Visual Cueing in Physics Problem Solving
Advisory Board Meeting
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ONGOING STUDIES

Introduction & Significance

Extensive research has been done in the domain of physics to understand how students answer simple conceptual questions about how the world works. [Trowbridge and McDermott 1980; McDermott et. al 1987] Interestingly, a consistent pattern of wrong answers to many of these questions has been found. Several cognitive top-down explanations have been provided, including misconceptions formed through interactions with the natural world or misapplication of conceptual resources [Docktor and Mestre 2011]. However, recent claims by Heckler [2011] have suggested a perceptual basis for students' incorrect answers, which are based on attention being directed to the most perceptually salient and plausibly relevant features in a problem. The most salient features capture attention through perceptual processes and less salient features have little opportunity to be considered. Heckler provides some evidence for perceptually-driven responses; however, the necessary eye movement data needed to observe these perceptual processes is not provided. Therefore, incorrect answers may be governed either by top-down processes relying on incorrectly learned or applied information, or by bottom-up perceptual processes resulting in certain elements capturing attention and leading to activation of reasoning resources based on these elements. If it is true that perceptual processes are primarily responsible for the consistent and wide spread pattern of incorrect answers on common physics questions, the instructional implications are immense. Simply redesigning problem diagrams and visualizations could alleviate many problems that were previously thought to be purely cognitive and difficult to change.

Background

This research builds on a previous study where eye movements of introductory and advanced physics students were measured while viewing physics problems with a diagram [Madsen et al., 2011]. Three areas of interest (AOIs) were defined for each diagram. First, thematically-relevant AOIs that contained information necessary to correctly answer the question were determined by experts in physics. Second, novice-like AOIs were defined based on coded interview data from novices [Madsen et al. 2011], and third, perceptually salient AOIs were defined as the area(s) on the diagram with the highest saliency rating according to the salience maps produced by a computational algorithm [Itti 2000]. For each problem, the percentage of time spent in each type of interest area was compared between students who answered the problem correctly and those who answered the problem incorrectly.

If top-down cognitive processes utilizing naïve theories or misapplied information were directing attention in physics problems, then those who answer the problems incorrectly should spend more time looking at the novice-like AOIs than those who answer correctly. If perceptual salience captures attention and leads students to an incorrect answer, then more time should be spent looking at perceptually salient AOIs. We found that in five of six problems, those who answered incorrectly spent significantly more time looking at the novice-like AOI than those who answered correctly. No differences were found between correct and incorrect solvers in the perceptually salient AOIs. However, it is important to note that Carmi and Itti [2006] studied the effects of perceptual saliency as a function of viewing time. They found that their model of perceptual salience performed best on the first six to seven fixations when viewing a scene. For the average viewer, this is equivalent to about the first two seconds of viewing. In light of this finding, we also compared the amount of time spent in the perceptually salient AOI during the first two seconds of viewing the diagram for those who answered correctly versus incorrectly. No significant differences were found between those who answered correctly versus incorrectly, although the data were in the predicted direction (i.e., the raw percentage of time spent in the perceptually salient AOI was higher for those who answered incorrectly on five of the six problems analyzed). Thus, it may be either that the small number of fixations observed in the first two seconds of diagram viewing lacked the statistical power to find an effect, or there may simply be no effect between those who answer correctly versus incorrectly on the viewing time of perceptually salient elements of the diagram. One major limitation of this study was that on several of the problems, the novice-like AOI overlapped the perceptually salient AOI. In this case, we can make no conclusion about the type of process, top-down or bottom-up, that lead an individual to attend to this area.

Motivation

The proposed experiment will build on this previous work and offers an improved design that will offer more conclusive evidence about the role of perceptual salience in physics problem solving. Specifically, we explore two possible hypotheses based on the role of perceptual salience.

One hypothesis is that initially, salient elements in the problem diagram capture learner's attention via bottom-up perceptual processes. If these salient areas are relevant to the problem solution and plausible, students activate certain reasoning resources based on these elements. For instance, if the novice-like area is the most perceptually salient, participant's will activate resources consistent with a novice-like conception and answer incorrectly. Conversely, if the salient areas are aligned with expert-like areas, the participant will activate scientifically correct resources and will answer correctly. When the novice-like and expert-like areas are equally salient, participants will answer either correctly or incorrectly in equal proportions. In all of these cases, the underlying process is bottom-up and salience driven. Consequently, students' answer patterns will be influenced by which area of the problem – novice-like or expert-like – is more salient.

An alternative hypothesis is that bottom-up processes driven by perceptual salience play a major role in guiding attention only for the first two seconds of viewing a problem. After this initial viewing, top-down processes are become more dominant and can disengage the learner's attention from the perceptually salient area(s) to other areas of the problem consistent with the learner's top-down conceptions. Ultimately, the perceptual salience of novice-like and expert-like areas will not influence the participants answer choices. Rather, it is the knowledge that learners already possess (correct or incorrect) that influences their answer choices. Consequently, students' answer patterns are not influenced by whether the novice- or expert-like are is more salient.

Thus, each of these two hypotheses above can lead to very different patterns of students' responses for physics problems where the novice-like or expert-like areas are either differently or equally salient. The motivation of this study is to test these completing hypotheses.

Research Questions

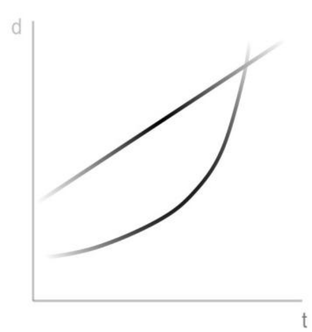
Our research questions are aimed at testing the competing hypotheses above. Specifically we ask: *How does the perceptual salience of elements in a physics problem diagram influence*:

1) *the eye movements of students in algebra-based physics?*
2) *the answering patterns of these students?*

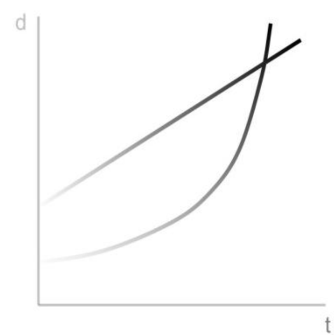
Experimental Design and Methods

We are currently conducting individual sessions with 60 students in second-semester algebra-based physics. We have access to students' test scores in their first semester algebra-based physics course. We will use these scores as an independent variable in in our analysis (explained below) to address the second research question. Eye movements are recorded on a set of 15 physics problems with diagrams that are known to have areas consistent with documented novice-like answers as well as areas consistent with the scientifically correct answer (expert-like area).

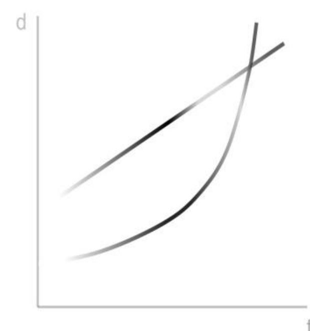
The luminance contrast of the problems diagrams is manipulated to alter the perceptual salience of elements in the problem and produce three versions of each. In one version, the novice-like area is the most perceptually salient, in another the expert-like area is the most perceptually salient and in a final version the novice-like and the expert-like areas will have approximately the same degree of perceptual salience. An example of the three versions of a problem are shown below



Problem version with expert-like area more salient than novice-like area.



Problem version with novice-like area more salient than expert-like area.



Problem version with novice-like and expert-like areas equally salient.

To measure the perceptual salience of elements in a diagram, we use the Saliency Toolbox [Wather & Koch, 2006]. This algorithm determines the relative perceptual salience of different elements in the diagram based on contrasts in color, orientations and luminance and outputs a numerical value representing the degree of perceptual salience. The algorithm then employs a "winner takes all" model and determines the order in which features in the diagram will be attended to based on their perceptual salience. To assure the appropriate area(s) in each diagram are indeed the most perceptually salient, we manipulate the luminance contrast until the desired areas were the first to be attended to, as predicted by the algorithm. Additionally, we need to make sure that the peak salience value of the desired area(s) are much greater than the peak salience values of the undesired areas. To do this we calculate a percent difference for the first three salience values and ensure between the desired areas are within 25% of each other.

Subjects view each problem on a computer screen while their eye movements are being recorded and will indicate their answers by annotating a paper copy of the problem. The problem statement and diagram appear on different computer screens, which the subject can toggle between. This prevents the perceptual salience of the text from interfering with the viewing of the diagram. After viewing a problem statement and diagram on the computer, participants indicate their answers to the problems on a paper copy of the diagram. At the end of the session, they are given a short, open-ended survey on the definitions of basic terms used in the problems. The result of this survey is used to determine if any participant lacks necessary background knowledge to answer any of the questions.

Analysis

To answer our first research question, we will look for correlation between the location of the first fixation and the salience condition to determine if the perceptual salience of the diagram elements influenced the learner's attention at the onset of viewing. Additionally, we will compare the percentage of time spent fixating in the expert-like area of interest (AOI) and the novice-like AOI for the three salience conditions. We will do this for the full duration of the diagram viewing as well as for the first 2 seconds of viewing. This comparison will allow us to determine how the salience condition influenced the participant's attention during the first 2 seconds of viewing as well as over the whole viewing period.

To answer our second research question about how the salience of the problem elements influences answering patterns, we will use a 3 x 2 ANOVA with salience condition and previous semester physics test scores as the independent variables and correctness of answer to study problems as the dependent variable. If we find a main effect of salience condition, we will have some evidence to support hypothesis 1. If we find a main effect of previous semester test score, we will have some evidence to support hypothesis 2. If we find an interaction between salience condition and previous semester test score, we would have some evidence to support the idea that those with different levels of prior knowledge interact with perceptually salient elements in a problem diagram differently.

We will also use a scan path analysis to gain insight on the spatio-temporal aspect of the eye movements. We will use an algorithm called ScanMatch [Cristino et al. 2010], which bins a saccade sequence both spatially and temporally and then recodes this information to create a sequence of letters, which represents the location, duration, and order of the fixations. The letter sequences of two sets of eye movements are then compared to each other to calculate a similarity score. A ScanMatch score near one represents two sequences of eye movements that are identical spatially and temporally. If perceptual salience has a strong influence on eye movements, there will be no statistically significant difference between mean ScanMatch score of all possible pairs of correct respondents with the mean ScanMatch score of all possible pairs of incorrect respondents. If top-down influences are more dominant, there will be statistically significant difference between the mean ScanMatch scores of the two groups. To make this comparison, we will use a 3 x 2 ANOVA with salience condition and previous semester physics test scores as the independent variables and ScanMatch score as the dependent variable.

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