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

PROJECT DESCRIPTION

Vision is a critically important medium of communication. We are continuously bombarded with images on television, cell phones, tablets, and other devices. Images of all kinds – graphs, pictures, animations, and others – are ubiquitous in education. While images can facilitate learning, they may also impede learning through increased cognitive load (Ayres & Paas, 2007). In order to design images that facilitate learning and problem solving, we must understand the factors that influence how learners use visual information to learn and to solve problems. Thus, the ***foundational questions*** addressed by this project are: *What are the malleable factors (i.e. factors that we can control) that affect learners' use of visual information while solving STEM problems? How can we alter these factors to positively influence students' problem solving in STEM? What moderating factors influence the outcome?*

SIGNIFICANCE

Problem solving is a major emphasis area of STEM education that has been studied extensively (review by Jonassen, 2011). Frequently, STEM problems – and their solutions – have strong visuospatial components. However, most research on STEM problem solving has not drawn from research in visual cognition. Recently, some researchers have begun to use eye movement data to gain deeper insights into how students read solved examples (Smith, Mestre & Ross, 2010) or to compare the differences between novices and experts on problem solving tasks (Feil & Mestre, 2007; Rosengrant, Thomson & Mzhoughi, 2009). This research indicates that much can be learned from further investigations into the role of visuospatial reasoning as students solve STEM problems.

Recent research (review by de Koning, et. al. 2009) has explored using visual cues to focus learners' attention on relevant areas of instructional imagery. Research on eye movements and cognition (e.g. Grant & Spivey, 2003; Thomas & Lleras, 2007; 2009; Madsen et. al., 2012) shows that using visual cues to influence attention can facilitate solving problems in which the visuospatial component is central to the problem. By having learners attend to the correct visual elements in a problem, they think about those elements and formulate the solution to the problem. These results illustrate embodied cognition in that bodily movements associated with attention affect higher order cognition associated with problem solving.

Many STEM problems fit this description, yet there has been little visual cueing research on STEM problem solving. The motivation for this project is to explore the malleable factors of visual cueing and feedback that affect learners' use of visual images while solving STEM problems with diagrams and how those malleable factors influence students' problem solving performance in math and science.

BRIEF REVIEW OF RELEVANT THEORY & EMPIRICAL STUDIES

Two theories are relevant here – representational change theory (RCT) of problem solving and the theory of multimedia learning (TML). Empirical work on visual cueing also offers a guide to our research.

Representational Change Theory (RCT)

RCT (Ohlsson, 1992) purports a cognitive mechanism of solving insight problems. Knoblich, Ohlsson and Raney (2001) demonstrated that RCT can explain learners' eye movements and problem solving performance. Sometimes a learner may construct an internal mental representation of a problem that prevents her from retrieving relevant concepts from long term memory, leading to an impasse (Ohlsson, 1992). This is also called the Einstellung effect – an initial idea blocking consideration of better ideas.

STEM problems often have features that trigger unproductive internal representations, causing an impasse. Some of these problems that are candidates for visual cueing have a diagram with two spatially distinct areas — a "thematically relevant" area, containing information needed to correctly solve the problem, and a "novice-like" area consistent with incorrect answers. Research by us (Madsen, et. al. 2012) and others (e.g. Bilalic et. al, 2008) has shown that incorrect solvers spend more time than correct solvers attending to novice-like areas of a problem diagram, consistent with the Einstellung effect.

Representational change theory (Ohlsson, 1992) purports three mechanisms to break an impasse (i) adding information to the problem to enrich the existing representation (i.e. *elaboration*); (ii) replacing the existing representation with a different, more productive representation (i.e. *re-encoding*); or (iii) removing unnecessary constraints often self-imposed by the problem solver (i.e. *constraint relaxation*). This project explores the use of visual cueing and feedback to harness two out of these three factors.

Theory of Multimedia Learning (TML)

Solving problems with text and diagrams involves coordinating information provided in these modalities with the learner's prior knowledge. TML (Mayer, 2001) identifies three distinct stages involved in learning from multimodal information. *Selection* is attending to relevant pieces of sensory information from each modality. *Organization* is using the selected information to create a coherent internal representation. *Integration* is combining internal representations with activated prior knowledge. All three stages of multimedia learning are influenced by the learner's prior knowledge.

Depending upon a learner's prior knowledge, two kinds of processes may dominate. *Top-down* processes dominate in expert learners with adequate domain knowledge enabling them to focus on the thematically relevant parts of an image critical for problem solving. Studies show that top-down processes dominate in determining where experts look while performing visual tasks in various fields such as art (Antes and Kristjanson, 1991), chess (Charness, 2001), and meteorology (Lowe, 1999). *Bottom-up* processes are faster and more primitive than top-down influences (Itti & Koch, 2000). They dominate in learners who lack prior knowledge to guide their attention and coordination. Such learners tend to focus on parts of the image that are perceptually salient rather than thematically relevant (Foulsham & Underwood, 2008; Lowe, 2003). Thus, by tracking learners' eyes, we can discover experts-novices differences (e.g., Tai, Loehr & Brigham, 2006; Fiel & Mestre, 2007; Rosengrant, Thomson & Mzhoughi, 2009).

Role of Eye Movements and Visual Cueing to Facilitate Problem Solving

Eye movement data can provide insights into learning with text (Rayner, 1998) and graphics (Mayer, 2010). A learner's eye movements may depend upon their prior knowledge (*knowledge effect*), audio narration (*modality effect*), and visual cues (*signaling/cueing effect*). The latter can facilitate the top-down processes that are key to improving STEM problem solving. Based on Mayer's (2001) theory of multimedia learning, de Koning et. al. (2009) proposed a framework for cueing to facilitate all three processes involved in multimedia learning – *selection*, *organization,* and *integration.*

Cueing Selection: Selection occurs because the brain can only process some of the information received by our retina. Thus, various parts of the visual information compete for our attention (Desimone & Duncan, 1995). Attentional processes are limited in space and time and learners are only aware of that part of the retinal information that has been attended to and entered into short-term memory (Triesman & Gelade, 1980; Irwin & Gordon, 1998; Simons & Chabris, 1999).

Visuospatial or temporal contrasts i.e., motion, unusual colors, luminance, and shape contrasts are most effective in attracting the learners' attention to thematically relevant information (Schnotz & Lowe, 2008). For instance, spotlight cues produced by reducing the luminance of all but relevant parts (de Koning et. al. 2007; 2010) or spreading color cues (Boucheix & Lowe, 2010) improve learning. Similarly, Grant and Spivey (2003) found that movement of a critical part of a diagram increased fixation times around that part and improved performance on Duncker's (1945) tumor problem. They proposed an implicit eye-movement-to-cognition link suggesting that eye movements can influence spatial reasoning. Follow-up research by (Thomas & Lleras, 2007) showed that learners whose eye movements embodied the solution were more likely to solve the problem. These studies converge on the consensus that cueing attention through luminance contrast, color, and motion can facilitate learners' attention to the thematically relevant parts of the problems, improving their problem solving performance.

Cueing Organization: Cues that assist the learner in recognizing associations and trends or constructing a mental representation facilitate organization. Text can be organized through outlines and headings (e.g. Lorch & Lorch, 1995, 1996). Graphics can be organized by exploded views of an object showing spatial relations (Tversky, et. al., 2002), highlighting parts of a graph representing trends (Shah, et. al., 1999), structural graphical organizers (Mautone & Mayer, 2007), or simply removal of extraneous information (Canham & Hegarty, 2010). Using static graphics to represent a dynamic event is particularly challenging (Hegarty, 1992). In such cases, numbers, lines, or arrows (Tversky, et. al., 2008) or spreading color cues (Boucheix & Lowe, 2010) representing temporally spaced events can serve as organization cues.

Cueing Integration: Cueing that helps learners relate 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) can make causal or functional relations explicit and facilitate creation of a situation model (Johnson-Laird, 1983). The small amount of research on using integration cues has not consistently shown promise on transfer tasks (e.g. Jamet, et. al., 2008). Clearly, more studies are needed to better understand this area.

In summary, cueing selection has been studied in-depth; but cueing organization or integration has been inadequately studied. Further, no clear cue categorization framework exists. For instance, spreading color cues (Boucheix & Lowe, 2010) or sequential motion cues (Thomas & Lleras; 2007; 2009) can cue either selection or organization. We need to expand on de Koning et al.'s (2009) tripartite taxonomy of cues' cognitive functions, allowing for multi-functionality. A related issue pertains to prior knowledge. As per TML, prior knowledge activation occurs during integration, but research shows it can be influenced by *integration* as well as *organization* cues, such that these processes are intertwined in some cases. We propose a conceptual model (discussed later) that connects the three processes articulated in TML with breaking impasse in RCT using visual cueing. Thus, we articulate an operational definition of cue types and in doing so collapse *organizational* and *integration* cue types into a single category.

RESULTS FROM PRIOR NSF SUPPORT

P.I. Rebello, Co-P.I. Loschky **(a) Award #:**1138697**, Amount:** $399,985, **Period:** 10/01/'11-- 09/30/'14.
(b) Project Title: *FIRE: Exploring Visual Cueing to Facilitate Problem Solving in Physics*
(c) Summary of Results: We explored and exploited the link between cognition and eye movements in physics problem solving. Through two studies (see '**Pilot Studies'** below) we tested our overarching hypothesis: *Visual cueing in physics problems with a strong visuospatial component can facilitate correct problem solving*. We found (1) statistically significant differences between the eye movements of correct and incorrect problem solvers, the former having longer dwell times in the expert areas and the latter in the novice areas; and (2) statistically significant differences on problem solving performance between cued and non-cued students. ***Intellectual Merit****:* We infuse ideas of vision cognition to transform research on physics problem solving. Mentee (Rebello) and his research group expanded their knowledge of visual cognition, promoting future interdisciplinary collaborations (such as the proposed project). ***Broader Impacts****:* We can potentially change the ways visual media are used to facilitate STEM problem solving. Specifically, results from the project have applications to online instruction.
(d) Publications: Peer reviewed articles are below, Six conference presentations were also given.

- 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, 020104. [link]
- Madsen, A., Rouinfar A., Larson A. M., Loschky, L. C. & Rebello, N. S. (2013). Do perceptually salient elements in physics problems influence students' eye movements and answer choices? *AIP Conf. Proc*. 1513, pp. 274-277. [link]
- Madsen, A. 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, 010122. [link]
- Madsen, A., Larson, A. M., Loschky, L. C., & Rebello, N. S. (2012). Using ScanMatch Scores to Understand Differences in Eye Movements between Correct and Incorrect Solvers, *Eye Tracking Research & Applications Symposium Proceedings*, March 28-30, 2012, Santa Barbara, CA. [link]
- Carmichael, A., Larson, E., Gire, L., Loschky, L. C., Rebello, N. S. (2011) How Does Visual Attention Differ Between Experts and Novices on Physics Problems? *AIP Conf. Proc*. 1289, pp. 93-96. [link]

(e) Brief Description of Data and Related Products: Data collected include eye-movement fixation times and locations and verbal responses from participants to the problems. Products include problems developed for the studies and associated visual cues. The project website is: http://web.phys.ksu.edu/fire

Pilot Studies

Studies completed under the FIRE grant serve as pilot studies for this project. The first study investigated the *knowledge effect*, the second the *cueing effect,* and the third effects of *cueing and feedback*. Participants were in an introductory conceptual physics course for non-science majors.

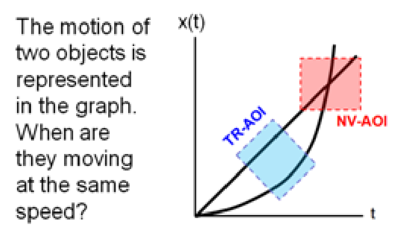

Fig. 1. Position vs. time graph of two objects, Thematically relevant (TR) and novice (NV) areas of interest (AOIs).

Pilot Study 1 (Madsen, et. al., 2012) *Hypothesis*: Correct problem solvers have longer dwell times in the thematically relevant areas of interest (TR-AOIs) while incorrect solvers have longer dwell times in novice-like areas of interest (NV-AOIs) consistent with naïve conceptions. *Method*: Eye movements of 22 participants solving six multiple-choice physics problems were recorded using an Eye

Link 1000 eye tracker. TR-AOIs, validated by three content experts, contained the thematically relevant visuospatial component needed to solve the problem. NV-AOIs were determined through interviews with students and confirmed by literature on students' naïve conceptions in physics. Figure 1 shows a problem adapted from McDermott et. al. (1987). The NV-AOI includes the intersection point and the TR-AOI includes the region where the graphs have the same slope. *Results*: A single factor ANOVA showed (Fig. 2) that correct solvers had a significantly ($p<0.05$) higher % dwell time in the TR-AOI than incorrect solvers. The opposite is true for the NV-AOI. Similar differences were seen in five of the six problems.

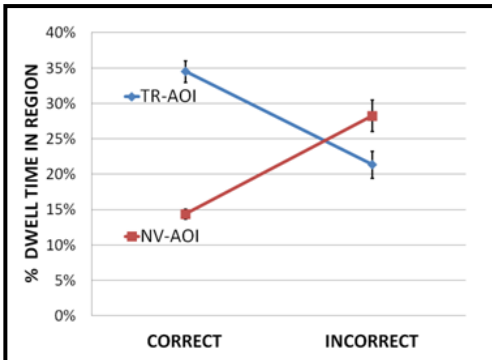

Fig. 2. Results of Pilot Study 1. % dwell time in AOIs for correct and incorrect solvers.

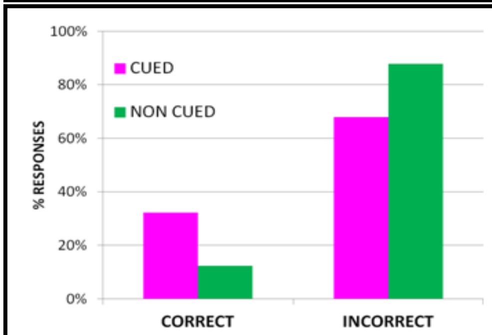

Fig. 3. Results of Pilot Study 2. % of correct and incorrect responses in each condition.

Pilot Study 2 (Madsen, et. al, 2013) *Hypothesis*: Cueing that aids learners to attend to thematically-relevant areas of a problem diagram improves performance on the cued problem as well as on a subsequent isomorphic transfer problem. *Method*: We selected 45 participants based on a pre-test to establish that they had declarative knowledge of the concepts. Participants were randomly assigned to two groups: cued (N=22) and non-cued (N=23). Both groups solved an initial problem from Pilot Study 1 followed by four isomorphic training problems. The cued group followed spatio-temporal cues (e.g. moving dots) embodying the solution (based on correct solvers' eye movements in Pilot Study 1) which implicitly cued them to attend to the thematically relevant areas, but did not indicate the answer. The non-cued group solved the same problems without any cues. *Results*: (Fig. 3), Fisher's exact test showed statistically significant ($p<0.05$) better performance of the cued group over the non-cued group. The Cramer's V effect size was 0.22, indicating a small effect.

Pilot Study 3 *Motivation:* Pilot Study 2 showed statistical significance, but small effect size. Transcripts indicated that most students were unaware that the cue was designed to facilitate them to solve the problem correctly. Further, most did not realize that they had solved it incorrectly. *Goal*: We aimed to explore (a) how students interpreted the cues when provided correctness feedback, and (b) what kinds of cues students would find most useful to facilitate problem solving. *Theory*: Theoretically, providing correctness feedback to an incorrect solver is akin to a discrepant event, causing cognitive dissonance (Festinger, 1957) or disequilibrium (Piaget,1964), which has been explored through eye-tracking studies (Graesser, et. al., 2005) and can invoke conceptual change (Posner, et. al., 1982). Feedback can improve learning (Mory, 2004), in computer-aided instruction (e.g. Fraij, 2010; Martin, et. al, 2002). *Method:* In individual, semi-structured interviews N=24 students solved an initial problem with no cue but with correctness feedback. Next, they were told that visual cues had been designed to help them solve the problem. After the cued problem was shown they were asked to describe what they thought the cue was attempting to do and whether it changed the way they thought about the problem. Starting with cues in Pilot Study 2, we made them progressively more explicit. Students described what aspects of the cue, if any, helped them solve the problem. *Results*: Feedback improved students' interpretation of the cues (a) Most interpreted the cues as intended and were able to solve the problem (b) Cues from Pilot Study 2 were often ineffective and more explicit cues were required. Organization/integration cues were most effective, while suppression cues were not. A later study (Rouinfar, et. al., 2013) confirmed the effectiveness of these cues.

How We Build on the Pilot Studies

Our pilot studies (#2) show that short duration visual cues that mimic expert eye movements can shift learners' attention to the thematically relevant areas and potentially improve problem solving performance. But, if solvers are unaware that their solution is incorrect, or that they are not told that the cues are designed to facilitate problem solving, the cues do not produce large effects. We have qualitative evidence (Pilot Study 3) that when learners are provided correctness feedback and the cues are of organization/integration type, problem solving performance improves significantly.

We hypothesize that *appropriate visual cues together with feedback can produce large effect improvements in problem solving performance.* We propose a conceptual model, based on known theories, consistent with this hypothesis, and experimentally test this hypothesis in a sequence of experiments.

CONCEPTUAL MODEL

Our conceptual model (Fig. 4) amalgamates concepts from RCT (Ohlsson, 1992) and TML (Mayer, 2001) and the framework for visual cueing (de Koning, et. al., 2009). Our model is also supported by prior empirical research including our own pilot studies (Madsen et. al., 2013; Rouinfar et. al., 2013).

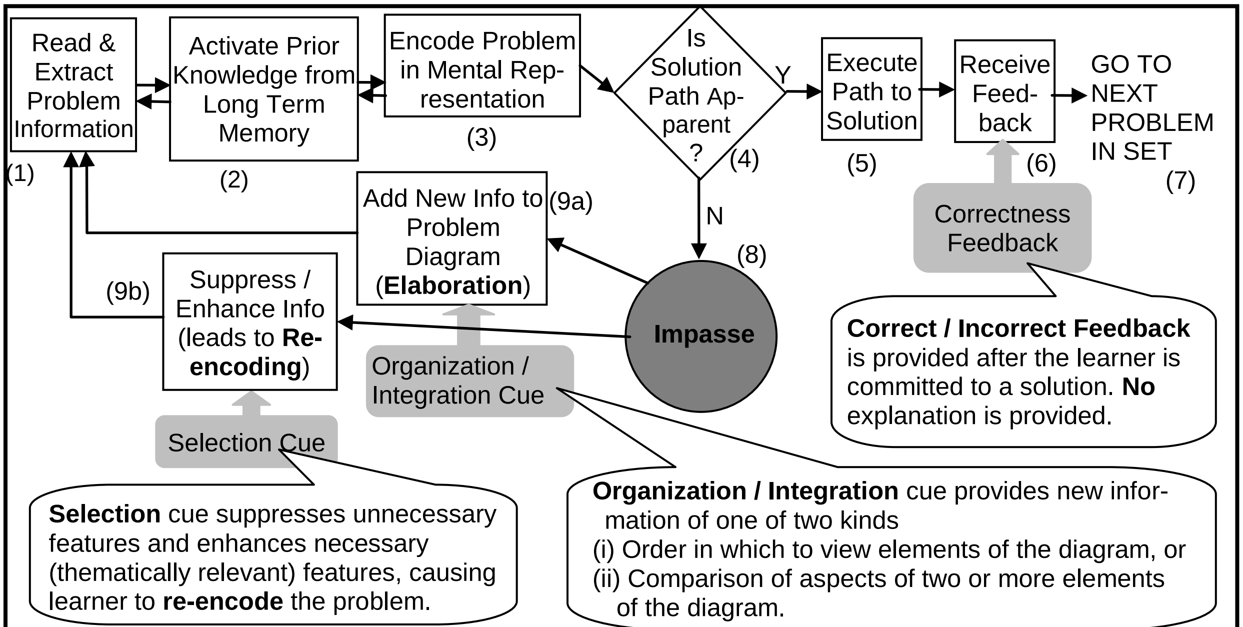

Fig. 4: Conceptual model integrating elements of RCT (Ohlsson, 1992) and TML (Mayer, 2001).

The conceptual model describes the steps needed to solve an insight problem. The learner first reads and extracts the problem information (step 1), based on which she activates prior knowledge from LTM (step 2). She associates this knowledge with problem features to encode the problem into a mental representation (step 3), based on which she decides whether a solution path is apparent (step 4). If she decides that is the case, the problem is now an algorithmic problem. She executes the solution strategy to find the answer (step 5). She receives feedback on the correctness of her answer (step 6). The feedback does *not* include an explanation of the underlying concept. Next, she receives a similar training problem. Figure 7,(Materials Development) illustrates the similarities between the initial and training problems.

There are two paths to an impasse (step 8). (i) She represents the problem and realizes that she does not know how to solve it (step 4). (ii) She has a novice-like representation, *thinks* she can solve the problem, does so incorrectly, gets feedback that it is so (steps 5-6). On the next problem (step 7), the path is no longer apparent, causing an impasse. We found that students representing the problem in Fig. 1 as "equal distances and times imply equal speeds" chose the graphs' intersection point, and were at an impasse on the next similar problem. Path (ii) to an impasse was much more common in Pilot Study 3.

As per RCT (Ohlsson, 1992), three possible mechanisms can break impasse: *elaboration*, *re-encoding*, or *constraint removal*. The latter lifts previous unnecessary constraints owing to incorrect assumptions or inappropriate ontological categorization (Chi, et. al., 1981). These kinds of problems are outside the scope of visual cueing. Elaboration and re-encoding – are discussed below.

Elaboration (step 9a) When a solver gathers insufficient information from the problem to form a coherent representation, the solution may not be apparent, causing an impasse. Cues that facilitate addition of critical new information are typically *organization/integration* type of cues. These help the learner (i) attend to information in a particular order or (ii) make comparisons between different elements of the diagram. A learner attending to the information provided by these cues (back to step 1) may activate previously dormant information from the long term memory (back to step 2) and eventually re-encode a representation for the problem (back to step 3). Examples of (i) are shown in Figs. 10-11.

Re-encoding (step 8b), involves backtracking through layers of the problem representation, replacing unproductive layers with new productive layers. S*election* cues facilitate re-encoding by prompting the learner to suppress irrelevant information and/or enhancing relevant information. The importance of suppression/inhibition of thematically irrelevant information for language comprehension has been shown by Gernsbacher & Fauster (1995) and we argue that it is equally important for re-encoding of problem representations. The learner then ignores irrelevant information and attends to relevant information (back to step 1), which in turn activates previously dormant prior knowledge from long term memory (back to step 2) and they encode a new representation for the problem (back to step 3). Examples are in Figs. 8-9.

The proposed research, which builds on pilot studies, is significant because it explores whether and *how visual cues together with feedback can facilitate elaboration and re-encoding to improve STEM problem solving*. These studies have potential implications for the design of computer-assisted instructional materials to facilitate STEM problem solving. Although materials development is beyond its scope, this project will lay the groundwork for the development of computer-assisted instructional programs that can be used to visually cue and provide feedback to learners to improve their STEM problem solving skills.

RESEARCH PLAN

Overview of Proposed Studies

Goals: We explore the influence of *malleable factors* (cues characteristics and feedback) and *moderating factors* (prior knowledge, initial problem correctness, and eye movements on initial problem) on *outcomes* (correctness and eye movements on training and transfer problems) in math and science problems involving graphics. (See Fig. 5.)

Rationale: Table 1 describes the rationale for factors and outcomes.

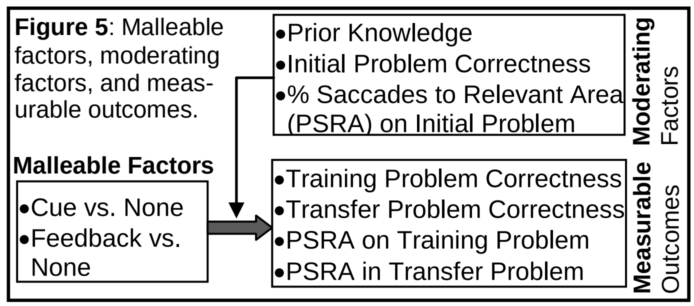

Figure 5: Malleable factors, moderating factors, and measurable outcomes.

Table 1. Rationale for malleable and moderating factors and outcomes.

Factor or Outcome		Rationale
Malleable Factor	• Cue vs. No Cue	• To test whether cues can affect the outcomes
	• Feedback vs. Not	• To test whether feedback can affect the outcomes
Moderating Factor	• Prior Knowledge (**PK**)	• Affects eye movements and problem solving strategies.
	• Initial Problem Performance (**IPC**)	• Takes into account if students know how to solve this type of problem.
	• PSRA (% Saccades to Relevant Area) on Initial Prob. (**IPSRA**)	• Takes into account how often learners move their eyes toward the thematically relevant area to which they must attend to solve the problem. Cues can affect how often the learner transitions to the thematically relevant area.
Measurable Outcome	• Training Problem Correctness (**O1**)	• Measures whether cues and/or feedback change performance on problems on which these are provided.
	• Transfer Problem Correctness (**O2**)	• Measures whether cues and/or feedback change performance on *future* problems on which these are *not* provided.
	• PSRA on Training Problem (**PSRA1**)	• Measures shift in covert attention toward relevant area due to cues / feedback on problems with cues and/or feedback.
	• PSRA on Transfer Problem (**PSRA2**)	• Measures shift in covert attention toward relevant area on *future* problems with *no* cues and/or feedback.

Eye movements are a relevant outcome measure in this study because they are an indicator of shifts in students' covert attention. As we know from Pilot Study 1 (Madsen, et. al, 2012), students' attention to relevant areas correlates with their correctness on the problem. The reason we use PSRA (Percent Saccades to Relevant Areas) as the outcome measure to assess eye movements rather than percentage dwell time in the relevant area is because we are interested in whether the cues *shift* learners' attention from points outside the relevant area to points inside the relevant area. This, we believe, is a more valid measure of whether the cues/feedback affects eye movements rather than percentage dwell time, because it takes into account *shifts* in learners' covert attention, rather than merely the percentage of time they fixate in a given area.

Summary of Studies: Each of the variables used in the studies are described in Table 2.

Table 2. Variables used in the studies

Studies	Independent Variables / Conditions (*Malleable* Factors)	Covariate (*Moderating* Factor)	Dependent Variables (*Outcomes)*
Study 1 (Math & Physics) *Selection* Cue (**C = C1**) **Study 2**: (Math & Physics) Organization /Integration Cue (**C = C2**)	(1) Training Cue (**C** = **C1**, **C2**) (2) Answer Feedback (**F**) (3) Cue + Feedback (**C**+**F**) (4) No Cue, No Feedback (**N**)	(1) Prior Knowledge Pre-Test score (**PK**) (2) Initial Problem Correctness (**IPC**) (3) PSRA on Initial Problem (**IPSRA**)	(1) Training Problem Correctness (**O1**) (2) PSRA on Training Problems (**PSRA1**) (3) Transfer Problem Correctness (**O2**) (4) PSRA on Transfer Problems (**PSRA2**)

Study Tasks: In each study, students will complete the sequence of tasks described in Figure 6. Details are described later.

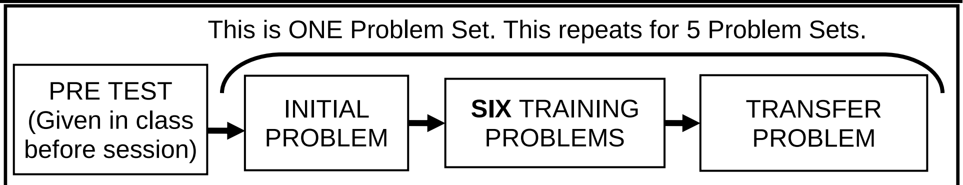

Figure 6: Sequence of tasks for each study

Materials Development

Materials: These include (a) prior knowledge of pre-test items and (b) a set of 10 problem items – five in math and five in physics. Both sets of items will have the following characteristics: (i) They will be taken from a standardized math and science assessment such as the ACT or NAEP (National Assessment of Academic Progress), whose psychometric properties have been tested; as well as conceptual inventories developed by educational researchers in the discipline. (ii) They will be items that students can answer based on material covered in class. Finally, in addition to (i) and (ii), the problem items will each have a visual element required to solve the problem that has two distinct areas – a *thematically relevant* area to which correct solvers must attend to and a *novice-like* area which incorrect solvers who get the problem incorrect are most likely to attend to.

We will alter the novice-like feature on each of these 10 problems to create 10 sets of six isomorphic *training problems* and the thematically relevant feature to create one *transfer problem* for each set designed to assess whether the participant has the correct representation of the relevant math and science concept applicable to a new situation. Figure 7 shows an example of two isomorphic training problems and a transfer problem.

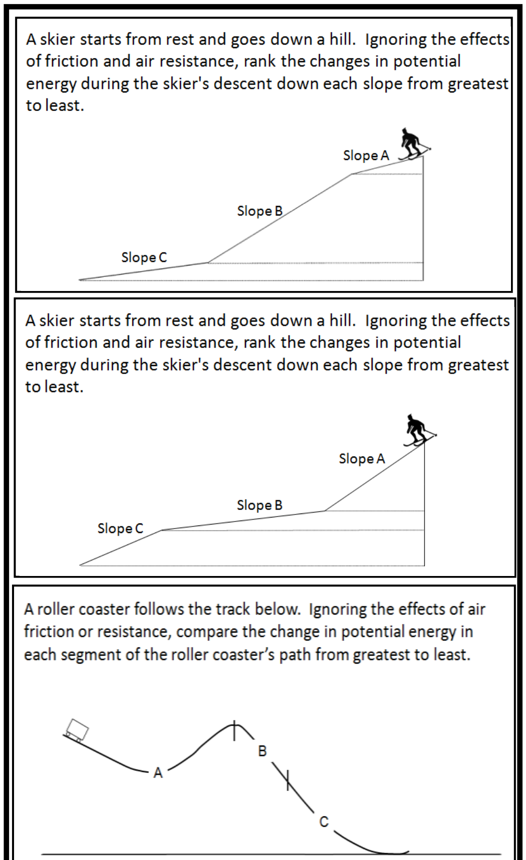

Figure 7: Example of two isomorphic training problems (top and middle) and the transfer problem (bottom).

In each set, the training problems will be counterbalanced to take into account ordering effects. It is important to emphasize that several studies have demonstrated the educational effectiveness of visual cueing in learning materials, even when the duration of the cues was on the order of several seconds to a minute. de Koning *et al*. (2007) sought to help students improve comprehension of the dynamics of the cardiovascular system.

To achieve this goal, students individually viewed an animation of the cardiovascular system. All students saw six cardiac cycles which each lasted for 10 seconds, for a total viewing time of 60 seconds. A subset of these students saw “spotlight cues” where all elements in the animation were slightly darkened except for the valve system. The spotlight cues began 10 seconds after the animation onset and lasted through the rest of the animation, for a total cueing time of 50 seconds. Students who viewed the animation with cues had higher comprehension and transfer scores. Our own pilot studies (Rouinfar, et. al, 2013) suggest that the 50s duration is too long and students will get bored. We use a shorter cue (8s) that can be replayed if necessary. In our most recent study, when the cue lasted for 8s, students rarely viewed a cue more than once or twice. We will create two kinds of visual cues based on our conceptual model (Fig. 4):

In the figure below, *A*, *B*, *C*, and *D* are collinear, *FC* is parallel to *ED*, *BE* is perpendicular to *ED*, and the measures of $\angle FAB$ and $\angle EBA$ are as marked. What is the measure of $\angle FCB$?

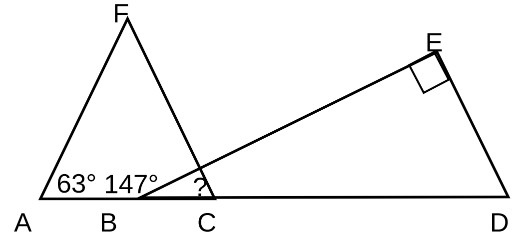

Figure 8a: Example of ACT math problem.

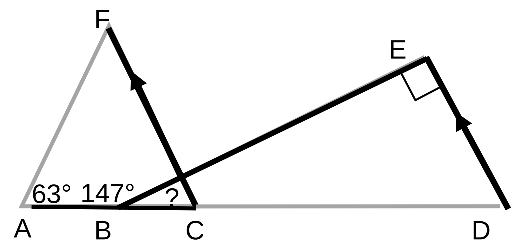

Figure 8b: *Selection* cues on problem in Fig. 8a.

A student tried to connect an electric circuit as shown. The light bulb did not light up. What can the student do to make the light bulb light up?

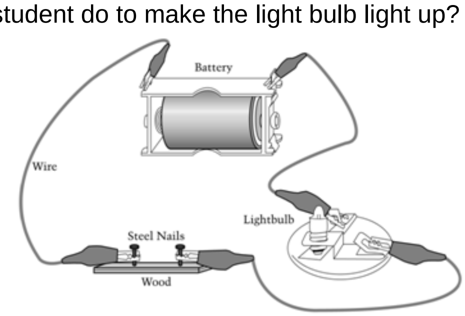

Figure 9a: Example of NAEP physics problem.

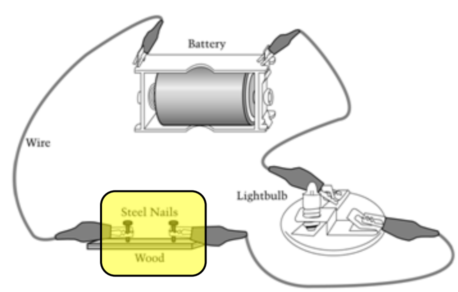

Figure 9b: Selection cues on problem in Fig. 9a.

Selection cues (**C1**) used in **Study 1** will facilitate re-encoding of the problem representation through two means: (i) Enhancement: Spotlight cues (e.g., de Koning et al., 2007; 2010) overlaid on the practice problem diagrams highlighting the thematically relevant areas of interest (Grant & Spivey, 2003; Thomas & Lleras, 2007; 2009); and (ii) Suppression: Fading of irrelevant areas, thereby enhancing the relevant areas which inhibits the activation of contextually inappropriate information (Gernsbacher *et. al.*, 1995).

Organization/Integration cues (**C2**) used in **Study 2** will facilitate the learner’s elaboration of the problem representation through cueing so that she can (i) alter the order in which to view elements of the diagram and (ii) compare aspects of two or more elements. Examples include spreading color or color coding (Kalyuga et al., 1999; Boucheix & Lowe, 2010), use of numbers and arrows (Tversky, et. al., 2008), and simultaneous flashing (Craig et al., 2002).

Not all problems are amenable to both kinds of cues. So, the problems for **Study 1**, which are amenable to *selection* cues (**C1**), will not be the same as the problems for **Study 2**, which are amenable to *organization/integration* cues (**C2**). There are some problems, however, for which both cue types would work. We will use these kinds of problems in both studies, so that we can compare the effects of the two cue types on these problems.

We will base the decision-making process for choosing particular types of cues for particular types of problems on our conceptual model (Figure 4) with underpinnings in RCT (Ohlsson, 1992), the TML (Mayer, 2001), and the Visual Cueing Framework (de Koning et al., 2009). The development of a taxonomy of cue types based on an empirically-tested theoretical analysis of problem types and cue types is an overarching long-term goal of the current research, and our conceptual model is an important first step towards this goal. However, at present, the field of educational cueing is still at an exploratory stage of theory development. Thus, the decision making process for designing the cues will proceed in a more theoretically guided, grounded research mode.

Examples of *Selection* Cues (C1) Our example for the math problem was taken from a practice question on the ACT and the science problem was taken from the NAEP. As you can see in Fig. 8a, the key elements that are needed to correctly solve the problem in Figure 8a involve the recognition that FC is parallel to ED and therefore the angle at the vertex of the small triangle formed with base BC is 90°. If students are unable to recognize this important fact about the diagram, they will be at an impasse. Thus, to overcome this impasse, it is important to suppress information such as that shown in a lighter shade (AF and CD and angle FAB) and enhance the parallelism between lines ED and FC, which is stated in the problem. The key issue is recognizing that you have parallel lines crossed by two transversals, and that lets you match various angles up. The initial diagram does not include the usual indicator that lines are parallel in a math diagram (putting matching arrowheads on the lines). The cues highlight the fact that the lines are parallel and one full transversal BE. This can help students recognize that BE perpendicular to DE and DE perpendicular to FC implies BE perpendicular to FC, then they can solve the problem reasonably easily from that point.

Quadrilateral ABCD is drawn on the standard (x,y) coordinate plane as shown below, with points E and F on AD. Point G is the center of rectangle BCEF. How many coordinate units long is AG?

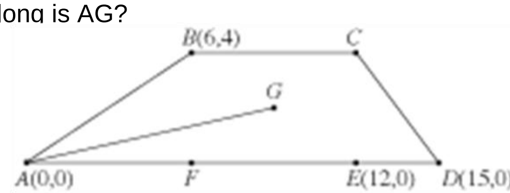

Figure 10a: Example of ACT math problem.

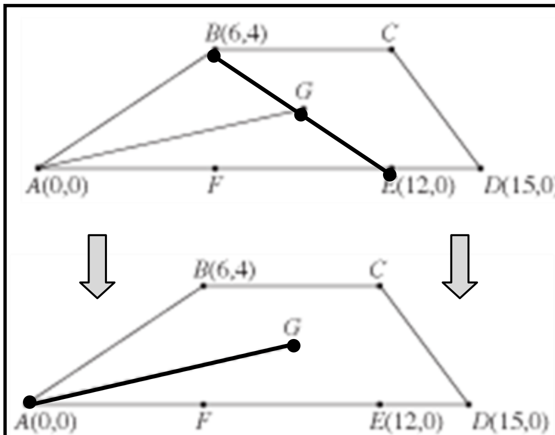

Figure 10b: Organization/Integration cue for problem in Fig. 10a.

For the problem in Figure 9a, it is important for learners to realize that the area of focus is where the two nails are embedded in the piece of wood and not anywhere else. In this case, spotlighting the area as shown in Figure 9b and simultaneously fading out the rest of the figure can enhance attention to the thematically relevant area of the figure. Our pilot study 3 showed us that suppression cues by themselves are not effective, whereas a combination of suppression and enhancement cues are. Therefore, we are focusing on the latter in this research project.

Examples of *Organization/Integration* Cues (C2) The math problem is from a practice question on the ACT and the science problem is from the NAEP. In the problem in Figure 10a, the impasse is most likely due to students not being able to find the (x,y) coordinates of point G. To overcome this impasse, students need to first recognize the implications of the fact that G is at the midpoint of the rectangle BCEF, which they are told in the question. This in turn means that G is at the midpoint of the diagonal BE and therefore, its coordinates are half the sum of the coordinates of B and E. To help students overcome the impasse, an *organization / integration* cue (Figure 10b), is a line drawn from B to E, which facilitates students to compare the distances from B to G and G to E and recognize that they are equal. Then in the next step, the cue should highlight the line drawn from A to G, so that students can compute the distance from A to G.

The picture shows the positions of two runners at one-second intervals as they move from left to right. At what point are the two runners running at approximately the same speed?

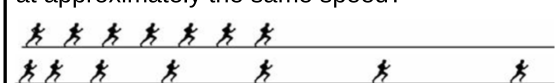

Figure 11a: Example of NAEP physics problem.

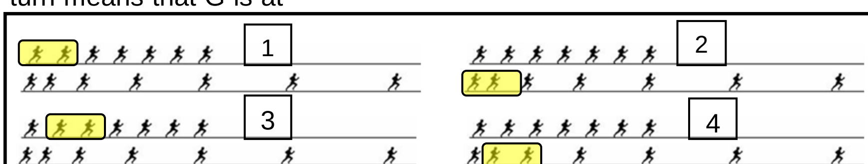

Figure 11b: Organization/Integration cue for problem in Fig. 11a.

In the problem in Figure 11a, the learner is required to compare the times when the distance between two consecutive snapshots in the two pictures are equal. This problem is similar to a problem on the Force

Concept Inventory (Hestenes, et. al., 1992). The common misconception is that the time when the two runners are traveling at about the same speed is when the positions of the two runners coincide.

In this case, students are not necessarily going to have an impasse rather they may use an incorrect representation and provide the wrong answer (the point where the runners are at the same position, i.e. the seventh snapshot at the top). However, when they receive feedback (in the F or C+F conditions) they are most likely to reach an impasse on the next problem in the sequence, because they will realize that their representation of comparing positions of the runners is incorrect and they need to do something else instead. In this case the organization/integration cue of the type shown in Figure 11b can facilitate the appropriate comparison in the correct sequence, so that learners compare distances between adjacent snapshots of the same runner rather than the positions of two runners.

Details of Studies

The two studies listed in Table 2 have identical designs and are described in detail below. The only difference between these studies is the type of cues that are used and consequently the kinds of problems amenable to using each type of these cues.

Research Questions: Both in **Study 1** (using *selection* cues **C1**) and **Study 2** (using *organization/integration* cues **C2**) we address the following research questions:

RQ1) Does ***correctness*** on the six ***training*** problems (**O1** – Outcome 1) differ as a function of the main effects of Cue or Feedback, or as a function of the interaction between Cue and Feedback after controlling for the scores on the prior knowledge pre-test (**PK** – Prior Knowledge) and on the correctness on the initial problem (**IPC** – Initial Problem Correctness)?

<u>Null Hypothesis</u>: H_0 – There are no significant differences between conditions on the correctness of the six training problems (**O1**) (i.e., there are no main effects of Cue or Feedback, and no interaction between Cue and Feedback) after controlling for the moderating factors (**PK, IPC**).

RQ2) Does ***correctness*** on ***transfer*** problems (**O2** – Outcome 2) differ as a function of the main effects of Cue or Feedback, or as a function of the interaction between Cue and Feedback, after controlling for the scores on the prior knowledge pre-test (**PK**) and on the correctness of the initial problem (**IPC**)?

<u>Null Hypothesis</u>: H_0 – There are no significant differences between conditions on the transfer problem correctness (**O2**) (i.e., there are no main effects of Cue or Feedback, and no interaction between Cue and Feedback) after controlling for the moderating factors (**PK, IPC**).

RQ3) Does the ***Percentage Saccades to Relevant Areas (PSRA)*** on each of the six ***training*** problems differ as a function of the interaction between Cue and Feedback, after controlling for the PSRA on the initial problem?

<u>Null Hypothesis</u>: H_0 – There are no significant differences between the conditions in the PSRA on the six training problems (i.e., there are no main effects of Cue or Feedback and no interaction between Cue and Feedback) after controlling for the PSRA on the initial problem.

RQ4) Does the ***PSRA*** on the ***transfer*** problem differ as functions of the main effects of Cue or Feedback, or as a function of the interaction between Cue and Feedback, after controlling for the PSRA on the initial problem?

<u>Null Hypothesis</u>: H_0 – There are no significant differences between the conditions in the PSRA on the transfer problems (i.e., there are no main effects of Cue or Feedback, and no interaction between Cue and Feedback) after controlling for the PSRA on the initial problem.

Participant Selection: Participants will be selected from introductory mathematics and physics classes at Kansas State University. The math classes include – *Intuitive Geometry*, *Plane Trigonometry*, *Math for Future Elementary Teachers*, and *Intermediate Algebra*. All of these cover geometry, trigonometry, and graphical concepts. The physics classes include – *Physical World* and *Concepts of Physics* (for future elementary teachers). These courses focus on conceptual – rather than algorithmic – problem solving and often utilize pictures and graphs. The math classes together have a total enrollment of over 300 students each year. The same is true for the physics classes. A brief pre-test of declarative knowledge will be administered to all students in these classes. We anticipate having about 150 participants from each cohort (math and physics), which will allow for about 30-35 students in each of the four conditions for each cohort.

Design: Both **Study 1** and **Study 2** are 2 (Cue versus No Cue) x 2 (Feedback versus No Feedback) between-groups designs concerning the independent variables that combine to create the four conditions (**C**, **F**, **F**+**C,** and **N**). We will randomly assign participants in each cohort (math and physics) to these four conditions such that each participant is in only one of the four conditions. **Study 1** will use the *selection* cue (**C1**). **Study 2** will use the *organization/integration* cue (**C2**).

Procedure: The procedure is summarized in Fig. 12, (repeat of Fig. 6). We will follow the steps below.

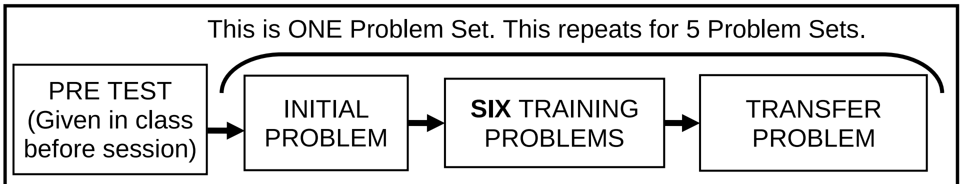

Figure 12: Sequence of tasks for each study

<u>Pre-Test</u>: A brief pre-test of declarative prior knowledge of the relevant concepts in mathematics or physics will be administered to all students in the targeted mathematics and physics classes. The pre-test will be administered before the start of the individual problem solving sessions on the eye-tracker. Based on their performance on the pre-test, we will select participants for our out-of-class individual session.

<u>Session</u>: Participants will meet with us for a 60-minute, out-of-class session. (i) Each participant will be given a brief explanation of what to expect during the session and the eye-tracking system will be calibrated. (ii) The researcher will instruct them to silently solve each problem appearing on a computer screen while their eye movements are recorded. They will be asked to indicate their answer verbally and provide an explanation to the researcher. (iii) They will see an initial problem with neither cues nor feedback. (iv) They will see a sequence of training problems. If they are in either the **C** or **C**+**F** condition, they will be told that "a few seconds after you begin viewing the problem, patterns *may* appear on the screen. Please watch these patterns and follow them with your eyes if they move until they disappear. The purpose of these moving patterns is to provide you a hint to solve the problem." (v) If they are in either the **F** or **C**+**F** condition they will receive verbal feedback after each training problem as to whether their answer is "correct" or "incorrect." No explanation or hint will be provided. (vi) They will see the transfer problem. **Steps iii.) through vi.) will repeat for all five (5) problem sets seen by each participant**.

Analysis: We will complete the following between-groups comparisons to address each of our research questions. An alpha level of significance $\alpha = 0.05$ will be used to test for significance.

RQ1) A 2 (Cue versus No Cue) x 2 (Feedback versus No Feedback) x 6 (Training Problems) mixed factorial ANCOVA will be conducted with the repeated presentation of six ***training*** problems within each problem set as the within-groups factor and the correctness of the training problems (O1 – Outcome 1) as the dependent measure. The pre-test prior knowledge score (PK) and the initial problem correctness (IPC) will be entered as the covariates.

RQ2) A 2 (Cue versus No Cue) x 2 (Feedback versus No Feedback) between groups factorial ANCOVA will be conducted with the ***transfer*** problem correctness (O2 – Outcome 2) for each problem set as the dependent measure. The pre-test prior knowledge score (PK) and the initial-problem correctness (IPC) will be entered as the covariates.

RQ3) A 2 (Cue versus No Cue) x 2 (Feedback versus No Feedback) x 6 (Training Problems) mixed factorial ANCOVA will be conducted with the repeated presentation of six ***training*** problems within each problem set as the within-groups factor and the percentage of saccades that go to the relevant areas (PSRA) on the training problems as the dependent measure. The PSRA on the initial problem will be entered as the covariate.

RQ4) A 2 (Cue versus No Cue) x 2 (Feedback versus No Feedback) between-groups factorial ANCOVA will be conducted with the PSRA on the ***transfer*** problem as the dependent measure. The PSRA on the initial problem will be entered as the covariate.

<u>NOTE</u>: Significant main effects and interactions will be probed using simple effects analyses and multiple comparison procedures using Bonferroni corrections of the alpha level to control for family-wise Type I error rates as appropriate.

<u>Power Analysis</u>: We have completed a power analysis. Sample sizes (N=150) in cohort will allow us to test our hypotheses with a power level that exceeds **0.80** in the detection of effects of at least medium size.

Validity Threats: The following potential threats have been identified and addressed.

(i) Equipment issues: As is true in any eye-tracking study, using an eye tracker may change the participants' problem solving behaviors. We will use the Tobii Glasses Eye Tracker that do not need an obtrusive head rest or chin support. We have budgeted funds to purchase the Tobii Glasses Eye Tracker.

(ii) Participants: Although participants for our study will be chosen from a pool of volunteers whose prior knowledge has been tested, it is nevertheless a convenience sample and not statistically representative of the entire population of students. We will strive to include a diverse pool of participants, with gender (about 50/50 female/male) and ethnicity representative of the target population. We will exclude learners who cannot use the eye-tracker such as those with eyeglasses or contact lenses above a certain power.

(iii) Problem tasks: It is possible that the problems that we select will not be representative of typical problems in the math and science courses. We will present the slate of problems to the instructors teaching the classes to tell us if the problems are representative of problems used in the class and suggest modifications as necessary.

(iv) Placebo effect: Students will be told that they will see moving shapes and that these moving shapes are supposed to provide a hint to solve the problem. Thus, a placebo effect is possible. An easy solution to this would be to include an uninformative cues control condition, which would be expected to do worse than the No-cue condition in our studies.

(v) Cue type: The different types of cues we propose to use are based on the visual cueing literature. However, within these categories, several variations are possible. We will conduct a brief exploratory study with a small group (~30 participants from each cohort), without an eye-tracker where we show them cues and get feedback from them about which cues are most effective.

(vi) Cue timing: We will not vary the timing of when the cue appears. Cues onset will be 10 seconds after the display and will repeat for eight (8) seconds. Students will be able to replay the cue as many times as they need. Pilot Study 3 suggests students have sufficient time to grasp the overall structure of the problem after the problem is shown and to attend to the cue after it appears. The cue duration time is longer than the four (4) seconds used by Thomas and Lleras (2007). We also will not alter the duration for which these cues are visible. Therefore, we will not investigate variations in cue timing. Such a study will be explored later, but is beyond the scope of this project.

(vii) Transfer proximity: A single problem is clearly an inadequate measure of transfer. Whether the particular problem assesses near transfer or far transfer is also debatable. To improve the validity of our transfer measure, after participants have provided an explanation for the transfer problem, they will be probed further with "*what if*…" type questions. So, we will investigate whether they have a robust mental model for solving not just this transfer problem, but a category of problems sharing the same concept.

TIMELINE

We complete two iterations of each study to double our participants and improve the statistical power.

Table 3: Timeline for project. Requested start date is July 1, 2014 and duration is 36 months.

Project Activities	07-12/ 2014	01-06/ 2015	07-12/ 2015	01-06/ 2016	06-12/ 2016	01-06/ 2017
Start of Project : Advisory Board Meeting	X					
Plan Study 1 (separate math & physics cohorts)	X					
Execute Study 1 (math & physics)		X				
Analyze Data from Study 1 (math & physics)		X				
Modify plan for Study 1 (math & physics)		X	X			
Execute Study 1: 2nd iteration (math & phys)			X			
Analyze Study 1 Data: 2nd iteration (math & phys)			X			
Write up Study 1 (math & phys) for publications			X			
Plan Study 2 (separate math & physics cohorts)			X			
Execute Study 2 (math & physics)				X		
Analyze Data from Study 2 (math & physics)				X		
Modify plan for Study 2 (math & physics)				X	X	
Execute Study 2: 2nd iteration (math & physics)					X	
Analyze Study 2 Data: 2nd iteration (math & phys)					X	X

Table 3: Timeline for project. Requested start date is July 1, 2014 and duration is 36 months.

Project Activities	**07-12/ 2014**	**01-06/ 2015**	**07-12/ 2015**	**01-06/ 2016**	**06-12/ 2016**	**01-06/ 2017**
Write up Study 2 (math & phys) for publications						X
Complete the final project report to NSF						X

Not included in the above are conference presentations and other dissemination activities. We will complete these activities in conjunction with the activities listed above.

SUMMARY OF PROJECT GOALS AND MEASUREABLE OUTCOMES

The goals, measures, and key outcomes for the project are described in Table 4 below.

Table 4: Goals and Measurable Outcomes

Goals: Investigate if…	Measurable Outcome
visual cueing and/or correctness feedback on training problems facilitate **improved problem solving performance** on ***training*** problems when controlling for prior knowledge and initial problem solving performance.	Significant (α = 0.05) improvement on ***training*** problem score, with a medium/large effect size.
visual cueing and/or correctness feedback on training problems facilitate **improved problem solving performance** on ***transfer*** problem when controlling for prior knowledge and initial problem solving performance.	Significant (α = 0.05) improvement on ***transfer*** problem score with a medium/large effect size.
visual cueing and/or correctness feedback on the training problems **increases percentage saccades to relevant areas** (***PSRA***) on the ***training*** problems when controlling for PSRA on the initial problem.	Significant (α = 0.05) increase in PSRA on ***training*** problems, with a medium/large effect size.
visual cueing and/or correctness feedback on the training problems **increases the *PSRA*** on ***transfer*** problem when controlling for the PSRA on initial problem.	A significant (α = 0.05) increase in PSRA on ***transfer*** problems, with a medium/large effect size.

PROJECT EVALUATION

The Advisory Board (see **Personnel** section) meets with the project staff once each year to examine plans before the studies are implemented. Further, the Advisory Board will provide their input on annual and final reports to NSF. Specifically, the Advisory Board provides formative feedback to the project staff regarding the degree to which the project objectives are being met by assessing the viability of the research studies to be completed by the project and the project's overall contributions to the body of knowledge at this interface of cognitive psychology and math and science education research. The overarching questions below guide this effort.

- How are the project activities advancing toward the research goals? What strategies and specific activities account for this progress?
- To what extent are the methodology and results of the research studies valid and reliable?
- How has the project contributed to the knowledge base of visual cueing that can be utilized in math and science problem solving?

Formative evaluation will be utilized to provide regular, ongoing feedback to the project team regarding progress. The summative evaluation will assess overall project success as documented through:

- Examining the project documentation and research activities of the project and aligning them with the goals and objectives of the project.
- Validating the research data and the outcomes of the developed studies.
- Examining potential for replication and extension of the studies.

The project team members will work with the Advisory Board to coordinate the project evaluation. Input from the Advisory Board will be included in reports submitted to NSF.

DISSEMINATION

Research from the project will be disseminated through talks and posters at conferences attended by researchers both in the cognitive psychology fields and STEM education fields. These include *Cognitive Science, Eye Tracking Research & Applications* as well as *National Association for Research in Science Teaching, American Educational Research Association* and *Physics Education Research Conference.* We will also present our research in peer-reviewed journals in areas that overlap between the two fields.

These would include *Journal of Educational Psychology, Learning and Instruction*, *Journal of Learning Sciences* as well as journals in the mathematics and science education fields such as *Journal of the American Mathematical Association, Physical Review Special Topics – Physics Education Research,* and *Journal of Research in Science Teaching*. We anticipate at least one article in each journal before the end of the project period. We will maintain an up-to-date website to disseminate these products.

PERSONNEL

Senior Personnel

Dr. N. Sanjay Rebello (P.I.) is Associate Professor of Physics Education. He has over 15 years' experience in physics education research (PER) and has published over 50 peer reviewed papers in PER. Research conducted by his group has focused on transfer of learning, problem solving, and the use of visualizations in math and science learning (e.g. Rebello, et. al. 2005, 2007, Gire et. al, 2011). Over the past two years, Dr. Rebello, in collaboration with Dr. Loschky and his group has completed work on visual cueing described in the pilot studies (Madsen et. al. 2012; 2013) as part of an NSF FIRE grant. As P.I., Dr. Rebello will have overall responsibility for the management of the project. This includes collaborating with the co-PIs, and the external advisory committee, in the overall execution of the project including (i) guiding the development of research protocols, materials and rubrics; (ii) collaborating with co-PIs; (iii) liaising with Physics Department faculty for planning and execution of the studies; (iv) supervising the graduate students, postdoctoral research associate, and project assistant in all aspects of their work; and (v) liaising with members of the advisory board.

Dr. Lester Loschky (co-P.I.), Associate Professor of Psychology, has investigated both basic and applied topics related to the role of eye movements and attention in scene perception for the last decade. In the basic domain, he has investigated how our eye movements affect our memory for the objects in scenes and how people rapidly comprehend the "gist" of their surroundings. A key question he has looked at has been the role of peripheral vision in that process and how the limits of visual resolution in the visual periphery affect rapid scene comprehension. These questions stem from the fact that our visual experience is parceled out into discrete eye fixations in which both central and peripheral information contribute and also vie for attention. His research in the applied realm has thus investigated how vision, task performance, and attention are affected by loss of peripheral image resolution in gaze-contingent multi-resolutional displays. Such displays push the technological envelope by using eye tracking to put high image resolution wherever the viewer is looking and lower resolution in their visual periphery. His research has been at the forefront of this area, which has applications to simulators, virtual reality, teleoperation, and remote piloting. Over the past two years, Dr. Loschky, in collaboration with Dr. Rebello and his group has completed work on visual cueing described in the pilot studies (Madsen et. al. 2012; 2013; Rouinfar, et. al, 2013) as part of an NSF FIRE grant. Dr. Loschky's responsibilities will include (i) providing his expertise in cognitive psychology, specifically vision cognition in the design of the studies; (ii) providing his expertise in the analysis and interpretation of the data; and (iii) facilitating the professional development of colleagues so that they become more aware of the potential underpinnings of cognitive psychology, especially vision cognition to STEM education.

Dr. Andrew G. Bennett (co-P.I.) is Professor of Mathematics Education & Mathematics Department Head. He is also director of the Center for Quantitative Education. He received his Ph.D. in 1985 from Princeton University. He has over 20 years of experience with design and programming of computer and online tools for teaching. He has experience with educational data mining and has also run summer workshops for teachers for a decade. He has published over 20 papers in this area. Dr. Bennett's main roles on the project will involve (i) working on the design of mathematics problems where students have to process multiple streams of information and visual cueing may prove useful; (ii) collaborating on data analysis; (iii) liaising with Mathematics Department faculty; and (iv) supervising a STEM education graduate student in mathematics education and the postdoctoral research associate.

Other Project Staff

Postdoctoral Research Associate (1) who has a Ph.D. in STEM Education, cognitive psychology, or a closely related field will take an active role on all aspects of the project. This individual would also have prior experience in research on eye movements and attention. These will include (i) developing and designing the interview protocols; (ii) analyzing qualitative and quantitative data from eye-tracking interviews with students; (iii) programming the eye tracker and accessories for the experiment; (iv) creating publishable papers and presenting talks to disseminate the research; and (v) assisting the project staff in mentoring of the graduate research assistants on the project.

Graduate Research Assistants (STEM Education - **2**) One who is completing a doctoral program in mathematics education and one in physics education research will assist the project team with (i) developing and designing the interview protocols; (ii) conducting the eye-tracking interviews; (iii) analyzing qualitative and quantitative data from eye-tracking interviews with students; and (iv) creating publishable papers and presenting talks to disseminate the research. The doctoral dissertation of these students will focus on various aspects of the research and analysis of eye-tracking interviews.

Graduate Research Assistant (Psychology **- 1**) who is completing a doctoral program in psychology with Dr. Loschky will assist the project team with (i) developing the protocols for the eye-tracking experiments; (ii) programming the eye tracker and accessories for the experiment; and (iii) converting the eye-tracking data into a form that can be analyzed by other personnel on the project.

Project Technical Assistant (1) will play an integral role in the project in several ways: (i) scheduling interviews with the participants and other project meetings; (ii) transcribing and coding interview data; (iii) organizing the quantitative eye-tracking data and assisting in the statistical analysis of these data; and (iv) Web management for dissemination of project results.

Advisory Board

The Advisory Board has two cognitive psychologists (Drs. Irwin and Ross) and two science education researchers who work at the interface with vision cognition (Dr. Mestre and Dr. Wiebe). The Board will meet with the project team once each year to provide guidance, feedback, and evaluation to the project.

Dr. Brian H. Ross is Professor of Psychology at University of Illinois. He has focused his research on how people learn new concepts in the course of problem solving, how they categorize problems, and how the way in which the categories are used affects learning. More recently, he has collaborated with Dr. Jose Mestre on studies of visual cognition in physics education research.

Dr. David E. Irwin is Professor of Psychology at University of Illinois. His research has investigated how attention and eye movements influence what people remember from a single glance at a scene and how people combine information in visual short-term memory across eye movements. More recently he has been investigating the effects of eye movements on cognitive processing. Dr. Irwin's insights arising from his research in this area will be particularly useful to our project.

Dr. Jose P. Mestre is Professor of Educational Psychology and Physics at University of Illinois. His research is at the interface of cognitive science with physics education, such as visual cognition and physics education research. Using techniques such as eye tracking, he has focused on how both experts and novices store, retrieve, and apply knowledge. His recent research is on the role of misconceptions in comprehending scientific text, visual processing of diagrams in problems, and conceptual problem solving. Dr. Mestre's experience in physics education research and cognitive psychology will be invaluable here.

Dr. Eric N. Wiebe is Professor of Science Education at North Carolina State University. Dr. Wiebe's research explores the perceptual and cognitive basis of 2-D and 3-D graphic communication; understanding how graphics can be used as a vehicle for communicating engineering and scientific information as part of the scientific discovery and engineering design process and promoting graphics literacy and the application of scientific visualization in primary, secondary, and post-secondary education. Dr. Wiebe's experience with research on multi-modal interactive learning tools and investigation of how specific technologies influence teaching and learning will be especially beneficial to this project.

BROADER IMPACTS

The purpose of the project is to investigate the malleable and moderating factors that influence how learners attend to visual information in STEM problems containing diagrams and how their attention, and feedback on correctness, influences the solutions they arrive at and their learning. We will focus on these basic research issues, rather than developing and testing educational interventions in the classroom, which are beyond the current project's scope. This project will lay the foundation for educational interventions in the future. These interventions will utilize what we have learned in the project about the efficacy of visual cueing, what kinds of cues (selection, organization/integration) are most beneficial for learning, and for what kinds of problems these cues are most beneficial. These insights will inform a future project to design visual cueing and feedback interventions to facilitate problem solving in STEM.