

Visualizing Feedback: Using Graphical Cues to Promote Self-Regulated Learning

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Abstract

We examined whether the addition of graphical cues on a concept map could promote self-regulated learning with online materials. College-aged students were provided with concept map visualizations to guide revisions of a scientific essay. These visualizations varied in their use of two graphical cues: color-coded nodes that indicated error types and size-scaled nodes that indicated the importance of domain ideas. Metacognitive strategies were assessed using students' self-reported visualization use and essay changes. Learning was assessed via true/false items, short answer questions, and self-generated concept maps. Results indicated that color-coding promoted better revision strategies, and both graphical cues supported deeper understanding of domain content compared to a typical concept map display. Implications are discussed for visual display designs that provide meaningful feedback during online learning.

Keywords: visualization; graphical display; self-regulated learning; multimedia; online learning

Introduction

Prior research has demonstrated that students experience many challenges in regulating their own learning in online environments (e.g., Azevedo, Guthrie, & Seibert, 2004). Because these online environments are inherently nonlinear and user-controlled, effective learning requires students to plan, monitor, and reflect in meaningful ways as they work with Web materials (e.g., Williams, 1996). Significant challenges remain in finding instructional strategies and materials that will support learners in the cognitive and metacognitive processes necessary to promote effective self-regulated, online learning. In this research we explored the potential benefits of using graphical cues (e.g., color-coding and size-scaled nodes) in concept maps to help guide students in effective self-regulated learning with online resources. Concept maps may serve as an effective advanced organizer for online learning, because they depict a coherent conceptual structure that may be difficult to extract from unorganized, online content. Prior research has shown that, for a given set of learning materials, concept map visualizations enhance the saliency of text macrostructures (O'Donnell, Dansereau, & Hall, 2002). Although concept maps have repeatedly been shown to enhance recall of main ideas from text, there has been little evidence that these visualizations can support knowledge transfer or effective metacognitive processing during learning.

Self-Regulated Learning in Online Environments

Online learning involves comprehension across many media-rich resources presented in a non-linear environment. Learning online (i.e., from the Web) is a complex task that involves both information search and retrieval (e.g., Marchionini, 1995, 2006) and comprehension of a variety of materials that lack overall coherence (e.g., Lynch, 2008). Searching for information online is a self-regulatory challenge because (among other demands) it requires planning a search strategy based upon individual learning goals. Assuming that students are able to complete the difficult task of finding and selecting relevant Web-based materials, they then face the challenge of successfully regulating their learning processes in order to develop meaningful domain understanding from the online resources themselves (e.g., Azevedo, Guthrie, & Seibert, 2004; Winne & Perry, 2000). Part of this self-regulated learning challenge is that learners must manage multiple, competing cognitive demands as they work with online materials. In the next section, we discuss the cognitive processes associated with self-regulated learning.

Processes of Self-Regulated Learning In online learning environments, students must make learning decisions (e.g., what are the most important ideas/concepts), plan how to learn targeted information, and constantly monitor their developing understanding (Williams, 1996). To effectively self-regulate, learners must monitor their knowledge development as they engage in planning effective learning strategies – overall, they must be strategic in these efforts, knowing when and how to adapt these strategies to match cognitive, motivational, and task conditions (e.g., Winne, 2001).

Research has revealed that learners typically demonstrate great difficulty in self-regulating their learning when using online environments to learn about complex topics, such as science; in the face of these challenges learners sometimes experience little overall knowledge gain even after online study (e.g., Azevedo & Cromley, 2004). Less effective learners in these online environments frequently lack effective planning, goal setting, monitoring of understanding, effective strategy use, and reflection on their overall learning progress.

In this research, we were particularly interested in effective planning during self-regulated, online learning. Planning is an important part of online learning because it

influences the ways that students seek information (i.e., search for resources online), in addition to the ways that they comprehend it (i.e., learning from the online resources).

Supporting Self-Regulated Learning Various methods have been investigated to support self-regulated learning in online environments; these methods include training in the processes of self-regulated learning (Azevedo & Cromley, 2004) and providing scaffolding hints and prompts during hypermedia learning (Azevedo, Cromley, & Seibert, 2004). Although both methods have shown promise, they also are relatively resource-intensive and may be difficult to scale into larger practice. For example, in Azevedo et al. (2004), adaptive scaffolding provided by human tutors facilitated the greatest gains in learning and the most effective self-regulated learning processes.

In this research, we explore the possibility of utilizing visual displays and graphical cues to support effective self-regulated learning while searching for and learning with online materials.

Learning with Visual Displays

Visual Displays and Learning Research on visual displays has demonstrated that the structure of a visual representation can change the knowledge representations formed by learners. For example, representing two steps in a process as occurring simultaneously in a visual graphic leads to closer association between the steps (as measured by reaction time) than when the steps are *described* as occurring simultaneously but appear linear in text order (Glenberg & Langson, 1988). Adjunct visual displays (i.e., cause-and-effect diagrams accompanying text) facilitated better comprehension and causal understanding than when learners were provided with text alone or cause-effect statements in a list form (McCrudden, Schraw, & Lehman, 2009).

Research in online reading and comprehension of hypertext indicates that graphical displays can impact the quality of students' comprehension, likely by providing a conceptual structure to hypertext materials. Salmerón et al. (2009) found that graphical overviews studied prior to reading complex hypertext content led to greater comprehension, even when participants had little or no prior knowledge. Students learn more when they follow online links in an order that is driven by conceptual coherence rather than student interest (Salmerón, Kintsch, & Cañas, 2006), but students with low prior knowledge most often choose links based upon screen position or interest (Salmerón, Kintsch, and Kintsch (2010).

The graphical overviews used by Salmerón et al. (2009) to structure hypertext learning are similar to concept maps, which have long been shown to support novice learners in facilitating recall of main text ideas (i.e., text macrostructure) when provided prior to learning (see O'Donnell, Dansereau, and Hall, 2002, for a review). However, there has been little evidence that these concept map visualizations can support effective metacognitive

processing or deeper understanding (as opposed to simple recall) during learning.

Graphical Cues in Visual Displays

Research has demonstrated that highlighting a specific feature within a diagram or other visual instruction can successfully direct the learner's attention to critical information and enhance learning and comprehension (e.g., de Koning, Tabbers, Rikers, & Paas, 2009; Mautone and Mayer, 2007). Thus, graphical cues can impact how learners process multimedia materials. From a self-regulated learning perspective, graphical cues could help learners plan their online learning activities and could scaffold their monitoring of their existing understanding by drawing attention to the weak concepts in the student work product, much like a human tutor would do.

Experiment

In this research we explored the impact of personalized feedback (through the use of graphical cues) in combination with a domain knowledge visualization to promote effective planning during self-regulated learning with online resources. These graphical cues were: 1) color-coding of feedback to indicate error types, and 2) size-scaling of nodes to indicate conceptual importance to the overall domain.

We hypothesized that color-coding would facilitate effective planning, by helping learners to implement more effective learning strategies as they revised specific types of problems in their existing understanding (e.g., looking up new information when their knowledge was incomplete). We hypothesized that size-scaling would help students engage in more effective planning, by helping them prioritize and focus on key domain content during online learning. Assessments focused on changes in self-reported planning (specifically prioritization of learning), self-reported revisions to a scientific essay, and domain learning.

Method

Participants Forty-four undergraduate students at the University of Utah participated in this study in partial fulfillment of a class research requirement.

Design This study utilized a 2 (color-coding vs. no color-coding) X 2 (size-scaling vs. no size-scaling), between-subjects experimental design. Participants were randomly assigned to one of the four experimental conditions upon arrival.

Materials

Draft Essay The learning task in this study asked participants to make revisions to an existing essay on plate tectonics. Providing this draft essay to all conditions allowed us to create a visualization that provided the same conceptual overview to all students, across which graphical cues could be varied systematically, and compare revisions to the same five targeted erroneous sentences across all conditions rather than judging individual essay quality.

Although the learning task is formatted like a writing intervention, we are not focused on the students' writing, per se. We are interested in how the graphical cues influence actions taken during the research and revision process.

The "draft" essay contained three types of errors that have been identified as common knowledge issues for novice, undergraduate science learners using an automatic feedback system for online learning (Butcher & Sumner, 2011; de la Chica et al., 2008): incorrect statements, missing concepts, and fragmented/incomplete knowledge. The draft essay contained five targeted errors (one incorrect statement, two missing concepts, and two fragmented/incomplete statements).

The draft essay was introduced to participants during the learning task by asking them to imagine that they had been assigned a group project – to write an essay on plate tectonics – for an introductory Earth Sciences class. The draft essay was introduced as the first draft, written by a fictitious member of their group. Each participant was told that his/her goal was to revise the essay so that it would be ready to submit for final grading.

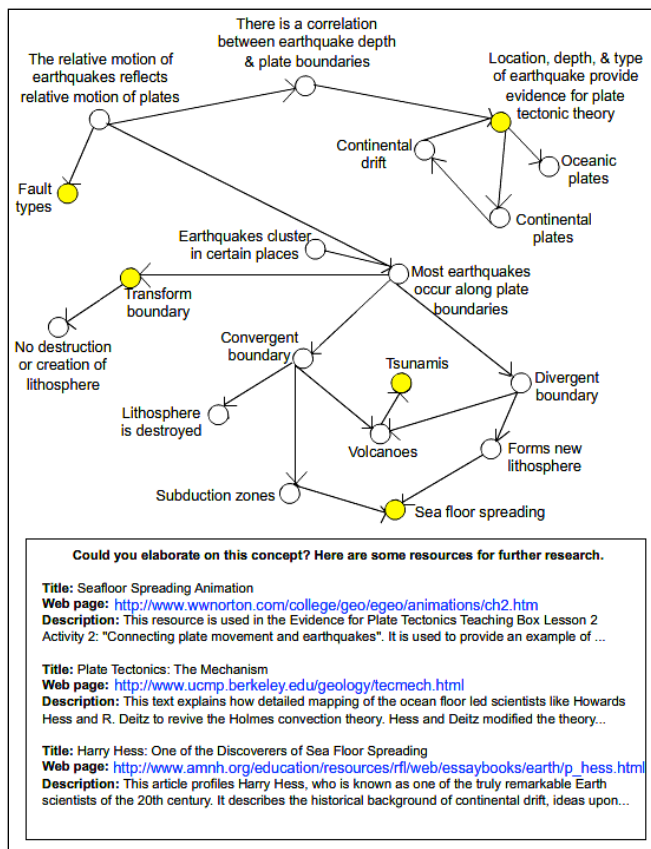


Figure 1: The concept map provided to the control group (no color-coded nodes, no size-scaling of nodes) with suggested resources for the sea floor spreading node are shown below the concept map.

Feedback Visualization In each condition a concept map visualization provided a domain overview (see Figures 1 and 2) in addition to feedback on the draft essay. The visualization was provided on a computer screen alongside a dynamic view of the draft essay the participant was tasked with revising. The concept map presented relevant concepts from the draft essay in nodes; arrows between the nodes indicated a relationship between connected concepts. Size-scaled nodes and color-coded nodes varied by condition.

All concept nodes in the visualization were interactive: nodes that were highlighted in some manner (by varied colors corresponding to different error types in the color-coding condition or by consistent, yellow highlighting in the no-color-coding condition) indicated errors that had been "detected" in the draft essay for that concept.

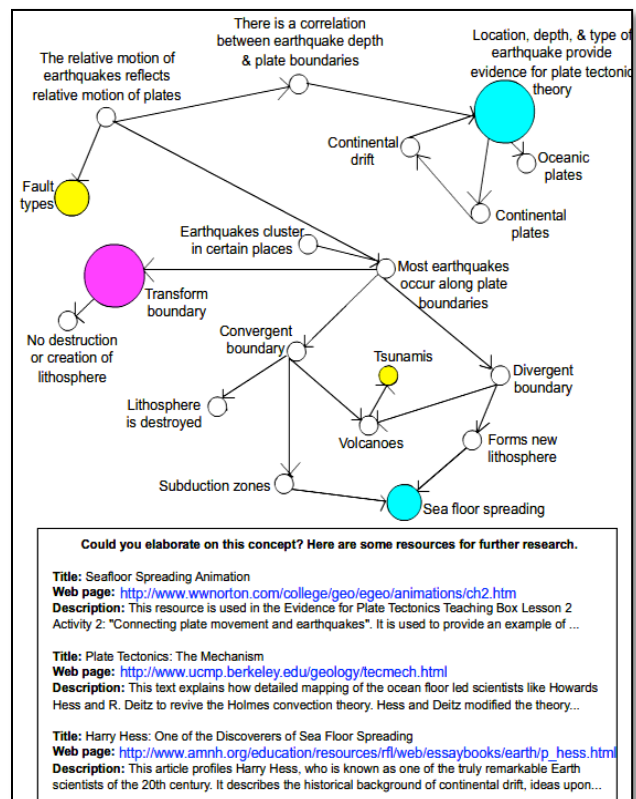


Figure 2: The concept map provided to participants in the combined condition with suggested resources for the sea floor spreading node are shown below the concept map.

When a student clicked a highlighted node, two things occurred. First, the sentence(s) in the draft essay corresponding to the click node were highlighted. The purpose of this highlighting was to support coordination across the visual and textual information provided to participants. Second, clicking a highlighted node in the visualization displayed a list of selected resources pertaining to the node drawn from the Digital Library for Earth System Education (<http://dlese.org>). Resources were selected based upon a prior study in which the draft essay had been

analyzed (Butcher & Sumner, 2011). All conditions were provided with the same suggested resources; students were free to use (or not to use) the resources in any manner that they wished. Presenting resources held the self-regulatory process of searching for applicable online resources constant across conditions and, therefore, information search and retrieval processes were not included in this study design or analysis.

Graphical Cues The control condition visualization displayed equal sized nodes and no color-coding beyond the consistent, yellow highlights that indicated an error in the essay (see Figure 1). Color-coded errors (see Figure 2) varied the color of the error node depending upon the error type. Pink nodes indicated incorrect information, blue nodes indicated fragmented knowledge, and yellow nodes indicated missing concepts. Size-scaling (see Figure 2) was used to indicate the importance of the node to the overall domain. The variance in circle diameter indicated the size difference. Large nodes were the most important domain ideas among the concepts detected as errors from the draft essay, medium nodes were moderately relevant to the domain, and small highlighted nodes were not completely necessary in understanding plate tectonic theory. Criticality to the domain was determined by relationship to the theory of plate tectonics.

Revision Questionnaire The revision questionnaire was a self-report measure that participants completed following the draft revision task. This questionnaire sought to determine how learners planned/prioritized their learning and what strategies they used to revise the draft essay.

Questions were split into two sections: section one asked how the participant utilized the concept map and what, if any, features guided revision; section two asked participants to explain – for each of the five essay errors – why the sentence had been targeted as problematic and how the participant had revised the error (if s/he had done so).

Students’ self-reported error revisions were coded to assess the effectiveness of strategy use; revisions were analyzed according to the Construction-Integration model (Kintsch, 1994). According to the CI model, knowledge that is integrated or transformed leads to the development of a situation model. The situation model is a flexible, long-lasting representation of knowledge that is associated with deep understanding and knowledge transfer. In contrast, knowledge that is learned in a rote manner (e.g., by memorizing) leads to a textbase representation. The textbase representation does not support application or transfer of knowledge. In the current study, students’ self-reported revisions were analyzed for whether they integrated or transformed knowledge (see Table 1 for examples); these revisions were coded as *deep*. Revisions that failed to transform or integrate information were coded as *shallow*; these revisions include revisions to grammar and style, as well as removal of errors (see Table 1).

Table 1: Self-Reported Revision Categories & Examples.

Reported Revision	Example
<i>Shallow</i>	
Deleted content	“I deleted it, it was incomplete and irrelevant.”
Grammar/stylistic changes	“The only thing I changed in the sentence was that I added rock after the word molten.”
<i>Deep</i>	
Describe relationships	“I talked about how sea floor spreading has little to do with creating volcanoes and more to do with recycling the sea floor.”
Integrate domain content	“I added information about what causes sea-floor spreading and mentioned convection currents in the magma.”

Learning Assessments Learning was assessed via true/false items, short answer questions, and a self-generated concept map. All assessments were completed before and after the essay revision and online learning task.

True/False Items. Factual knowledge was assessed using a true/false test that targeted general, factual knowledge about plate tectonics. For example, *plate boundaries can be convergent, divergent, or transform*. This test included 40 items; participants were given one point per correct response for a maximum total score of 40 points.

Short Answer Questions. Short answer questions were designed to test knowledge transfer/application. Each question asked participants to apply their understanding of plate tectonics to a problem that had not been learned or encountered in the online materials. For example, *John says that most volcanoes are located at transform plate boundaries – where friction between plate boundaries creates great heat that melts rock into molten lava. Is John right about the typical location and cause of volcanoes?* Short answer questions were scored using a rubric that specified a point for each relevant idea unit. The maximum score on the short answer test was 20 points.

Concept Map Generation. Concept maps were compared within subjects by analyzing change in concept map structure to classify participants as either indicating non-learning (1 point), surface learning (2 points), or meaningful learning (3 points), using the map structures described by Hay (2007; Hay, et al., 2008). Non-learning was indicated by an unchanged knowledge structure; surface learning was indicated by some new or rejected concepts but no new links between prior and new knowledge; and meaningful learning was indicated by significant revision to the knowledge structure. Concept maps were used to assess students’ depth of domain understanding.

Procedure First, participants were assessed on their prior knowledge of plate tectonic theory using the learning assessments. Following the pretests, participants were

briefed on the essay task. Once the participants read the provided draft essay, they used their randomly assigned condition to explore online materials and revise the essay. Participants were given 35 minutes to revise the draft essay. Immediately following the revision task, participants had 20 minutes to complete the revision questionnaire. Finally, participants again completed the learning assessments (the true/false items, short answer questions, and concept map generation). Total study duration was two hours.

Analysis Results were analyzed using a repeated measures multivariate analysis of variance for pre and post true/false and short answers. A multivariate analysis of variance was calculated for the revision questionnaire (since this assessment was given only after learning) and concept map structural change. A Chi square was performed for self-reported use of graphical cues. Alpha level was set at $p = .05$ for all analyses.

Results

Learning Assessments Results showed a main effect of test time for true/false items ($F_{(1,40)} = 6.58, p < .01$) and short answer questions ($F_{(1,40)} = 5.81, p < .02$). Means and standard deviations for true/false and short answer are shown in Table 2. All students gained significant factual knowledge between pre- and posttest on the true/false statements and short answer questions. This is not surprising, given that the learning task supported specific error revision and provided sufficient online resources with information for revising those areas. There were no significant differences between graphical cue conditions on these assessments ($F_s < 1$).

Table 2: M and (SD) for Learning Assessments.

Condition	True/False Items %		Short Answer Total	
	Pretest	Posttest	Pretest	Posttest
Control	.60(.03)	.62(.02)	3.8(.85)	4.8(.94)
Color-coded	.67(.02)	.69(.02)	5.3(.78)	6.7(.86)
Size-scaled	.59(.03)	.67(.02)	3.8(.81)	5.5(.90)
Both color-coded and size-scaled	.59(.03)	.63(.02)	3.8(.81)	3.8(.90)

However, results did show condition differences when examining the measure of domain understanding. Scores from students' self-generated concept maps showed a significant interaction between independent variables ($F_{(1,40)} = 4.23, p < .04; \eta^2 = .10$). Table 3 displays concept map scores by condition. Since concept maps reflect key domain ideas and their relationships, this result indicates that graphical cues can impact deeper domain understanding during online learning, possibly by providing a conceptual organization to scaffold online activities. The size-scaled condition showed the strongest concept map scores, suggesting that providing domain centrality cues may help guide overall domain exploration.

Table 3: M and (SD) for Concept Map Generation.

Condition	M (SD)
Control	1.90 (.32)
Color-coded	2.25 (.45)
Size-scaled	2.36 (.51)
Both color-coded and size-scaled	2.18 (.41)

Self-Reported Revisions Participants using the color-coded concept map reported making more revisions to target sentences compared to participants who saw the size-scaled nodes ($F_{(1,40)} = 8.84, p < .01; \eta^2 = .18$). Another main effect for the color-coded concept map was found in self-reported revision quality; participants in the color-coded condition reported making significantly more deep revisions to the essay's five identified errors ($F_{(1,40)} = 52.4, p < .01; \eta^2 = .29$). There was no observed interaction of the independent variables. Overall, 89% of participants reported prioritizing their essay revisions by error type, as indicated by the color-coding graphical cue (e.g., fixing incorrect sentences first, then missing concepts, and fragmented concepts last). Table 4 reports statistics for both the total errors modified out of five targeted error sentences in the draft essay and the percent of self-reported revisions classified as deep.

Table 4: M and (SD) for Self-Reported Revisions.

Condition	# Modified	% Deep Revisions
Control	2.10 (1.19)	.06 (.09)
Color-coded	3.17 (1.03)	.35 (.21)
Size-scaled	1.73 (1.10)	.11 (.13)
Both (color-coded and size-scaled)	2.73 (1.27)	.25 (.22)

Use of Graphical Cues A Chi square was calculated for the number of participants who reported using the graphical cues. As seen in Table 5, more students reported prioritizing their revisions based upon graphical cues when they viewed the color-coded nodes compared to those who did not see color-coded nodes ($\chi^2 = 11.78, p < .01$).

Table 5: N for Graphical Cues Usage.

Color-Coded	Used Graphical Cues
Yes	15
No	3

Discussion and Conclusion

Overall, results suggest that students can make use of graphical cues integrated within a domain knowledge visualization to support key online self-regulated learning processes such as planning by prioritization. Findings show that color-coding of errors in a concept map helped students prioritize their revisions, supported more frequent revision, and improved the quality of students' revision strategies.

Students' inattention to size-scaled nodes may indicate that they are unable to utilize indicators of domain centrality

within the experimental learning task. Although size-scaled nodes failed to impact students' perceived processes and strategies, they ultimately did have an effect on students' final conceptual understanding of the domain (as represented in the post-learning, self-generated concept maps). Thus, while size-scaling may not impact the strategic processes of which students are aware (and can report), these cues may support deeper conceptual coherence of encountered information in an online environment.

Notably, color-coding not only improved the frequency with which students reported revising errors, but also the depth of their reported revision strategies. It should also be noted that this result occurred even though the control condition saw a concept map in which errors were highlighted (but not color-coded by error type). In this case, the visual cue provides an effective method for strategically processing error types as a planning tool during self-regulated learning.

More work is needed to understand the range of graphical cues that can support self-regulated learning in online environments. This study provides a promising first step in demonstrating that well-designed cues in visual displays can have a positive and significant effect on self-regulated learning. Research is underway to investigate the impact of the feedback content (error type and concept importance) versus the saliency of the graphical cues (color-coding and size-scaling).

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