investigated how students' confidence in solving a problem is related to their performance and visual attention on the problem, and how outcome feedback changes performance, confidence and visual attention.

Answers to Research Questions

This section addresses the research questions that were formulated at the beginning of the study.

Research Question 1

The first research question asked about how visual cueing and outcome feedback influence students' performance on the initial, training, transfer and delayed transfer problems. We found that the combination of visual cueing and outcome feedback was the most effective in helping students solve the problems. On all the problems with the exception of the initial problem, participants in the Cue + Feedback condition provided the significantly most number of correct responses.

We also found that students' performance on the training, transfer, and delayed transfer problems were significantly better than their performance on the initial problem regardless of whether they see cues on the training problems or not, or whether they receive outcome feedback or not. However, students who saw cues and received outcome feedback showed stronger improvement over the initial problem.

Analysis of the training problem performance showed that regardless of the performance on the initial problem, students who received outcome feedback before each training problem solved significantly more training problems than those who did not receive any feedback. Students who saw visual cues on the training problems correctly solved significantly more training problems than those who did not see visual cues if they solved the initial problem incorrectly.

Research Question 2

The second research question asked how visual cueing and outcome feedback influence performance on the near and far transfer problems, which were presented immediately after the training problems.

For the near transfer problems, students in the Cue + Feedback condition had the significantly highest percentage of correct answers, while participants in the No Cue + No Feedback had the lowest percentage of correct answers. When we analyzed the performance in each problem set, we found that in both the Ball and Graph problem sets, students in the Cue + Feedback condition were the significantly highest performing. There were no significant differences in the four conditions for the Skier and Roller Coaster problem sets. For the far transfer problems, we found no significant differences in the four conditions.

Thus, the combination of visual cueing and outcome feedback can help improve performance on near transfer problems, but not on far transfer problems.

Research Question 3

Research question 3 asked about the influence of visual cueing and outcome feedback on retention. To do this, we compared the performance of students in the four conditions on near and far transfer problems, which were presented about two weeks after the main study.

We found that students who saw visual cues and received outcome feedback on the training problems two weeks prior had the significantly highest percentage of delayed near transfer problems solved correctly. Analysis of each problem set showed that for the Ball and Graph problem sets, students in the Cue + Feedback condition were the highest performing, while students in the No Cue + No Feedback condition were the lowest performing. Similar to the results on the far transfer problems, we found no significant differences the four conditions.

Answers to research questions 2 and 3 suggest that the combination of visual cueing and outcome feedback can help promote immediate learning and retention of conceptual physics problems with diagrams that have a slightly different surface feature from training problems.

Research Question 4

In research question 4, we explored the effects of visual cueing and outcome feedback on students' confidence in solving the problems.

Our results showed that for students who received outcome feedback on a problem, students who saw cues on the next problem reported a significantly higher confidence in solving the problem than those who did not see cues. There was no significant difference in the reported confidence between those who saw cues and those who did not see cues when they did not receive feedback on the previous problem.

We also found that for students who were told that they were correct solving a problem reported significantly higher confidence ratings in solving the next problem than those who were not told they were correct. Conversely, students who were told that they solved a problem incorrectly reported lower confidence level ratings in solving the next problem than those who were told that they were correct.

Research Question 5

Research question 5 asks about the effects of visual cueing and outcome feedback on the students' visual attention on the thematically relevant area of the initial and training problem diagrams.

We found that students who solved a problem correctly attended to the thematically relevant information of the problem diagram significantly more than those who solve the problem incorrectly. On the other hand, students who incorrectly solved a problem attended to the novice-like area of the problem diagram that is consistent with common student misconceptions found in the literature. This is consistent with the results found by Madsen *et al.* (2012).

We also found that visual attention on the thematically relevant information on the initial problem were not significantly different in the four conditions. On all four training problems, we found that participants who saw visual cues had significantly higher thematically relevant PT/PA on the problem diagrams than those who did not see cues. There was no significant difference on the attention on the thematically relevant information between students who received outcome feedback on a previous problem and students who did not receive outcome feedback.

Research Question 6

In research question 6, we were interested in the effects of visual cueing and outcome feedback on students' visual attention on the thematically relevant information of a problem diagram, if they solve the initial problem incorrectly and then solve the near or far transfer problem correctly.

For students who demonstrated immediate learning on the near transfer problem, students who saw visual cues on the training problems had higher thematically relevant PT/PA on the training problems, on average, than students who did not see cues. However, students who saw cues on the training problems eventually had lower thematically relevant PT/PA on the near transfer problem than those who did not see cues. This result suggests that visual cues can help automatize the extraction of problem-relevant information on near transfer problem diagrams. We did not find evidence that outcome feedback can also automatize the extraction of problem-relevant information on near transfer problem diagrams.

For students who demonstrated immediate learning on the far transfer problem, we found that those who saw cues on the training problems had significantly higher thematically relevant PT/PA on the training problem diagrams than those who did not see cues. However the thematically relevant PT/PA on the far transfer problem diagram is the same for both who saw cues and did not see cues. This suggests that visual cues may not have helped automatize the extraction of relevant information on the far transfer problem diagram. We did not find evidence of automaticity as a result of receiving outcome feedback.

Research Question 7

Research question 7 is an extension of the previous research question in that it asks whether we find evidence of automaticity of extracting relevant information for students who demonstrated both immediate learning and retention.

We found that for students who incorrectly solved the initial problem and then correctly solved both the near transfer and delayed near transfer problems, visual attention on the thematically relevant area of the near transfer and delayed near transfer problems is higher for those who did not see cues on the training problems than those who saw cues. Thus, visual cues can automatize the extraction of relevant information on both near transfer and delayed near transfer problem diagram. We also found evidence of visual cueing automatizing the extraction of problem-relevant information on far transfer and delayed far transfer problem diagrams.

Comparing students who received outcome feedback to students who did not receive outcome feedback, we found that those who did not receive feedback attended to the relevant information more than those who received feedback, but only on the delayed far transfer problem. Thus, outcome feedback can help automatize the extraction of problem-relevant information on delayed far transfer problem diagrams.

Research Question 8

On the last research question, we asked how students' confidence in solving a problem is related in their visual attention on the thematically relevant information on the problem.

We found that participants who reported high confidence in solving a problem also attended to the thematically relevant area of the problem diagram on the training, transfer, and delayed transfer problems, but not on the initial problem. This is consistent with previous results that students who solve a problem correctly attend to the thematically relevant area more than those who solve a problem incorrectly, and that participants who have higher confidence in solving a problem tend to solve the problem correctly.

On the initial problems, we found no significant difference in the students' visual attention on the thematically relevant area of the diagram, even though those who reported higher confidence ratings were more likely to solve the initial problem correctly than those who reported lower confidence ratings.

We also found that outcome feedback is able to moderate problem solving performance, confidence, and visual attention such that participants who receive outcome feedback have higher performance than those who do not receive outcome feedback. They also show an increase in the visual attention on the relevant information, although it is not immediately evident. Finally, participants who get a problem incorrect and receive feedback have lower confidence than those who do not receive feedback, but if they subsequently correctly solve a later problem, the feedback allows their confidence to jump back up. Thus, feedback helps learners calibrate their confidence, which is essential for learning.

Discussion

We investigated the effects of visual cueing and outcome feedback on students' performance, confidence, and visual attention when solving conceptual physics problems that contain diagrams. Our results show that the combination of visual cueing and outcome feedback helps students correctly solve conceptual physics problems that they were previously unable to solve (training problems). We found that significantly more students solved the training problems correctly after seeing visual cues and receiving correctness feedback. This result is consistent with the results of our previous study (Rouinfar, 2014a; Rouinfar, *et al.*, 2014b). Using our conceptual model, these results suggest that visual cues have helped the students to re-represent the problems in a productive way through elaboration and re-encoding. The combination of visual cueing and outcome feedback produced the most successful performance on the training problems in the study. After a student in the Cue + Feedback condition learned that their response is incorrect, he or she likely reached an impasse on the next problem in the set. The visual cues could then help the student overcome impasse and solve the problems correctly. If the student's response is incorrect, his confidence in solving the next problem decreases. The visual cues then help reinforce the correct mental representation, leading to a higher confidence in solving the next problem correctly.

From an educational standpoint, it is not sufficient that visual cues can help students only on problems in which they receive visual cues or outcome feedback. Therefore, we had students solve two related physics problems without the help of visual cues or outcome feedback at the end of each problem set. The first problem contained surface features that are slightly different from the initial and training problems (near transfer), while the second problem had surface features that were considerably different from the initial and training problems (far transfer). In order to demonstrate retention, we asked the students to solve the near and far transfer problems after two weeks (delayed transfer). Our results suggest that the combination of visual cues and outcome feedback can promote immediate learning and retention on the near transfer problems. This result is consistent of our previous result (Rouinfar, 2014a; Rouinfar, *et al.*, 2014b) that visual cues and outcome feedback help students successfully solve near transfer problems. We extended this result and showed that visual cues and outcome feedback also help students successfully solve near transfer problems, not only immediately after training, but also after two weeks. Our findings suggest that visual cues and outcome feedback had no statistically significant effect on the far transfer or delayed far transfer problems. We speculate that considerably changing the surface features of the problem made the problems too easy or too difficult that seeing cues or receiving feedback did not matter.

In the current study we also explored how overt visual attention is related to the cognitive processes involved in problem solving. Consistent with previous results (Madsen, *et al.*, 2013a; 2013b; Rouinfar, *et al.*, 2014b), we found that participants who solve a problem correctly spend significantly more time attending to the thematically relevant information in the problem diagram. We investigated how participants' visual attention in the relevant area of the diagram shifted as they solved the initial, training, transfer, and delayed transfer problems in each set. Our results suggest that for participants who demonstrated improvement from the initial to the near transfer problem, participants in the cued group had significantly less PT/PA in the thematically relevant area of the near transfer problem diagram. This is consistent with the automatization hypothesis (Rouinfar *et al.*, 2014b) that repeated training in extracting the relevant information increases participants' efficiency in doing so.

We extended the previous study in several significant ways. First, we investigated visual attention on the far transfer problem, as well as the delayed near and delayed far transfer problems. Our results showed that for participants who demonstrated immediate learning and retention on the near transfer problems, participants who saw cues on the training problems had less PT/PA on the thematically relevant information of the near transfer and delayed near transfer problems. Thus, visual cues can automatize the extraction of relevant information on near transfer and delayed near transfer problem diagrams. We also found evidence that for participants who demonstrated immediate learning and retention on the far transfer problems, visual cues can automatize the extraction of problem-relevant information on the far transfer and delayed far transfer problems, while outcome feedback helped automatize the extraction of problem-relevant information on the delayed far transfer problems only.

What is interesting is that for participants who demonstrated immediate learning and retention on the near or far transfer problems, participants who saw cues on the training problems also had higher PT/PA on the thematically relevant information of the training problem diagram. This is in line with the processing priority hypothesis (Rouinfar *et al.*, 2014c). Participants who have previously been cued would have learned to attend to the relevant information and thus spend more time processing the relevant information on the training problems than participants who have not been cued.

Our eye movement results suggest that participants who see cues on the training problems spend more time attending to the relevant information on the training problems than participants who do not see cues. Repeated attention to the relevant information on the training problems would then result in participants processing relevant information on the transfer and delayed transfer problems in a more automatized manner.

Limitations and Future Work

We found evidence that the combination of visual cueing and outcome feedback can help students improve performance on training, transfer, and delayed transfer problems. We also found evidence that visual cues and outcome feedback can help automatize the extraction of problem-relevant information on transfer and delayed transfer problem diagrams.

One limitation of the study is the far transfer problems that we presented were easier than the near transfer problems such that we did not find significant differences in the four conditions on the far transfer and delayed far transfer problems. Thus, we recommend investigating how to construct the far transfer problem more carefully such that they not only increase in complexity, but also in difficulty.

The problems investigated in this study are problems that are amenable to the use visual cues to improve performance. However, our study has not covered the full scope of problems that can be improved by visual cues, and not all problems can be improved by visual cues. Therefore, future work should explore problems that may be improved with visual cues.

Participants were instructed to verbalize their thought process as they solved the problems. Future research should involve the analysis of the think-aloud protocols for evidence of encountering impasse, and then achieving insight. The relationship between learners' utterances and problem solving accuracy, confidence, and visual attention should also be examined.

References

Anderson, J. R. (1992). Automaticity and the ACT theory. *The American journal of psychology*, 165-180.

Antes, J. R., & Kristjanson, A. F. (1991). Discriminating artists from nonartists by their eye-fixation patterns. *Perceptual and Motor Skills, 73*(3), 893-894.

Arkes, H. R., Christensen, C., Lai, C., & Blumer, C. (1987). Two methods of reducing overconfidence. *Organizational Behavior and Human Decision Processes, 39*(1), 133-144.

Baluch, F., & Itti, L. (2011). Mechanisms of top-down attention. *Trends in Neurosciences, 34*(4), 210-224.

Bangert-Drowns, R. L., Kulik, C. C., Kulik, J. A., & Morgan, M. (1991). The instructional effect of feedback in test-like events. *Review of Educational Research, 61*(2), 213-238.

Bargh, J. A., & Ferguson, M. J. (2000). Beyond behaviorism: on the automaticity of higher mental processes. *Psychological bulletin, 126*(6), 925.

Beckmann, N., Beckmann, J. F., & Elliott, J. G. (2009). Self-confidence and performance goal orientation interactively predict performance in a reasoning test with accuracy feedback. *Learning and Individual Differences*, *19*(2), 277-282.

Bilalić, M., McLeod, P., & Gobet, F. (2008). Why good thoughts block better ones: The mechanism of the pernicious einstellung (set) effect. *Cognition*, *108*(3), 652-661.

Bornstein, B. H., & Zickafoose, D. J. (1999). " I know I know it, I know I saw it": The stability of the confidence–accuracy relationship across domains. *Journal of Experimental Psychology: Applied*, *5*(1), 76.

Boucheix, J., & Lowe, R. K. (2010). An eye tracking comparison of external pointing cues and internal continuous cues in learning with complex animations. *Learning and Instruction, 20*(2), 123-135.

Butler, D. L., & Winne, P. H. (1995). Feedback and self-regulated learning: A theoretical synthesis. *Review of Educational Research*, *65*(3), 245-281.

Carroll, S., & Swain, M. (1993). Explicit and implicit negative feedback. *Studies in Second Language Acquisition, 15*(03), 357-386.

Carroll, S., Swain, M., & Roberge, Y. (1992). The role of feedback in adult second language acquisition: Error correction and morphological generalizations. *Applied Psycholinguistics, 13*(02), 173-198.

Chi, M. (1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science. In R. Giere, & H. Feigl (Eds.), *Cognitive models of science* (pp. 129-186) University of Minnesota Press.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*(2), 121-152.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63*(1), 1-49.

Craig, S. D., Gholson, B., & Driscoll, D. M. (2002). Animated pedagogical agents in multimedia educational environments: Effects of agent properties, picture features and redundancy. *Journal of Educational Psychology, 94*(2), 428.

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

Docktor, J. L., Mestre, J. P., Gire, E., & Rebello, N. S. (2012). *Eye patterns while interpreting kinematics graphs.* Poster presented at the American Association of Physics Teachers Annual Conference, Philadelphia, PA.

Docktor, J. L., & Mestre, J. P. (2014). Synthesis of discipline-based education research in physics. *Physical Review Special Topics-Physics Education Research, 10*(2), 020119.

Duncker, K., & Lees, L. S. (1945). On problem-solving. *Psychological Monographs, 58*(5), i-113.

Einhauser, W., Rutishauser, U., & Koch, C. (2008). Task-demands can immediately reverse the effects of sensory-driven saliency in complex visual stimuli. *Journal of Vision, 8*(2), 2.1-19.

Eivazi, S., & Bednarik, R. (2010). Inferring problem solving strategies using eye-tracking: System description and evaluation. Paper presented at the *Proceedings of the 10th Koli Calling International Conference on Computing Education Research,* 55-61.

Eivazi, S., & Bednarik, R. (2011). Predicting problem-solving behavior and performance levels from visual attention data. Paper presented at the *Proc. Workshop on Eye Gaze in Intelligent Human Machine Interaction at IUI,* 9-16.

Ellis, J. J., Glaholt, M. G., & Reingold, E. M. (2011). Eye movements reveal solution knowledge prior to insight. *Consciousness and Cognition, 20*(3), 768-776.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review, 87*(3), 215.

Epelboim, J., & Suppes, P. (2001). A model of eye movements and visual working memory during problem solving in geometry. *Vision Research, 41*(12), 1561-1574.

Feil, A., & Mestre, J. P. (2010). Change blindness as a means of studying expertise in physics. *The Journal of the Learning Sciences, 19*(4), 480-505.

Festinger, L. (1962). *A theory of cognitive dissonance* Stanford university press.

Fischer, I., & Budescu, D. V. (2005). When do those who know more also know more about how much they know? The development of confidence and performance in categorical decision tasks. *Organizational Behavior and Human Decision Processes, 98*(1), 39-53.

Fischhoff, B. (1982). Debiasing. In D. Kahneman, P. Slovic, & A. Tversky (Eds.), *Judgment under uncertainty: Heuristics and biases* (pp. 422—444).

Fischhoff, B., Slovic, P., & Lichtenstein, S. (1977). Knowing with certainty: The appropriateness of extreme confidence. *Journal of Experimental Psychology: Human perception and performance, 3*(4), 552.

Fletcher-Watson, S., Findlay, J. M., Leekam, S. R., & Benson, V. (2008). Rapid detection of person information in a naturalistic scene. *Perception, 37*(4), 571-583.

Foulsham, T., & Underwood, G. (2007). How does the purpose of inspection influence the potency of visual salience in scene perception? *Perception, 36*(8), 1123-1138.

Fraij, F. (2010). The impact of feedback in computer-aided instruction. *International Journal of Soft Computing, 5*(2), 67-71.

González-Vallejo, C., & Bonham, A. (2007). Aligning confidence with accuracy: Revisiting the role of feedback. *Acta Psychologica, 125*(2), 221-239.

Grant, E. R., & Spivey, M. J. (2003). Eye movements and problem solving: Guiding attention guides thought. *Psychological Science, 14*(5), 462-466.

Guitton, D., Buchtel, H. A., & Douglas, R. (1985). Frontal lobe lesions in man cause difficulties in suppressing reflexive glances and in generating goal-directed saccades. *Experimental Brain Research, 58*(3), 455-472.

Halloun, I. A., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics, 53*(11), 1043-1055.

Hammer, D. (2000). Student resources for learning introductory physics. *American Journal of Physics, 68*(S1), S52-S59.

Heckler, A. F. (2011). The ubiquitous patterns of incorrect answers to science questions: The role of automatic, bottom-up processes. In J. P. Mestre, & B. H. Ross (Eds.), (pp. 227)

Hegarty, M., Canham, M. S., & Fabrikant, S. I. (2010). Thinking about the weather: How display salience and knowledge affect performance in a graphic inference task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*(1), 37.

Hein, E., & Moore, C. M. (2009). Explicit eye movements failed to facilitate the precision of subsequent attentional localization. *Experimental Brain Research, 197*(4), 387-393.

Henderson, J. M. (1993). Visual attention and saccadic eye movements. Paper presented at the *Annual Meeting of the Psychonomic Society, 31st, 1990, New Orleans, LA.*

Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception & Psychophysics, 57*(6), 787-795.

Hsu, L., Brewe, E., Foster, T. M., & Harper, K. A. (2004). Resource letter RPS-1: Research in problem solving. *American Journal of Physics*, *72*(9), 1147-1156.

Irwin, D. E., Colcombe, A. M., Kramer, A. F., & Hahn, S. (2000). Attentional and oculomotor capture by onset, luminance and color singletons. *Vision Research*, *40*(10-12), 1443-1458.

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research, 40*(10-12), 1489-1506.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63-85.

Jones, G. (2003). Testing two cognitive theories of insight. *Journal of Experimental Psychology.Learning, Memory, and Cognition*, *29*(5), 1017-1027.

Just, M. A., & Carpenter, P. A. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review, 87*(4), 329.

Kalyuga, S., Chandler, P., & Sweller, J. (1999). Managing split-attention and redundancy in multimedia instruction. *Applied Cognitive Psychology*, *13*(4), 351-371.

Kassin, S. M., Ellsworth, P. C., & Smith, V. L. (1989). The" general acceptance" of psychological research on eyewitness testimony: A survey of the experts. *American Psychologist*, *44*(8), 1089.

Knoblich, G., Öllinger, M., & Spivey, M. J. (2005). Tracking the eyes to obtain insight into insight problem solving. *Cognitive Processes in Eye Guidance,* 355-375.

Knoblich, G., Ohlsson, S., & Raney, G. E. (2001). An eye movement study of insight problem solving. *Memory & Cognition*, *29*(7), 1000-1009.

Koriat, A., Lichtenstein, S., & Fischhoff, B. (1980). Reasons for confidence. *Journal of Experimental Psychology: Human learning and memory*, *6*(2), 107.

Kowler, E., Anderson, E., Dosher, B., & Blaser, E. (1995). The role of attention in the programming of saccades. *Vision Research, 35*(13), 1897-1916.

Kramer, A. F., Strayer, D. L., & Buckley, J. (1989, October). Factors Influencing the Development and Transfer of Automatic Processing. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 33, No. 19, pp. 1248-1252). SAGE Publications.

Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Expert and novice performance in solving physics problems. *Science, 208*(4450), 1335-1342.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*(1), 65-100.

Leow, R. P. (2000). A study of the role of awareness in foreign language behavior. *Studies in Second Language Acquisition, 22*(04), 557-584.

Lin, J., & Lin, S. (2014). Tracking eye movements when solving geometry problems with handwriting devices. *J.Eye Mov.Res, 7*, 1-15.

Litchfield, D., & Ball, L. J. (2011). Using another's gaze as an explicit aid to insight problem solving. *The Quarterly Journal of Experimental Psychology*, *64*(4), 649-656.

Lichtenstein, S., & Fischhoff, B. (1977). Do those who know more also know more about how much they know? *Organizational behavior and human performance*, *20*(2), 159-183.

Lichtenstein, S., Fischhoff, B., & Phillips, L. D. (1977). *Calibration of probabilities: The state of the art* (pp. 275-324). Springer Netherlands.

Logan, G. D. (1978). Attention in character-classification tasks: Evidence for the automaticity of component stages. *Journal of Experimental Psychology: General*, *107*(1), 32.

Logan, G. D. (1979). On the use of a concurrent memory load to measure attention and automaticity. *Journal of Experimental Psychology: Human Perception and Performance*, *5*(2), 189.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological review*, *95*(4), 492.

Logan, G. D. (1985). Skill and automaticity: Relations, implications, and future directions. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *39*(2), 367.

Loschky, L. C, & Harrington, M. (2013). A cognitive neuroscientific approach to studying the role of awareness in L2 learning. *Noticing and Second Language Acquisition: Studies in Honor of Richard Schmidt, 289*.

Lowe, R. K. (1989). Search strategies and inference in the exploration of scientific diagrams. *Educational Psychology, 9*(1), 27-44.

Madsen, A., Rouinfar, A., Larson, A., Loschky, L., & Rebello, N. S. (2013). Do perceptually salient elements in physics problems influence students’ eye movements and answer choices. Paper presented at the *American Institute of Physics Conference Series, 1513* 274-277.

Madsen, A. M., Larson, A. M., Loschky, L. C., & Rebello, N. S. (2012). Differences in visual attention between those who correctly and incorrectly answer physics problems. *Physical Review Special Topics - Physics Education Research, 8*(1), 010122.

Madsen, A., Rouinfar, A., Larson, A. M., Loschky, L. C., & Rebello, N. S. (2013). Can short duration visual cues influence students' reasoning and eye movements in physics problems? *Physical Review Special Topics - Physics Education Research, 9*(2), 020104.

Maier, N. R. F. (1931). Reasoning in humans. II. the solution of a problem and its appearance in consciousness. *Journal of Comparative Psychology, 12*(2), 181-194.

Maloney, D. (1993). Research on Problem Solving: Physics. In Gabel , D. (Ed.), *Handbook of research in science teaching and learning* (327).

Martin, T. L., Pear, J. J., & Martin, G. L. (2002). Feedback and its effectiveness in a computer-aided personalized system of instruction course. *Journal of Applied Behavior Analysis, 35*(4), 427-430.

Matell, M. S., & Jacoby, J. (1972). Is there an optimal number of alternatives for Likert-scale items? Effects of testing time and scale properties. *Journal of Applied Psychology, 56*(6), 506.

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

Mayer, R. E. (2001). *Multimedia Learning*. Cambridge University Press.

McCloskey, M. (1983). Intuitive physics. *Scientific American, 248*(4), 122-130.

McDermott, L. C., & Redish, E. F. (1999). Resource letter: PER-1: Physics education research. *American Journal of Physics, 67*(9), 755-767.

Meyer, B. J. F. (1975). *The organization of prose and its effects on memory* North-Holland Publishing Co.

Mital, P., Smith, T., Hill, R., & Henderson, J. (2011). Clustering of gaze during dynamic scene viewing is predicted by motion. *Cognitive Computation, 3*(1), 5-24.

Mitchell, J. P., Macrae, C. N., & Gilchrist, I. D. (2002). Working memory and the suppression of reflexive saccades. *Journal of Cognitive Neuroscience, 14*(1), 95-103.

Mory, E. H. (2004). Feedback research revisited. *Handbook of Research on Educational Communications and Technology, 2*, 745-783.

Ohlsson, S. (1984). Restructing revisited: I. Summary and critique of the Gestalt theory of problem solving. *Scandinavian journal of psychology, 25*(1), 65-78.

Ohlsson, S. (1992). Information-processing explanations of insight and related phenomena. *Advances in the Psychology of Thinking*, Chap. 1,1-44.

Paige, J. M., & Simon, H. A. (1966). Cognitive processes in solving algebra word problems. *Problem Solving: Research, Method, and Theory,* 15-16.

Pea, R. D. (1987). Socializing the knowledge transfer problem. *International Journal of Educational Research, 11*(6), 639-663.

Perfect, T. J., Hollins, T. S., & Hunt, A. L. (2000). Practice and feedback effects on the confidence-accuracy relation in eyewitness memory. *Memory, 8*(4), 235-244.

Piaget, J. (1964). Development and learning. In Gauvain, M., & Cole, M. (Eds.), *Readings on the Development of Children, 2nd Ed*. W. H. Freeman and Company.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124*(3), 372-422.

Reingold, E. M., Charness, N., Pomplun, M., & Stampe, D. M. (2001). Visual span in expert chess players: Evidence from eye movements. *Psychological Science, 12*(1), 48-55.

Rosengrant, D., Hearrington, D., Alvarado, K., Keeble, D., Rebello, N. S., Engelhardt, P. V., & Singh, C. (2012). Following student gaze patterns in physical science lectures. Paper presented at the *AIP Conference Proceedings-American Institute of Physics*, *1413*(1) 323.

Rosengrant, D., Thomson, C., & Mzoughi, T. (2009). Comparing experts and novices in solving electrical circuit problems with the help of eye-tracking. *AIP Conference Proceedings, 1179*(1) 249-252.

Rouinfar, A. (2014). *Influence of Visual Cueing and Outcome Feedback on Physics Problem Solving and Visual Attention* (Doctoral dissertation). Kansas State University.

Rouinfar, A., Agra, E., Larson, A., Loschky, L., & Rebello, N. (2014). Can visual cues and correctness feedback influence students' reasoning? Paper presented at the *Physics Education Research Conference,* Minneapolis, MN.

Rouinfar, A., Agra, E., Larson, A. M., Rebello, N. S., & Loschky, L. C. (2014). Linking attentional processes and conceptual problem solving: Visual cues facilitate the automaticity of extracting relevant information from diagrams. *Frontiers in Psychology, 5*, 1094.

Rumelhart, D. E., & Norman, D. A. (1976). *Accretion, tuning and restructuring: Three modes of learning* (No. 7602). California Univ San Diego La Jolla Center For Human Information Processing.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological review*, *84*(1), 1.

Scialfa, C. T., Jenkins, L., Hamaluk, E., & Skaloud, P. (2000). Aging and the development of automaticity in conjunction search. *Journals Of Gerontology Series B, 55*(1), p27-46.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological review*, *84*(2), 127.

Shinoda, H., Hayhoe, M. M., & Shrivastava, A. (2001). What controls attention in natural environments? *Vision Research, 41*(25), 3535-3545.

Simon, H. A., & Newell, A. (1971). Human problem solving: The state of the theory in 1970. *American Psychologist, 26*(2), 145-159.

Singh, C. (2002). When physical intuition fails. *American Journal of Physics*, *70*(11), 1103-1109.

Smith, A. D., Mestre, J. P., & Ross, B. H. (2010). Eye-gaze patterns as students study worked-out examples in mechanics. *Physical Review Special Topics-Physics Education Research*, *6*(2), 020118.

Sporer, S. L., Penrod, S., Read, D., & Cutler, B. (1995). Choosing, confidence, and accuracy: A meta-analysis of the confidence-accuracy relation in eyewitness identification studies. *Psychological Bulletin*, *118*(3), 315.

Susac, A., Bubic, A., Kaponja, J., Planinic, M., & Palmovic, M. (2014). Eye movements reveal students' strategies in simple equation solving. *International Journal of Science and Mathematics Education*, *12*(3), 555-577.

Tai, R. H., Loehr, J. F., & Brigham, F. J. (2006). An exploration of the use of eye-gaze tracking to study problem-solving on standardized science assessments. *International Journal of Research & Method in Education*, *29*(2), 185-208.

Theeuwes, J., Kramer, A. F., Hahn, S., & Irwin, D. E. (1998). Our eyes do not always go where we want them to go: Capture of the eyes by new objects. *Psychological Science, 9*(5), 379-385.

Theeuwes, J., & Godthelp, H. (1995). Self-explaining roads. *Safety Science, 19*(2–3), 217-225.

Thomas, L. E., Ambinder, M. S., Hsieh, B., Levinthal, B., Crowell, J. A., Irwin, D. E., …, Wang, R. F. (2006). Fruitful visual search: Inhibition of return in a virtual foraging task. *Psychonomic Bulletin & Review, 13*(5), 891-895.

Thomas, L. E., & Lleras, A. (2007). Moving eyes and moving thought: On the spatial compatibility between eye movements and cognition. *Psychonomic Bulletin & Review, 14*(4), 663-668.

Thomas, L. E., & Lleras, A. (2009). Covert shifts of attention function as an implicit aid to insight. *Cognition*, *111*(2), 168-174.

Thorndike, E. L. (1911). *Animal intelligence: Experimental studies*. Macmillan.

Van Gog, T., Jarodzka, H., Scheiter, K., Gerjets, P., & Paas, F. (2009). Attention guidance during example study via the model's eye movements. *Computers in Human Behavior, 25*(3), 785-791.

Zhao, M., Gersch, T. M., Schnitzer, B. S., Dosher, B. A., & Kowler, E. (2012). Eye movements and attention: The role of pre-saccadic shifts of attention in perception, memory and the control of saccades. *Vision Research, 74*, 40-60.

Appendix A - Informed Consent Form

Figure A.1 Informed consent form used in both the main and delayed transfer experiments.

KANSAS STATE UNIVERSITY

INFORMED CONSENT FORM

PROJECT TITLE: Research on the Use of Visual Cueing and Feedback to Facilitate Problem Solving

APPROVAL DATE OF PROJECT: 8/9/2013 **EXPIRATION DATE OF PROJECT:** 8/9/2015

PRINCIPAL INVESTIGATOR: CO-INVESTIGATOR(S): Principal Investigator: Dr. N. Sanjay Rebello Co-Investigators: Dr. Lester C. Loschky (Associate Professor, Psychological Sciences) Dr. Andrew G. Bennett (Professor & Head, Mathematics), Jennifer Johnson (GRA, Mathematics), Elise Agra, Tianlong Zu, Bahar Modir (GRA, Physics), Mitchell Burkett (URA, Physics), Xian Wu (GRA, Physics), Jeffrey Murray (URA, Physics), Drew Johnson (URA, Physics)

CONTACT AND PHONE FOR ANY PROBLEMS/QUESTIONS: 116 Cardwell Hall, KSU Physics Dept Phone: 785-532-1539

IRB CHAIR CONTACT/PHONE INFORMATION:

- Rick Scheidt, Chair, Committee on Research Involving Human Subjects, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224.
- Jerry Jaax, Associate Vice Provost for Research Compliance and University Veterinarian, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224.

SPONSOR OF PROJECT: National Science Foundation

PURPOSE OF THE RESEARCH: To examine the relationship between visual cues in a physics and mathematics problem and students' cognition regarding the problem.

PROCEDURES OR METHODS TO BE USED: You will participate in any one of the following studies:

1) Individual Clinical Interviews: During this part of the study you will be asked to explain their reasoning as they solve a physics or algebra problem.
2) Eye Tracking: This experiment will use an eye tracker to record your eye movements. Certain features may disqualify you from participation in the study. If you wear glasses or hard contact lenses, then the eye tracker will not be able to record eye movements reliably. Please notify the experimenter, since this may disqualify you from participating in the study. In this study, a series of physics problems containing images will be presented. For each problem you will be asked to solve the problem and explain your reasoning. After the completion of the experiment, you will have an opportunity to ask any question that you have regarding the experiment, and we will answer the question to the best of our ability
3) You may be asked if you are willing to provide consent to allow the researcher to access your exam scores from the most recent previous physics or mathematics course, if any that you have completed at Kansas State University. As with other data, these scores will be kept completely confidential.

ALTERNATIVE PROCEDURES OR TREATMENTS, IF ANY, THAT MIGHT BE ADVANTAGEOUS TO SUBJECT:

Participants have the option to read an article discussing relevant research being conducted in the fields of Physics or Mathematics and write a one-page summary about it and how it influences our everyday lives

LENGTH OF STUDY: 60 minutes

RISKS ANTICIPATED: No known risks are anticipated

BENEFITS ANTICIPATED: Participant will become aware of how they need to pay attention to certain aspects of a problem that might improve their ability to solve certain kinds of physics or algebra problems.

EXTENT OF CONFIDENTIALITY: All participants will remain anonymous. Each participant will be given a "participant number" and will only be identifiable in terms of this number

IS COMPENSATION OR MEDICAL TREATMENT AVAILABLE IF INJURY OCCURS: Not applicable. No known risks

PARENTAL APPROVAL FOR MINORS: Only subjects 18 or older are included in the study.

TERMS OF PARTICIPATION: I understand this project is research, and that my participation is completely voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled.

I verify that my signature below indicates that I have read and understand this consent form, and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

(Remember that it is a requirement for the P.I. to maintain a signed and dated copy of the same consent form signed and kept by the participant

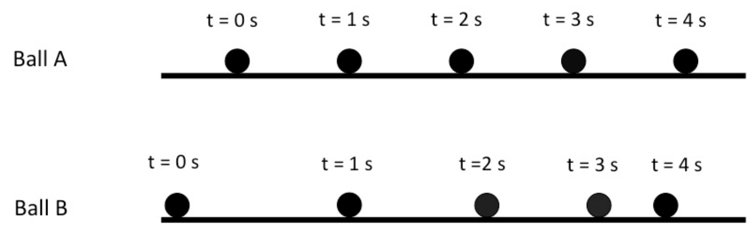
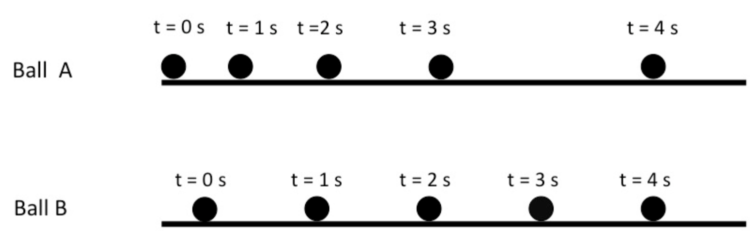
Participant Name: ______________________

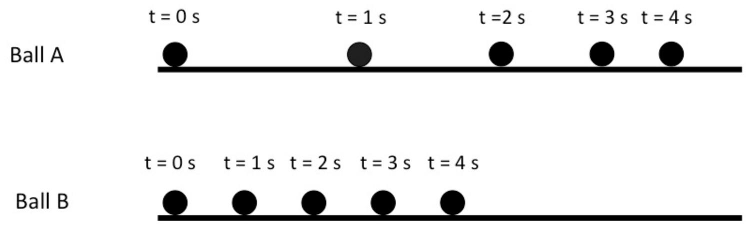
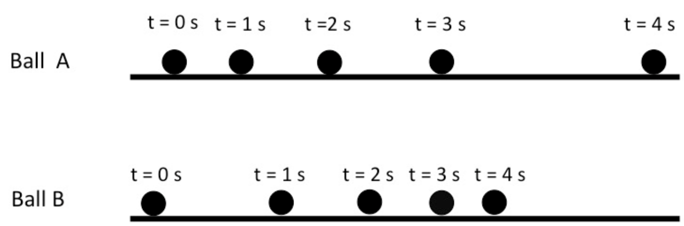
Participant Signature: ______________________ **Date:** ____________

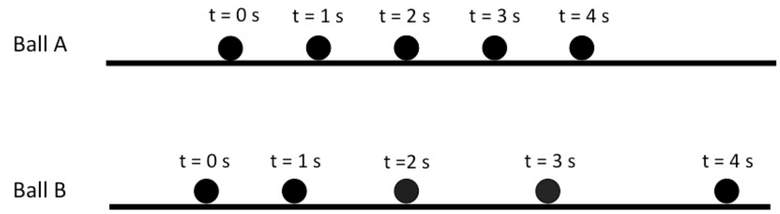
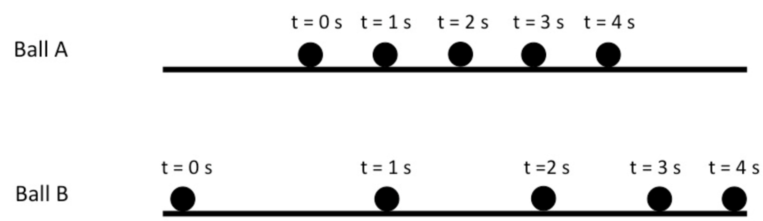
Witness to Signature: (project staff) ______________________ **Date:** ____________

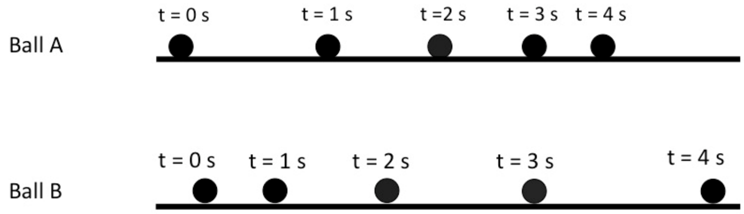
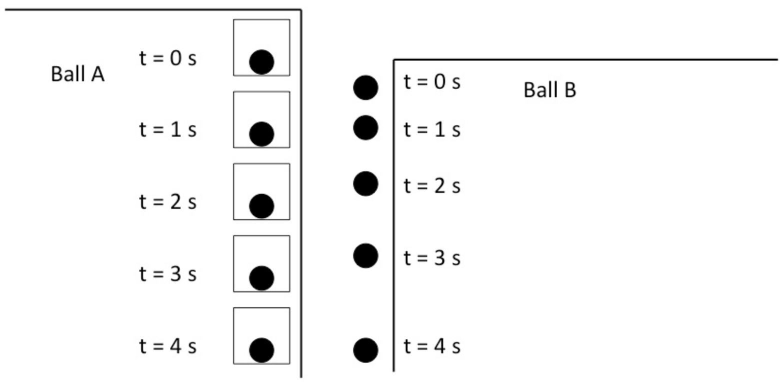
Appendix B - Problems Investigated

Figure B.1 Ball problem set presented in the study.

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

<table>
<tr>
<td rowspan="2">Training Problems</td>
<td>Two balls roll along the paths shown. A snapshot of the position of the balls is taken every second. At what point in time does Ball B have the same speed as Ball A?
</td>
</tr>
<tr>
<td>Two balls roll along the paths shown. A snapshot of the position of the balls is taken every second. At what point in time does Ball B have the same speed as Ball A?
</td>
</tr>
</table>

<table>
<tr>
<td rowspan="2">Training Problems</td>
<td>Two balls roll along the paths shown. A snapshot of the position of the balls is taken every second. At what point in time does Ball B have the same speed as Ball A?

</td>
</tr>
<tr>
<td>Two balls roll along the paths shown. A snapshot of the position of the balls is taken every second. At what point in time does Ball B have the same speed as Ball A?

</td>
</tr>
</table>

Training Problems	Two balls roll along the paths shown. A snapshot of the position of the balls is taken every second. At what point in time does Ball B have the same speed as Ball A? 
Near Transfer Problem	Ball A begins riding downward in an elevator at the same time Ball B is dropped from the roof of an adjacent building. A snapshot of the balls is taken every second. At what point in time does Ball B have the same speed as Ball A? 

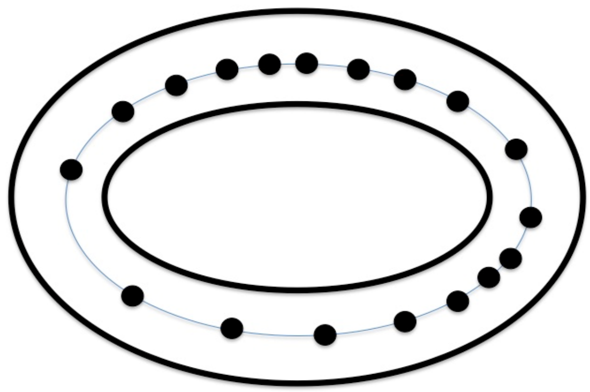
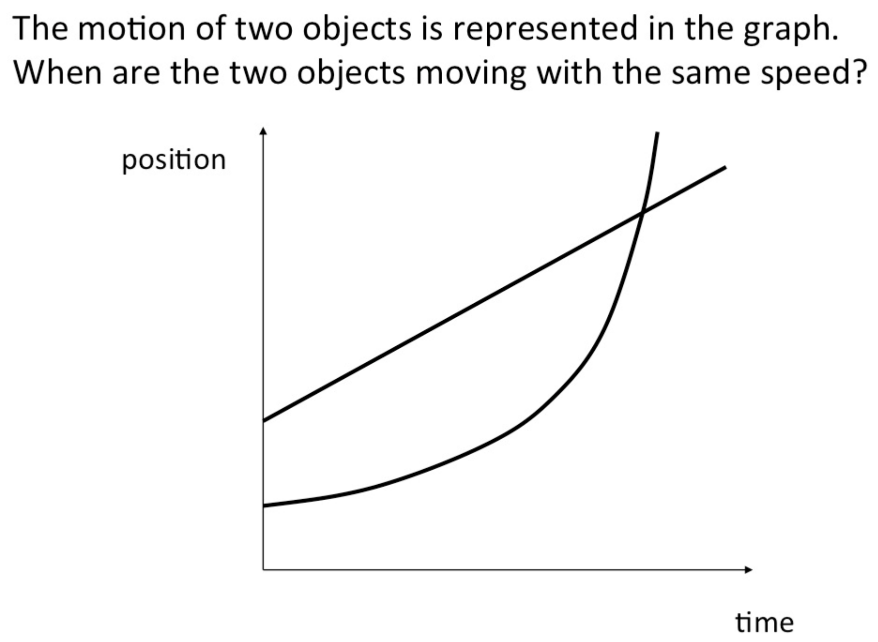
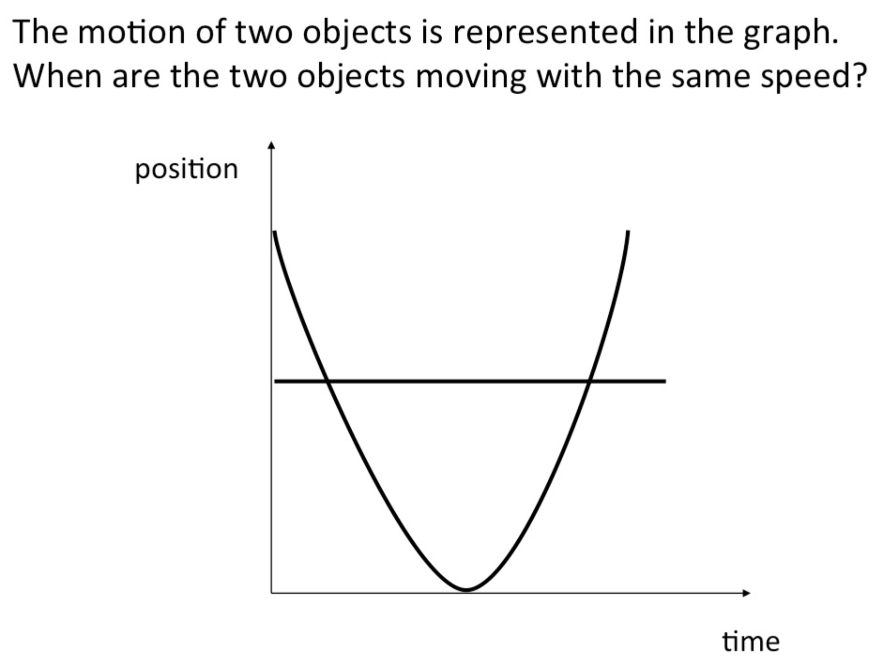
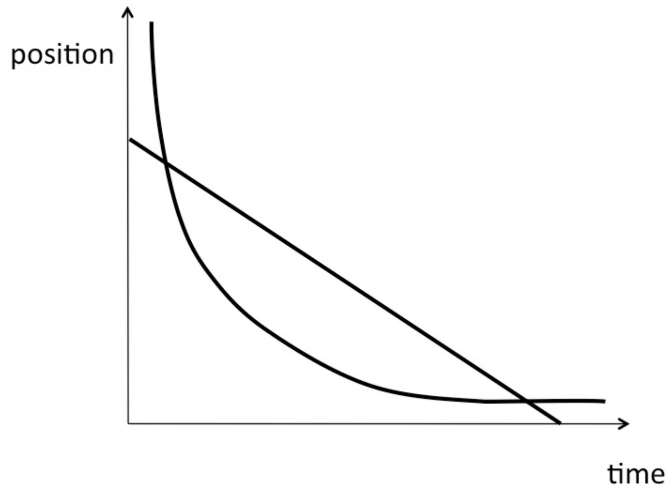
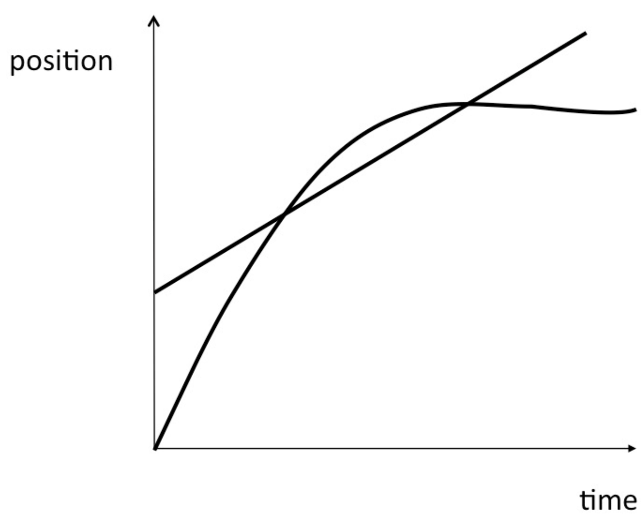
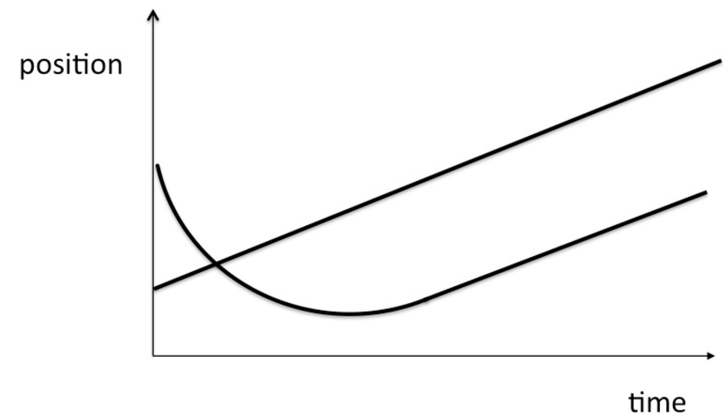
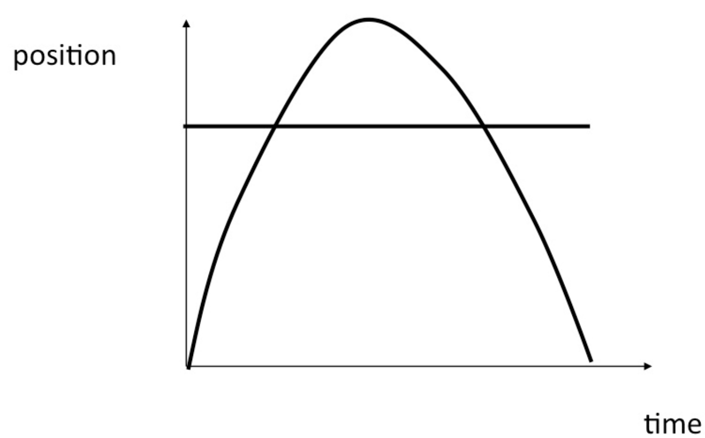
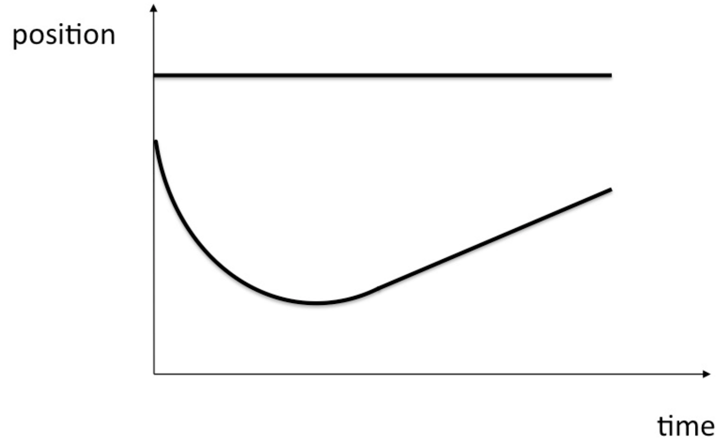
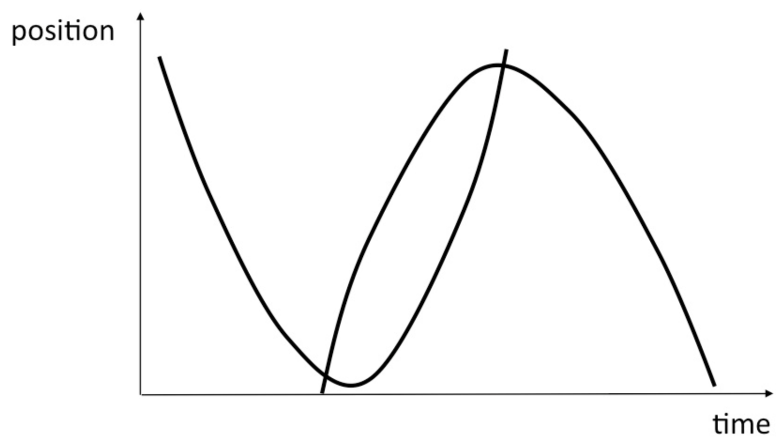
Far Transfer Problem	A runner runs along a track. The following diagram, viewed from above, shows the position of the runner at each second. At which point in time is the runner moving the fastest? 

Figure B.2 Graph problem set presented in the study.

Initial Problem	
Training Problems	

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

<table>
<tr>
<td rowspan="2">Training Problems</td>
<td>The motion of two objects is represented in the graph.
When are the two objects moving with the same speed?
</td>
</tr>
<tr>
<td>The motion of two objects is represented in the graph.
When are the two objects moving with the same speed?
</td>
</tr>
</table>

<table>
<tr>
<td>Training Problems</td>
<td>The motion of two objects is represented in the graph.
When are the two objects moving with the same speed?

</td>
</tr>
<tr>
<td>Near Transfer Problem</td>
<td>The motion of two objects is represented in the graph.
When are the two objects moving with the same speed?

</td>
</tr>
</table>

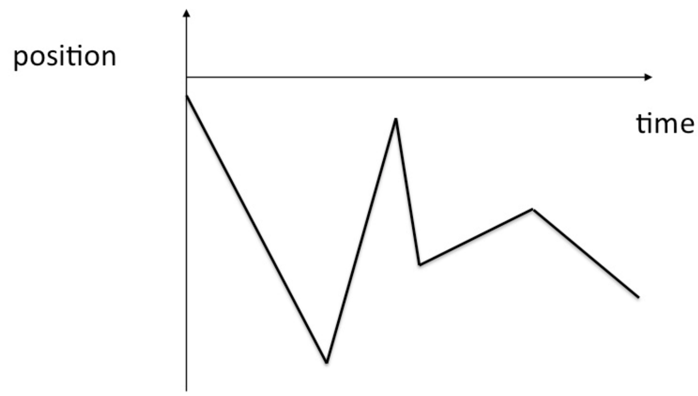
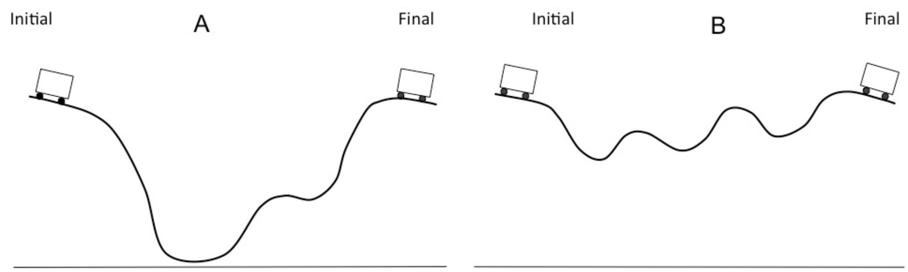
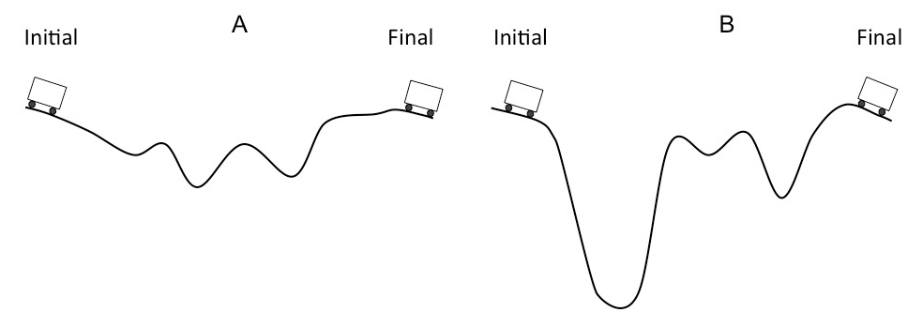
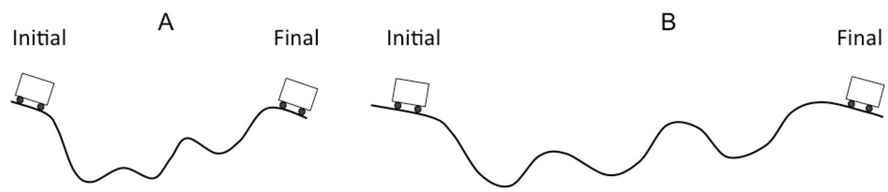
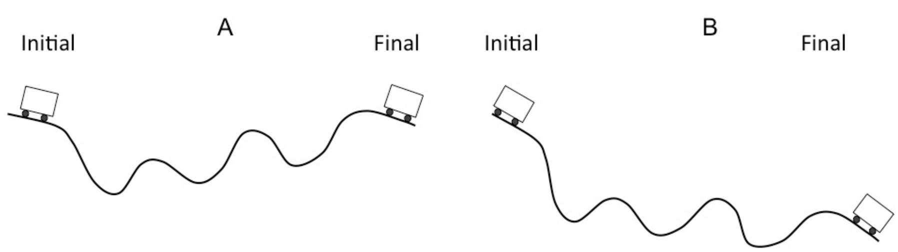
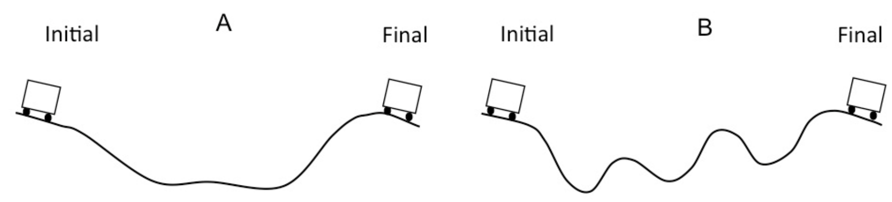
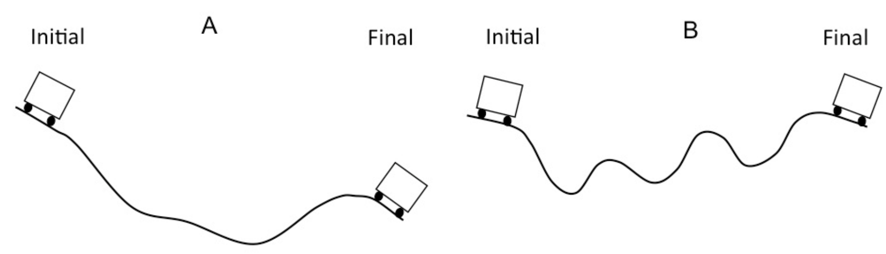
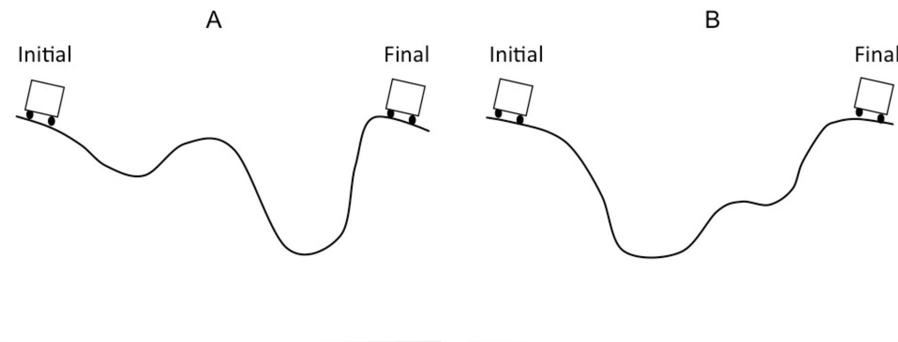
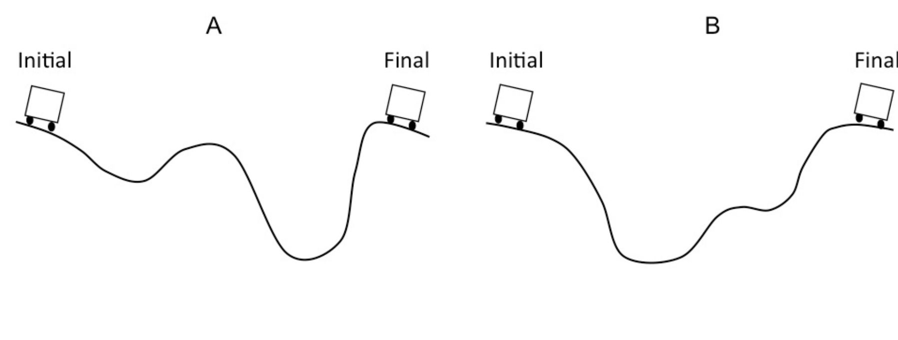
Far Transfer Problem	The motion of an object is represented by the graph. When is the object moving the fastest? 

Figure B.3 Roller Coaster problem set presented in the study.

Initial Problem	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) 
Training Problems	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) 

<table>
<tr><td rowspan="2">Training Problems</td><td>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)

</td></tr>
<tr><td>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)

</td></tr>
</table>

Training Problems	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) 
	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) 

<table>
<tr>
<td>Training Problems</td>
<td>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)

</td>
</tr>
<tr>
<td>Near Transfer Problem</td>
<td>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)

</td>
</tr>
</table>

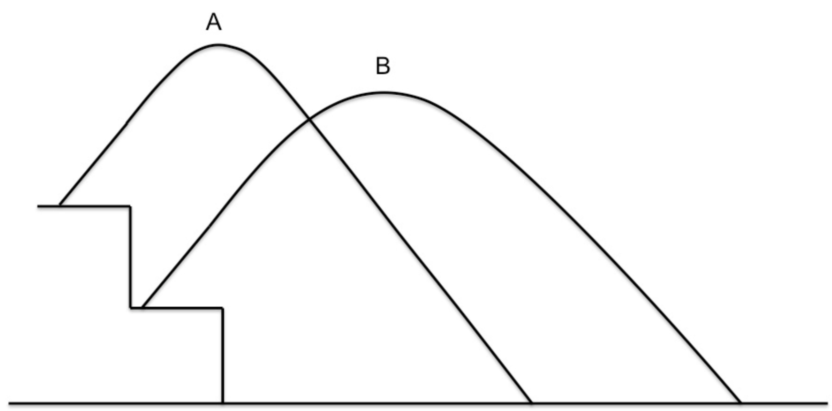
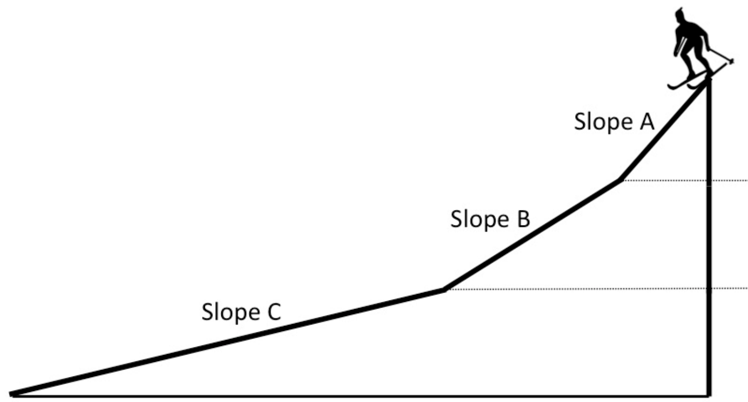
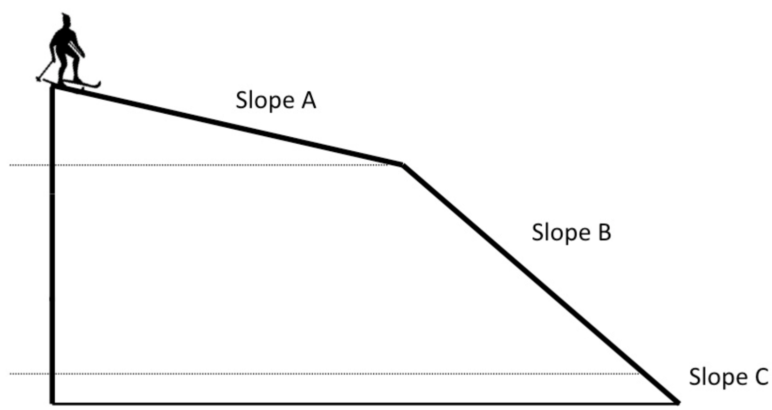
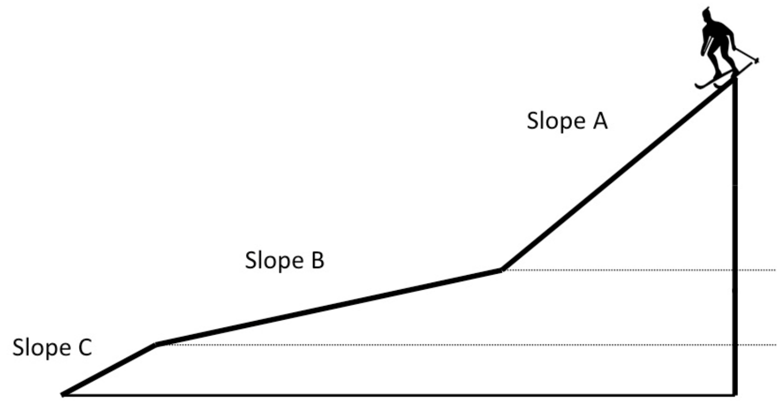
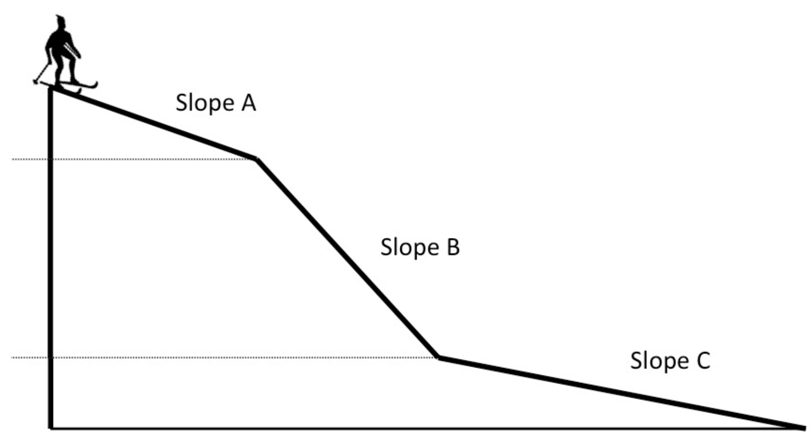
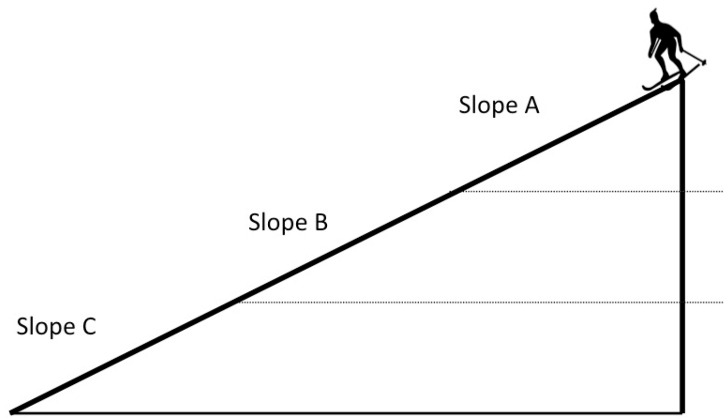
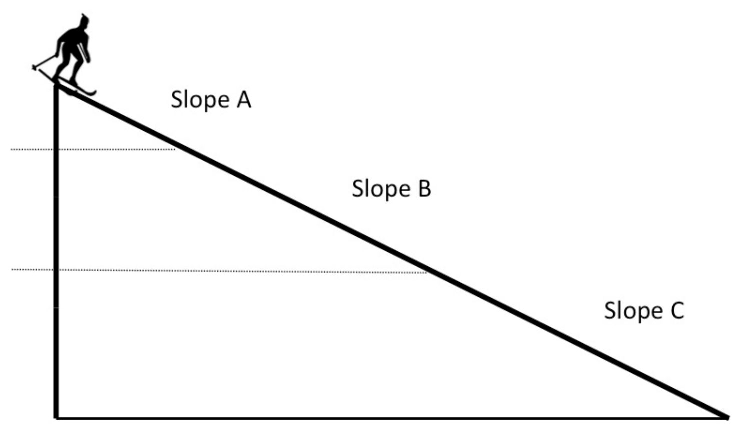
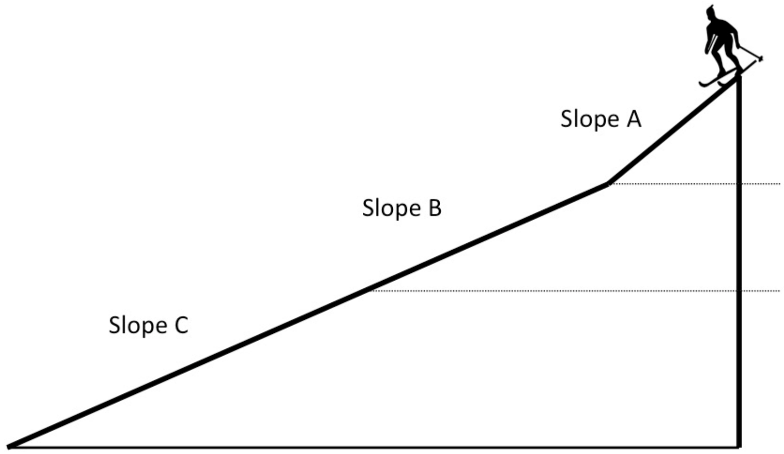
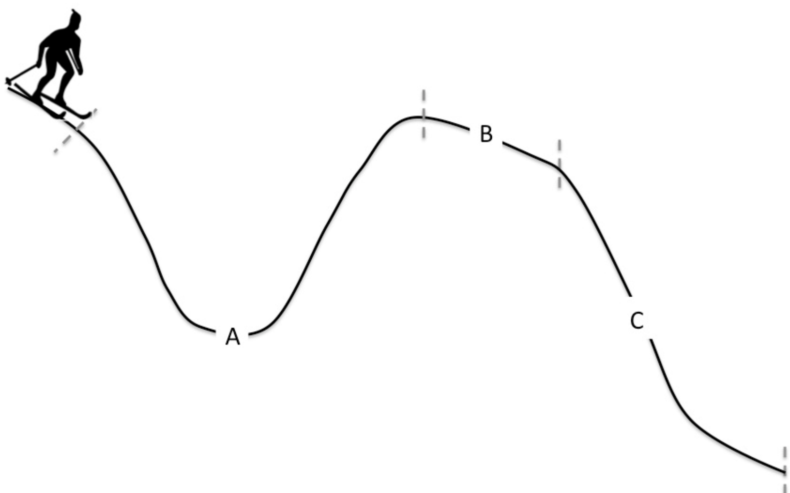
Far Transfer Problem	Two identical stones, A and B, are shot from a cliff with identical initial speeds. How do the speeds of the stones compare the instant before they hit the ground? 

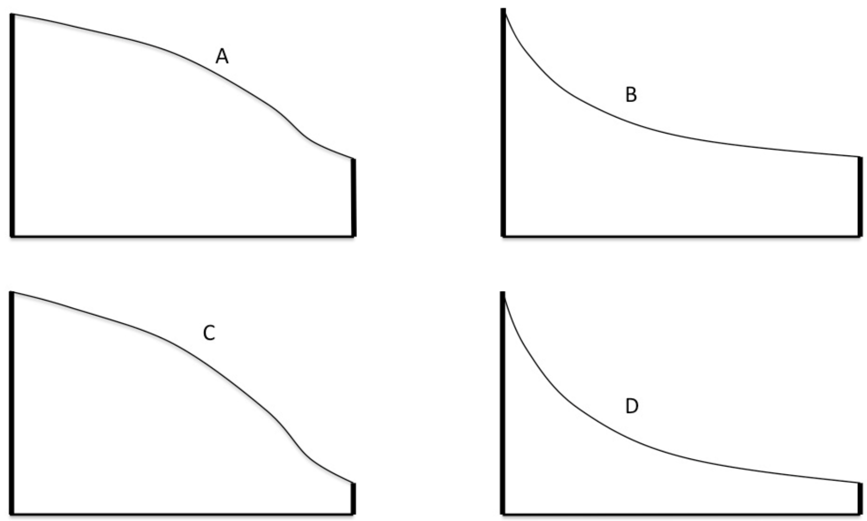
Figure B.4 Skier problem set presented in the study.

Initial Problem	Rank the potential energy lost during the skier's descent down each slope from greatest to least. (That is, rank the potential energy lost 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.) 
Training Problems	Rank the potential energy lost during the skier's descent down each slope from greatest to least. (That is, rank the potential energy lost 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.) 

Training Problems	Rank the potential energy <u>lost</u> during the skier's descent down each slope from greatest to least. (That is, rank the potential energy <u>lost</u> 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.) 
	Rank the potential energy <u>lost</u> during the skier's descent down each slope from greatest to least. (That is, rank the potential energy <u>lost</u> 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.) 

Training Problems	Rank the potential energy <u>lost</u> during the skier's descent down each slope from greatest to least. (That is, rank the potential energy <u>lost</u> 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.) 
	Rank the potential energy <u>lost</u> during the skier's descent down each slope from greatest to least. (That is, rank the potential energy <u>lost</u> 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.) 

Training Problems	Rank the potential energy <u>lost</u> during the skier's descent down each slope from greatest to least. (That is, rank the potential energy <u>lost</u> 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.) 
Near Transfer Problem	A skier moves down a track. Rank the potential energy <u>lost</u> by the skier in each section of the track from greatest to least. The dotted lines indicate the beginning and ending of each section of the track. (Rank the potential energy <u>lost</u>, not the total value of the potential energy.) 

<table>
<tr>
<td>Far Transfer Problem</td>
<td>A young girl slid down four frictionless playground slides as shown below. Compare the potential energy lost by the girl in each slide.

</td>
</tr>
</table>

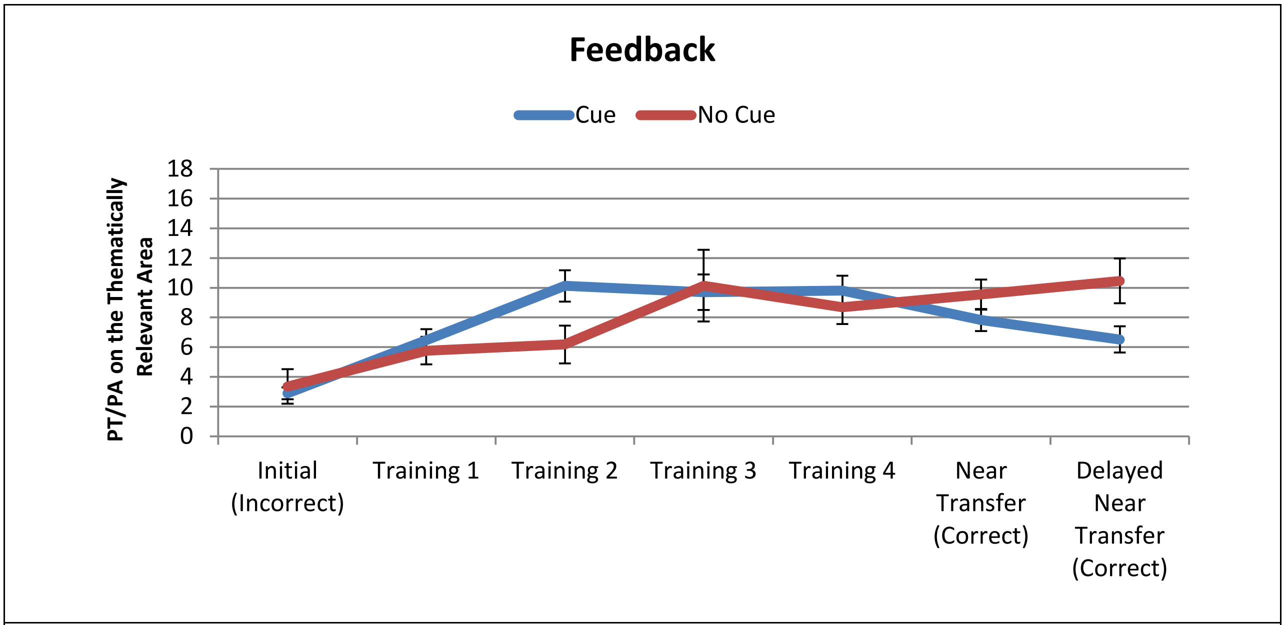
Appendix C - Results of the Mixed Factorial ANOVA on the Visual Attention of Participants who Demonstrated Immediate Learning and Retention on the Near Transfer Problems

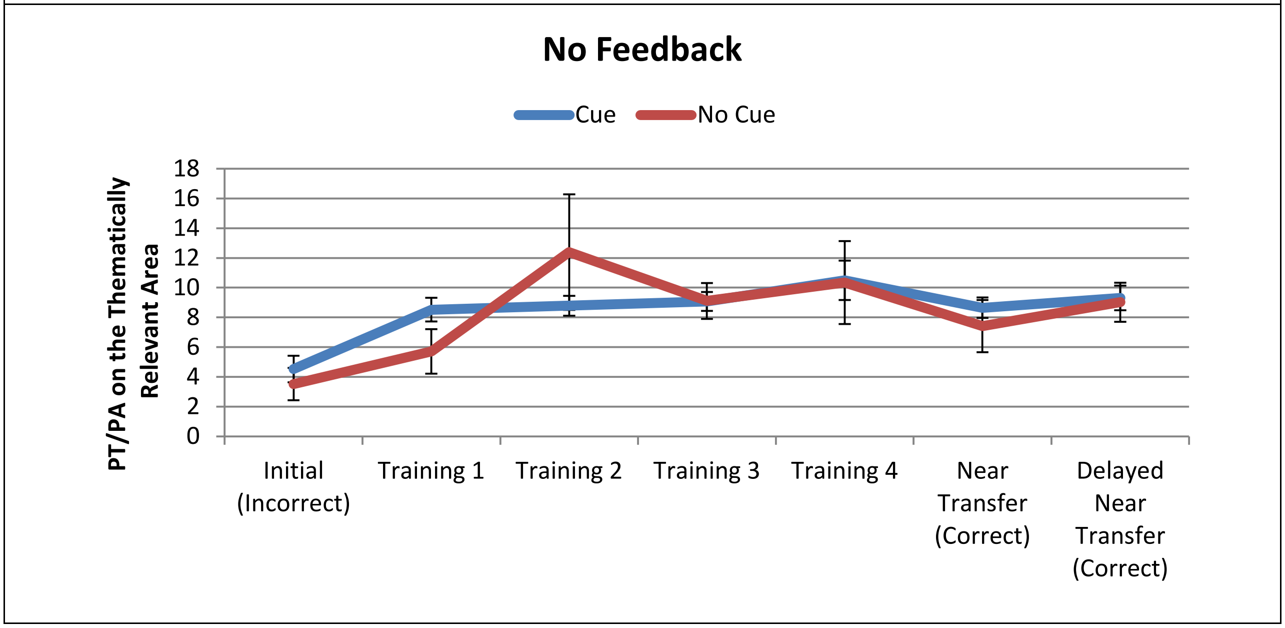
Table C.1 Results of the mixed factorial ANOVA comparing the effects of cue and feedback on participants' visual attention on the thematically relevant area of diagram on the initial, training, near transfer, and delayed near transfer problems for the subset of participants who solved the initial problem incorrectly and then solved both the near transfer and delayed near transfer problems correctly. The Greenhouse-Geisser correction was applied to the degrees of freedom because Mauchly's assumption of sphericity was violated. The significance level is α = .05.

Effect	ANOVA Result	p	η_p^2
Cue	$F(1, 57)=0.01$	.916	.000
Feedback	$F(1, 57)=0.89$	.349	.015
Problem	$F(4.9, 281.0)=14.98$	<.001	.208
Cue*Feedback	$F(1, 57)=0.07$	.790	.001
Cue*Problem	$F(4.9, 281.0)=0.88$	.494	.015
Feedback*Problem	$F(4.9, 281.0)=0.94$	.454	.016
Cue*Feedback*Problem	$F(4.9, 281.0)=2.83$	.017	.047

Appendix D - Probing the Cue*Feedback*Problem Interaction for Participants who Demonstrated Immediate Learning and Retention on the Near Transfer Problems

Figure D.1 Comparison between the Cue and No Cue conditions with respect to the visual attention on the thematically relevant area of the diagram on the initial, training, and far transfer problems for the Feedback (top) and No Feedback (bottom) conditions for the subset of participants who incorrectly solved the initial problem and then correctly solved the far transfer problem. Error bars denote ±1 standard error of the mean.





Appendix E - Results of the Mixed Factorial ANOVA on the Visual Attention of Participants who Demonstrated Immediate Learning and Retention on the Far Transfer Problems

Table E.1 Results of the mixed factorial ANOVA comparing the effects of cue and feedback on participants' visual attention on the thematically relevant area of diagram on the initial, training, far transfer, and delayed far transfer problems for the subset of participants who solved the initial problem incorrectly and then solved both the near transfer and delayed far transfer problems correctly. The Greenhouse-Geisser correction was applied to the degrees of freedom because Mauchly's assumption of sphericity was violated. The significance level is α = .05.

Effect	ANOVA Result	p	η_p^2
Cue	$F(1, 72)=4.98$	.029	.065
Feedback	$F(1, 72)=0.53$	.470	.007
Problem	$F(3.5, 252.4)=22.77$	<.001	.240
Cue*Feedback	$F(1, 72)=0.89$	.349	.012
Cue*Problem	$F(3.5, 252.4)=1.55$	.194	.021
Feedback*Problem	$F(3.5, 252.4)=0.85$	.484	.012
Cue*Feedback*Problem	$F(3.5, 252.4)=1.35$	.255	.018