Navigational spatial displays: The role of metacognition as cognitive load

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Abstract

One hundred and six undergraduates searched a hypermedia environment under three navigational conditions, wrote an essay measuring their comprehension, and completed a test of metacognition. The map conditions were spatial/semantic, spatial only, and none. Analyses revealed that a navigational map capable of incurring an integrative cognitive model of the meaningful relationships underlying website content incurs significantly more metacognitive load and higher levels of comprehension. When the map was incapable of revealing these relationships, metacognitive skills were of no value and compromised learning performance. The results demonstrate that a navigational map can create significantly more cognitive load; however, the nature of the load—whether germane or extraneous—is based on the degree to which the map permits integrative model construction during processing.

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Learners who navigate Internet websites spend much of their cognitive effort orienting to the content and structure of the site. This orientation generally occurs at the expense of the elaborative and evaluative processing necessary for deriving deep levels of comprehension and achieving instructional goals (Eveland & Dunwoody, 2000). The condition appears with surprising regularity across a broad spectrum of learning outcomes, patterns of navigational behavior and a variety of hypermedia environments (Baylor, 2001; McDonald & Stevenson, 1998; Nilsson & Mayer, 2002). McDonald and Stevenson (1998), for example, showed that the learning outcomes of learners navigating a hypermedia environment are decreased when the navigational structure of the environment is unavailable because the learners need to simultaneously attend to the task at hand while trying to orient themselves to the spatial configuration of the site. Even forcing learners to think about the structure of the hypermedia environment is not a certainty for better navigation (Nilsson & Mayer, 2002). That is, learners, when afforded information about the navigational structure of content within a website, fail to show performance increases in content comprehension relative to learners without...
it—although decreasing the effort required to comprehend the structure of a website improves learners’ navigation performance over time.

Other researchers have found similar results. Tripp and Roby (1990), for example, found that the absence of either a graphical advanced organizer or a spatial metaphor for the organization of a website hindered the amount learners acquired from the site. Finally, Chen and Rada (1996) and Simpson and McKnight (1990) in general found that learners given the opportunity to derive structural knowledge of a site were more efficient in their navigational behavior, visited fewer extraneous pages, and yielded more efficient achievement of specific instructional goals. In short, the problem with hypermedia learning is that learners must be able to (a) comprehend the information available in the site, (b) keep the structure of the site in mind, and (c) integrate the information into a cognitive model that allows them to achieve their instructional goals. The investigation reported here was designed to address this problem.

The problems learners experience in balancing content comprehension with orientation to navigational structure is typically explained via the concept of cognitive load—the amount of space consumed in a limited working memory incurred by the cognitive demands necessary for orienting to a website’s navigational structure, navigating the site and deriving a cognitive model for comprehending its contents (Paas, Renkl, & Sweller, 2003). Sweller’s (1988) Cognitive Load Theory is based upon Baddeley’s (1986) Working Memory Model—a tripartite system of working memory comprised of a central executive and its two slave subsystems: the phonological loop and the visuospatial sketchpad.

One of the ways to reduce cognitive load in hypermedia navigation is to provide learners with a navigational map. Site maps presumably reduce learners’ cognitive load because they reduce the disorientation learners experience by making explicit the navigational structure of the site (Danielson, 2002; Eveland & Dunwoody, 2000; Nielson, 2000; Zizi & Beaudouin-Lafon, 1995). Danielson (2002) contended that a map depicting the nodes and links between locations in a website is all that is necessary to decrease the level of disorientation learners experience when they navigate a site. Park and Kim (2000) agreed, finding that the provision of a navigational map assists learners in orienting themselves, finding relevant textual information, and decreasing cognitive load because the map leaves more space in working memory for processing information.

However, we believe that it is unclear why a navigational map should reduce a learner’s cognitive load during hypermedia navigation. While navigational maps presumably orient learners to their present location within a website, there is no clear evidence as to what underlying cognitive activities are incurred by the presence of the maps. Navigational maps provide more, not less, information when websites are searched. Maps also convey a myriad of different types of information, which can cause an increase in cognitive load instead of reducing it. It is also unclear as to whether the reduction of cognitive load by using a navigational map for discerning a website’s structure allows learners to derive deeper comprehension of the information contained within the site. Thus, we believe that it is unclear which factors of a map are responsible for the reduction of cognitive load, and what cognitive variables are involved in learners’ performance as a function of the load reduction. Finally, we are not convinced that the provision of a website map reduces learners’ cognitive load. The investigation reported here addressed these issues directly.

1. Cognitive processing of maps

A number of researchers have attempted to explain the way maps and other graphic adjuncts are processed together with text (cf. Robinson, Katayama, & Fan, 1996; Schnott, Bannert, & Seufert, 2002; Shah & Carpenter, 1995; Shah, Hegarty, & Mayer, 1999; Verdi & Kulhavy, 2002; Winn, 1994). In the main, the role of the displays is explained in terms of the limitations of working memory and their role in either increasing or reducing cognitive load.

According to Kulhavy’s Conjoint Retention Model (Kulhavy & Stock, 1996) a map is encoded as a single chunk of information in working memory and acts as an organizer for the semantic and spatial relations it represents. There has been a great deal of research on maps with adjunct text (Kulhavy, Stock, & Kealy, 1993; Kulhavy, Stock, Peterson, Pridemore, & Klein, 1992; Schwartz, 1997; Schwartz & Kulhavy, 1988; Verdi, Johnson, Stock, Kulhavy, & Whitman-Ahern, 1997). The results of this research reveal that maps reliably facilitate the long-term retention of adjunct text and suggest that maps free up working memory for processing, leading to deeper comprehension of text. Kulhavy and his colleagues, employing Paivio’s (1986) dual coding model, explain that maps, as graphic adjuncts to text, are processed in the visual store, while text is processed in the verbal store. The referential links between the two allow the propositions of text held in the verbal store to be placed at specific locations on the map in the visual store. Once placed there, the map image is used by learners to “unpack” the verbal propositions of text during the retrieval process. Thus,
the map serves as an organizational framework with which to encode, store and retrieve text elements in memory. That is, map-text elements are combined into one informational “chunk” and sent to long-term memory as a unitary representation.

However, while the conjoint retention model has been repeatedly demonstrated empirically to both explain and reveal the facilitation effects of maps on the comprehension of text, the model has not been employed to explain the value of maps in hypermedia environments. Moreover, others (e.g. Mayer, 1997; Schnotz et al., 2002) contend that the conjoint retention model is insufficient to explain the value of maps on text simply as a function of the slot-availability hypothesis. Schnotz et al. (2002) maintain that because maps and text are based on different sign systems and use different principles of representation, they are encoded separately and stored differently. That is, the mental models constructed from the descriptive (text-based) and depictive (graphic-based) information of maps and text, respectively, are created through two separate systems. Descriptive information contained in the surface structure of text is initially processed verbally, and then broken down into its propositional parts. On the other hand, depictive information is initially perceived visually and then represented internally as a visual image. The two are transformed into separate mental models containing both descriptive and depictive information that are shared and integrated during the comprehension process. Thus, the information contained in each influences, and is influenced by, the other for the interpretation and comprehension of both. However, the net effect is a heavier, rather than lighter, load on the working memory system; and we contend particularly heavy when a map is used with text in a hypermedia environment. In the present investigation, we were concerned with the nature of this load when a map is employed in hypermedia for purposes of navigation.

2. Maps, navigation and cognitive load

There is a clear difference between a map that is used in attempting to navigate a website and a map that is simply a graphic used to represent the relationship of text. Maps, when incorporated into a website, serve more than just one purpose. A navigational map is indeed a graphic that may be used for the interpretation of the text, but it also shows where a learner is in his/her navigation and provides locational cues for information present in the website. A website map also can convey the semantic relationships inherent in the text contained across pages of a site. These added functions require much more cognitive processing than a typical linear map used to aid text comprehension. The results of Nilsson and Mayer (2002) underscore this point.

Nilsson and Mayer (2002) found that using maps to navigate a website, results in incomplete cognitive model construction by learners because they are only able to handle a portion of the website due to cognitive load. Thus, maps are useful for showing learners where to find relevant information, orient to the structure of a site and cue important connections between concepts across various website locations. However, the maps cause more cognitive load to create the cognitive models necessary to represent all of the spatial—locational information, in addition to website content. Farris, Jones, and Elgin (2002), found similar results in that their site map’s utility was lessened when it did not convey the site’s conceptual relationships. Stanton, Taylor, and Tweedie (1992) also found that learners were unable to fully comprehend the content and structure of a website with the use of a map because the site map impaired learners’ construction of content schema. In short, website maps may help with learner’s navigational behavior, but seem to compromise the construction of mental models necessary to cognitively represent website-derived knowledge.

When taken together, the evidence seems to suggest that navigational maps may have utility in reducing load for purposes of navigation, but not in freeing up the cognitive resources necessary for developing a complete model for cognitively representing the content of the site. It may also be that more than one type of cognitive load is generated during website navigation—especially in the presence of a navigational map. For example, Sweller, van Merrienboer, and Paas (1998) describe three types of cognitive load: intrinsic, extraneous, and germane. Intrinsic load is the type of immutable load inherent in the parameters of a task; extraneous load is the load resulting from irrelevant or unnecessary task features, and germane load is the load resulting from relevant and pertinent cognitive activities necessary for achieving instructional goals—that is, the type of load enhancing a learner’s ability to retain information meaningfully (Paas et al., 2003). It is important to note that increasing germane cognitive load is necessary and helpful in monitoring problem solving skills and strategy use. However, the point is that navigational maps probably reduce or intensify one of the three types of load, depending upon the purposes for which the map is designed and/or the purpose for which it is used by a learner. We set out to demonstrate the point that website maps induce different types
of cognitive load depending upon the design of the website map, the type of cognitive processing in which the learner is engaged, and the way the map is used pursuant to a learner’s instructional goals.

3. Executive functioning and cognitive load

In order to be effective, then, a website map should engender germane cognitive load and minimize cognitive load that is extraneous. However, since the type of load generated by a map is contingent upon the learner’s instructional goals, we propose that the type of processing learners use when navigating a site is based on a learner’s appraisal of the utility of a map relative to these goals. Valke (2002) discusses this type of processing as “metacognitive load”, and suggests that when cognitive load is high under conditions of web-based learning, the explicit monitoring of cognitive processes indigenous to metacognition occurs within the realm of germane cognitive load. Thus, a learner’s estimation of the utilitarian value of a website map is metacognitive. When a learner evaluates the utility of a map as high, the load engendered is germane to the task; and when low, the load is extraneous.

In either case, the load produced under these conditions is due to processing in the executive portion of working memory. Thus, since germane cognitive load can be thought of as operating within the central executive of working memory (Valke, 2002), we contend that website maps, in order to be effectively employed, should be germane to the instructional task and engender metacognitive skills that are relevant.

In the present investigation, we set out to demonstrate the relationship between germane cognitive load and metacognition when learners are required to navigate and construct meaning from a website while using a navigational map. Guided by the findings of recent investigations on metacognition, we knew that the level of a learner’s metacognitive skill was a significant predictor of information recall under conditions when a site map was complex (Schwartz, Anderson, Hong, Howard, & McGee, 2004). That is, a complex map differentiated between learners according to their metacognitive skills, with learners possessing high levels of metacognition showing significantly better ability to make meaning of the information contained in the site. We also knew that website comprehension could be predicted from learners’ metacognitive skills; learners comprehended significantly more from a website when their metacognition was high (Schwartz, Oppy, & Gust, 1999). Finally, Eckhardt, Probst, and Schnotz (2003) suggested that the learning aids attached to multimedia learning environments are mediated in their efficacy by learners’ metacognitive skills. In short, learners learned more from a website if, when necessary, they had to engage their metacognitive skills.

And yet, each of the investigations above failed to differentiate the type of cognitive load generated when metacognitive skills were in use—whether the load was germane or extraneous. We contend that it is essential to determine the type of load, and the metacognitive skills incurred by this load, in order to be able to make predictions about learning outcomes. Thus, we presented learners with clear instructional goals, having them search a website using one of two navigational maps or none at all. The website contained information about concepts and principles explaining basic theories of learning. The learners’ task was to learn as much information as possible in order to advise a taskforce of university administrators on ways to help college students make good behavioral choices across a broad cross-section of university life. One map revealed information of the meaningful relationships between learning concepts by virtue of the spatial arrangement between the map’s links and nodes. The other map conveyed only web-page location within the site. The first was capable of helping learners generate an integrative model of the semantic text base across pages of the site; the second was capable of revealing only text-page location.

If we are correct in our assumptions of the way map design, metacognitive skills, and instructional goals interact in the context of cognitive load, we can expect predictable patterns of performance to result. Thus, when a website map is designed to generate a mental model integrating the text base of the site with the site structure and the goal of the learner is to deeply comprehend the structure and meaning of the site, then metacognitive skills would need to be high in order to achieve the goal. Cognitive load would be high but germane. When cognitive load is high and germane, performance would be expected to be high relative to the instructional goal. However, when learners have low metacognitive skill, the load is high and extraneous, yielding performance levels that are expected to be low relative to the instructional goal. That is, learners with low metacognitive skill navigating a website with a complex navigational aid will show lower performance on comprehension and retention tasks. The cognitive load incurred from using this navigational aid is high and non-productive to the learner. We expect this to occur because a learner must negotiate elements of the website with a complicated site map that requires a great deal of cognitive effort. The information within the site would be more difficult to retain because much of the learners’ metacognitive ability is being engaged by the usage of the site map. Thus, we contend that, under the latter condition, the load is extraneous because
learners with low metacognitive skills cannot make use of a complex map design for deriving an integrative mental model for deep comprehension.

On the other hand, when a website map is designed to reveal only the structure of a site, and the goal of the learner is to deeply comprehend the structure and meaning of the site, then the goal and the map are inconsistent, rendering metacognitive skills of little to no value. Under this condition, cognitive load is high, but extraneous. Thus, when cognitive load is high and extraneous, performance would be expected to be low relative to the instructional goal—at least for those learners with high metacognitive skills. Since the map is void of information relative to the way website content can be combined theoretically, learners’ inclination to use metacognitive skills for this purpose would create extraneous cognitive load expected to compromise their performance.

Finally, when learners have low metacognitive skills, the cognitive load necessary to meet the instructional goals is germane when utilizing a spatial only navigational aid, rendering performance that is higher. Higher performance, however, would be expected only on surface level retention measures because an integrative model of comprehension is unnecessary for performance. We expect this to occur due to Kalyuga, Ayres, Chandler, and Sweller’s (2003) Expertise Reversal Effect. This effect explains that there are some instructional aids (i.e., site maps) that help learners with low knowledge (either conceptual or metacognitive) but are a hindrance to those with high levels of expertise. That is, the cognitive load that the spatial only site map incurs actually helps those learners with low metacognitive skill. Thus, cognitive load is still rendered but is germane to the task. The investigation below was designed to test these hypotheses.

4. Method design

4.1. Design

Two factors, Navigational Structure and Metacognitive Evaluation were combined to yield 6 experimental cells. The resulting design was a 3 Navigational Structure (Semantic & Spatial vs. Spatial only vs. None) × 2 Metacognitive Evaluation (High vs. Low) fixed analysis of variance, with the metacognitive evaluation factor manipulated as a between-subjects variable.

5. Subjects

5.1. Participants

One hundred and six undergraduate volunteers were sampled from a midsize western university. Of the total, 79 were female and 27 were male. Each participant was randomly assigned to one of the between-subjects groups. Equivalent proportions of each sex were distributed evenly across each experimental cell. Participants were primarily white, middle class students averaging 22 years of age, with no apparent sensory or learning disabilities that would preclude their participation in the investigation.

6. Materials and instruments

6.1. Experimental website

The experimental website was a 22-page hypermedia environment consisting of 5 pages of introductory information and 17 pages of text describing basic concepts in learning. The introductory information was comprised of an informed consent page, a page of general instructions, a page to route participants to one of the three experimental conditions, and 2 pages of condition-specific instructions. The learning pages were designed with a title at the top, a list of concept names on the left, and 1 to 2 paragraphs, averaging 175 words in length in the lower half of the page.

Each page described one of 17 learning concepts derived from the learning chapter of a popular general psychology textbook (Myers, 1999). Relative to the three conditions of navigational structure, each page was navigable to the other 16 pages by either one of three methods—a graphical site-map designating semantic and spatial relationships between the concepts, a graphical site-map designating only spatial contiguity between pages, or a back and next button only. In the map-absent condition, the navigational buttons were placed according to standard web-page design at
the bottom of each page. When the site-maps were present, they were located in the top right hand corner of the page. When there was no site-map, a simple non-navigable logo was shown. The concept names listed in the left column were not hyperlinked to other pages in any of the three conditions of navigational structure.

6.2. Navigational maps

The basic navigational site-map was a diagram consisting of 17 nodes and 9 links. The nodes were circular and the links were straight lines. When the map conveyed both semantic and spatial relationships, the location of contiguous node pairs were placed relative to each other in a 3-dimensional spatial orientation, with distance, direction and depth equivalent to the semantic relational structure between the nodes (See Fig. 1). The 3D depiction was necessary to reveal both the semantic relational structure and the spatial distances between concept node pairs.

This structure was derived by evaluating the semantic relationships between content on each page using Latent Semantic Analysis (LSA) (Landauer, Foltz, & Laham, 1998). LSA is a statically based method for representing the meaning of words, phrases, sentences, or a collection of sentences in the context of a larger corpus of text; that is, a technique for inferring relations among textual excerpts of a passage to the entire passage as a whole. (See http://lsa.colorado.edu.) The method yields an associative value of relational meaning between each passage segment (see Table 1). The text used in our investigation was sampled from a commonly used general psychology textbook comprising the large corpus of text within the LSA site. The text was then divided by concepts into separate pages of our experimental site, with the semantic basis of the text retained and the surface structure modified for ease of reading.

The values were used to set the distances between pairs of nodes in the 3-dimensional space. When the site-map conveyed only spatial relationships, the contiguity between the nodes was the same as the site-map described above, but the distances of the links between and the size of the nodes were equal (see Fig. 2).

6.3. Measure of metacognition

The Inventory of Metacognitive Self-Regulation (IMSR) (Howard, McGee, Shia, & Hong, 2000) was used to measure participants’ metacognitive knowledge and skills. The IMSR is a 32-item self-report questionnaire, requiring respondents to rate themselves on a 5-point Likert scale (with 1 = never; 5 = always) on statements describing the activities they engage in when they attempt to solve problems during learning. The instrument has been reliably analyzed into 5 separate factors—Knowledge of Cognition (K), Evaluation During Cognition (E), Subtask Monitoring (SM), Objectivity During Cognition (O), Problem Representation (PR), and a Total Metacognition Score (TM). The K factor comprises 8 items intended to measure how much respondents understand about the organization of their own memory in addition to the way they learn. The E factor contains 6 items designed to measure the degree to which
a learner double-checks his or her problem-solving strategy to evaluate its efficacy and success. Factor SM contains 5 items designed to assess a learner’s ability to strategically decompose a problem to its subtask routines and monitor strategy choice and success. The O factor comprises 6 items assessing a learner’s ability to objectively reflect on his or her learning as it proceeds. Finally, the PR factor contains 5 items measuring the degree to which a learner understands a problem fully before attempting its solution, with the combination of all items on the instrument yielding a total metacognition score.

Howard et al. (2001) established the instrument’s reliability using the method of internal consistency yielding a coefficient alpha = 0.94 for the entire instrument, and ranging between an alpha = 0.72 and an alpha = 0.87 for each of the separate factors. Howard et al. (2000) also calculated a varimax rotation of a principle components factor analysis to support the construct validity of the instrument. The analysis yielded 5 independent factors with eigenvalues exceeding 1.12, accounting for approximately 52% of the instrument’s total variance.

6.4. Problem-based scenario

A 327-word problem-based scenario was written by the authors and presented to participants in order to give context to the content contained in the website. The problem suggested that some people learn better or faster than others and some people make significant errors of conduct in their lives. The scenario suggested that these assumptions apply widely to college students. Thus, the scenario directed participants to learn as much as possible about the basic concepts of learning contained in the website with the goal of presenting these concepts to a fictitious university task force. The objective of the task force was to establish a program to help students make better choices and better adjust to college life. The scenario directed students to write a position paper incorporating what was learned from the website with what the task force needed to know about learning.

6.5. Dependent measures

Two dependent measures were used—one, an essay requiring students to respond by writing a position paper to the hypothetical problem-based scenario and two, a free-recall task. In the essay, participants were instructed to incorporate the content contained on the pages of the website into a solution of the problem posed to them. The free-recall task directed participants to record as many terms and concept descriptions they had learned from the site, in addition to the
way the concepts may or may not relate to one another. That is, learners were directed to write down everything they remembered from the site trying to understand and explain how the concepts are related to each other. Procedure Participants were run at individual computers in groups ranging between 2 and 15 in a computer lab. When participants arrived, they were directed to a computer of their choice with at least one unoccupied computer between them. The computer monitors were turned off and the keyboards set to the side. When the participants were seated, they were handed an envelope containing a packet comprised of the following materials: (a) a demographic data sheet, (b) the two dependent measures, (c) the IMSR, and (d) a number between 1 and 3 clearly marked on the outside of their envelope. They were then directed to turn on their monitor.

The monitors were set on a standard informed consent page. The page was read aloud by a proctor while participants read it to themselves. When the page was completed, participants were directed to click the “next” button if they elected to participate. If they declined, they were excused.

On the following page, participants were directed to read a page of instructions. The instructions briefly described the topic of the website and explained that it contained basic theories of learning. Participants were told that they would be learning the contents in order to solve a simulated problem in which learning concepts were necessary for a solution. Participants were also informed that they would have 25 min to navigate the site in order to try to understand as deeply as possible the concepts described on each page, in addition to determining the way the concepts related to one another across pages. Questions were answered, and participants were subsequently directed to click “next” to a page containing only three buttons labeled “1”, “2”, or “3” each of which corresponded to one of the three experimental conditions. They were directed to refer to the number on the outside of their envelope in order to know which of the three buttons to click.

When participants clicked one of the three numbers, they were directed to instructions for each condition, followed by the problem-based scenario on the subsequent page. The scenario was read aloud, but the condition instructions were read silently to avoid between-condition contamination of directives.

When the scenario instructions were completed, participants were directed to click “next”, which took them to the page containing the “acquisition” concept. The 25-min period began, and participants were free to navigate the site any way they wished, relative to their experimental condition.

When the 25-min study period elapsed, participants were directed to turn off their monitors and remove the packet contained in their envelope. In order to circumvent retrieval from short term memory, the demographic data sheet was presented first along with two benign clerical tasks in which participants were asked to write down the serial number of their computer and the number appearing on their packet. Next, participants had 15 min to complete the essay, and an additional 15 min to complete the free-recall task. The procedural sequence concluded with 5 min allotted for completion of the IMSR. Finally, participants were debriefed, thanked, and excused.
7. Results

Three separate protocols were scored for analysis in this investigation: 1) the free recall task, 2) the problem based essay, and 3) the IMSR. The free recall protocols were scored for both the number of idea units contained in the passages and the number of concept descriptions recalled. The essay was evaluated for the degree to which participants critiqued or evaluated the possible outcomes of their suggestions. The index was assessed using a scoring rubric ranging between 0 and 4, with 0 = an absence of the index in the essay and 4 = perfect representation of the index in the essay. Three independent raters scored the protocols on the index, with 11% of the protocols redundantly assessed. The resulting inter-rater reliability yielded a consistency value of 100%. Finally, the IMSR was scored for each of three factors and the total score, with high and low groups formed by sampling learners a quarter standard deviation above and below each factor mean score. Since the standard deviations were not uniform for each factor of the IMSR, the number of subjects within high and low metacognitive groups varied slightly for each analysis. All analyses were evaluated as statistically significant if the alpha level was less than or equal to 0.05.

In order to determine the effects of Navigational Structure and Metacognitive Skill on learners’ retention of content in the website, a MANOVA was calculated on the group centroid of the number of idea units and concept descriptions recalled, since both measures were highly correlated, \( r = 0.64, p < 0.01 \). However, while it was possible to test metacognitive skills with a number of indices of the factor, only metacognitive evaluation was used for the analysis since we were only interested in the effects due to learners’ skill level in monitoring the efficacy of the strategy they chose to acquire and retain information. Using Roy’s Largest Root to estimate the multivariate \( F \) values, the analysis yielded only a significant effect for the interaction \( F (2, 91) = 6.35, p = 0.00 \). Specifically, the univariate \( F \) tests reached significance for both the number of idea units recalled from the website, \( F (2, 91) = 5.70, p = 0.01 \), and the number of concept descriptions recalled, \( F (2, 91) = 4.56, p = 0.01 \).

As for the number of idea units recalled, the analysis revealed that there was no effect due to metacognitive evaluation skills, high (M = 10.39; SD = 4.07) or low (M = 8.74; SD = 3.80), when learners searched the website without the benefit of a sitemap. However, learners navigating via the map with spatial contiguity only remembered significantly more idea units when their metacognitive evaluation skills were low (M = 12.38; SD = 6.26) rather than high (M = 8.25; SD = 5.20). The reverse was true for learners navigating with the site map displaying both semantic and spatial relationships. Learners high in metacognitive evaluative skills (M = 10.35; SD = 4.15) outperformed those who were low (M = 7.06; SD = 3.86). (See Fig. 3 for the interaction.)

![Fig. 3. Site Map × Metacognitive Evaluation for number of idea units recalled.](#)
As for the number of concept descriptions recalled, the analysis revealed the same pattern of results. Specifically, metacognitive evaluation skills failed to interact with navigational structure when the maps were absent (High: M = 3.54; SD = 2.07; Low: M = 3.00; SD = 2.38). However, again, in the map condition showing only spatial contiguity learners low (M = 4.13; SD = 2.73) in metacognitive evaluation skills remembered more concept descriptions than learners whose skills were high (M = 2.50; SD = 1.79). On the other hand, learners high in metacognitive evaluation skills (M = 4.12; SD = 2.50) outperformed their counterparts (M = 2.31; SD = 2.21) in the map condition showing semantic and spatial relations. (See Fig. 4 for the interaction.) All other multivariate and univariate F values failed to reach an acceptable level of statistical significance.

In order to determine the effects of Navigational Structure and Metacognitive Skill on learners’ performance on the essay question, four univariate ANOVA’s were calculated with each aspect of metacognitive skill used to represent the factor in the analyses. When metacognitive evaluation skills were used as the independent variable, the analysis yielded a main effect for navigational structure, $F(2, 91) = 3.01, p = 0.05$. The effect due to navigational structure revealed that learners navigating the site using the map showing both semantic and spatial relationships (M = 0.60; SD = 1.03) and spatial contiguity only (M = 0.50, SD = 1.01) outperformed learners receiving no map at all (M = 0.09; SD = 0.53). Neither the effect of metacognitive evaluation, nor the interaction reached an acceptable level of statistical significance. (See Table 2 for the means and standard deviations of the analysis.)

When metacognitive skill was represented by learners’ skills in cognitively representing the problem, the analysis again yielded a main effect for navigational structure, $F(2, 80) = 3.44, p = 0.04$. Again the effect was due to higher performance among learners using both the map with both semantic and spatial relationships (M = 0.69; SD = 1.07) and spatial contiguity only (M = 0.70; SD = 1.17), relative to no map at all (M = 0.10; SD = 0.55). Again, neither the effect of metacognitive problem representation, nor the interaction reached an acceptable level of statistical significance. (See Table 3 for the means and standard deviations of the analysis.)

When metacognitive objectivity skills were used as the independent variable, the analysis revealed a main effect for navigational structure, $F(2, 94) = 3.41, p = 0.04$, and the interaction between the navigational structure and metacognitive objectivity skills, $F(2, 94) = 3.82, p = 0.03$. The main effect for navigational structure again revealed that learners using no site map (M = 0.09; SD = 0.52) did significantly poorer than those who navigated with the map showing spatial contiguity only (M = 0.60; SD = 0.09) and the map representing both semantic and spatial relationships (M = 0.56; SD = 1.01). While the effect of metacognitive objectivity skills alone did not reach an acceptable level of statistical significance, objectivity varied differentially with navigational structure. That is, learners high in metacognitive objectivity (M = 1.0; SD = 1.21) evaluated and critiqued the possible solutions they generated significantly more than learners low in objectivity skills (M = 0.13; SD = 0.50) when navigating the site with a map.

![Fig. 4. Site Map × Metacognitive Evaluation for number of concept descriptions recalled.](image-url)
showing both semantic and spatial relationships. Learners navigating the site in either of the other two groups failed to differ from one another relative to their level of metacognitive skills in objectivity. (See Fig. 5 for the interaction.)

In the last analysis of the basic experimental design, total metacognitive skills were used as the independent variable. The analysis yielded a main effect for navigational structure, $F(2, 96) = 3.37, p = 0.04$, and the interaction between the navigational structure and total metacognitive skill, $F(2, 96) = 3.77, p = 0.03$. The main effect for navigational structure once again revealed that learners navigating without the benefit of a site map ($M = 0.09; SD = 0.52$) performed significantly poorer than learners using the map showing spatial contiguity only ($M = 0.64; SD = 1.11$). Learners in the semantic/spatial map condition ($M = 0.56; SD = 0.99$) were roughly equivalent to their spatial only counterparts. However, total metacognitive skill mediated the relationship. That is, when navigating the website using the map with semantic and spatial relationships shown, learners high in total metacognitive skill ($M = 0.95; SD = 1.18$) critiqued and evaluated their essay solutions significantly more than learners whose total metacognitive skills were low ($M = 0.12; SD = 0.49$). Total metacognitive skills failed to differentially mediate the performance of learners in the other two groups of navigational structure. (See Fig. 6 for the interaction.)

### 7.1. Relationships and predictions

Since indices of metacognitive skill mediated the effects of navigational structure on aspects of learners’ performance, we were interested in the degree to which the performance measures on the essay could be predicted when learners navigated the site using only the map showing semantic and spatial relationships. Thus, a step-wise multiple linear regression analysis was calculated. We were interested in the degree to which learners’ tendency to critique and evaluate their essay solutions were influenced by the weighted combination of the number of idea units and concept descriptions they recalled, in addition to the various aspects of metacognitive skill (specifically, metacognitive evaluation, metacognitive problem representation, metacognitive objectivity, and total metacognition). The analysis revealed significance for the regression model, $F(1, 35) = 8.09, p = 0.00$. Specifically, the critique of essay solutions was due to learners’ overall skills in metacognition, $t = 2.55, p = 0.02$, as well as the number of learning concepts they recalled, $t = 2.35, p = 0.03$, accounting for 33% of the total variance. All other predictors failed to contribute significantly to the prediction model.

### 8. Discussion

The results of this investigation revealed that the use of complex navigational maps is mediated by the metacognitive skills of learners during hypermedia navigation. We found that learners afforded a navigational map containing

<table>
<thead>
<tr>
<th>Navigational structure</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>No site map, $n = 32$</td>
<td>M 0.16 M</td>
<td>M 0.00</td>
</tr>
<tr>
<td></td>
<td>SD 0.69</td>
<td>SD 0.00</td>
</tr>
<tr>
<td>Spatial only, $n = 32$</td>
<td>M 0.50 M</td>
<td>M 0.50</td>
</tr>
<tr>
<td></td>
<td>SD 1.15</td>
<td>SD 0.89</td>
</tr>
<tr>
<td>Spatial/semantic, $n = 33$</td>
<td>M 0.33 M</td>
<td>M 0.48</td>
</tr>
<tr>
<td></td>
<td>SD 0.89</td>
<td>SD 0.94</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Navigational structure</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>No site map, $n = 30$</td>
<td>M 0.00 M</td>
<td>M 0.19</td>
</tr>
<tr>
<td></td>
<td>SD 0.00</td>
<td>SD 0.75</td>
</tr>
<tr>
<td>Spatial only, $n = 27$</td>
<td>M 0.50 M</td>
<td>M 0.87</td>
</tr>
<tr>
<td></td>
<td>SD 0.90</td>
<td>SD 1.36</td>
</tr>
<tr>
<td>Spatial/semantic, $n = 29$</td>
<td>M 0.55 M</td>
<td>M 0.78</td>
</tr>
<tr>
<td></td>
<td>SD 0.93</td>
<td>SD 1.17</td>
</tr>
</tbody>
</table>
spatial and semantic information revealing the relationships between pages required higher metacognitive skills to be able to fully comprehend the information within the map and the website and make use of that information to achieve their instructional goals. That is, those with better metacognitive skills derived deeper comprehension of the material available in the site and were able to critique and evaluate their own possible solutions to the problem-based scenario in which the learning goal was based. Conversely, learners navigating with the spatial-only map comprehended more web-based material only if their metacognitive skills were comparatively low. We expected that these results would be well explained by the Expertise Reversal Effect (ERE) (Kalyuga et al., 2003).

The ERE explains that for learners with high knowledge (at least domain knowledge), some instructional aids are too simplistic to be of value. This simplicity causes extraneous cognitive load because the simplistic information inherent in the aid becomes redundant with the knowledge already possessed by the learner. In other words, some instructional techniques that are extremely effective for inexperienced learners can lose their effectiveness and have negative consequences when utilized by more experienced and expert learners (Kalyuga et al., 2003).

Since metacognitive skills can be regarded as a type of domain knowledge that learners bring to a task (Sweller, 2005, personal communication), it is reasonable to assume that they operate similarly. That is, when metacognitive skills are high, the knowledge probably also becomes redundant with the strategy information implied by the inherent structure of a simple aid resulting in cognitive load that is high and extraneous. Thus, for more knowledgeable learners, rather than risking the conflict between their strategic abilities and the strategy inherent in the simple aid, it is preferable for them to eliminate the guidance offered by it. Indeed, Kalyuga et al. (2003) explain that under conditions like these, when fully guided instructional material is presented to more experienced learners, a part or all of the provided instructional guidance becomes redundant and compromises performance because of the extraneous load. On the other hand, when metacognitive knowledge is low, the ERE predicts that learners will perform better with a more simplistic instructional aid because they require the guidance of it to process the target information. The information is not redundant for them, as it is for high skill learners, because they do not have the metacognitive skills necessary to comprehend the information in the site without the use of the aid.
In our investigation, the results revealed this reversal. That is, the learners with low metacognitive skill had deeper comprehension of the website material than those with high metacognitive skill when navigating with the spatial only site map. This simple navigational aid incurred germane cognitive load for those with low metacognitive skill but extraneous cognitive load for those whose metacognitive skill was high. The simplicity of the site map probably substituted for low metacognitive skill because the structure of the map provided an apparent navigational strategy. However, the simplicity of the spatial only site map caused the high metacognitive learners to process redundant units of information. This is because the learners apparently already possessed the metacognitive knowledge necessary to comprehend the site without the use of the simple site map. In fact, the spatial-only map hindered their “expertise” rendering their metacognitive skills unnecessary. Therefore, high metacognitive learners in the spatial-only map condition were ill equipped to answer with deeper comprehension because the map did not provide enough information necessary to construct a cognitive model of the information present in the site.

The Expertise Reversal Effect traditionally does not predict that less knowledgeable learners will outperform their more knowledgeable counterparts for the same activity. Normally, it is the instructional technique that reverses, not the relative ability of the experts and novices. We found that learners with low metacognitive skill outperformed learners high in metacognitive skill when navigating with the spatial-only map. Thus, our data suggests that the mechanism for utilizing domain knowledge is apparently quite different from that of metacognitive skill. Domain knowledge is stored in long term memory schematically and is accessed when needed by the working memory system. Metacognitive skill, on the other hand, is a central executive function that serves to monitor and control that knowledge once it is accessed and transferred to working memory. Since the two (e.g. domain knowledge and metacognitive skills) are fundamentally different in structure and function, it is not surprising that the differences occurred. Still, however, differences in the ERE due to expertise in domain knowledge and metacognitive skill are in need of careful empirical differentiation in order to separate the properties and functions of these working memory operations.

Finally, our regression model permitted us to predict learners’ deeper comprehension of the material in the site from the learners’ overall metacognitive skills as well as their surface level retention of the material. Indeed, if the two
variables are combined as predictors, 33% of the variance can be explained within our indices of deeper level comprehension of the website content. Specifically, metacognitive skills and learning concept retention contributed to the learners’ deeper comprehension of the material, in addition to their ability to critique their own answers to the essay question.

We predicted higher website comprehension among navigational map users based on the results of Danielson (2002). Danielson found that a map depicting the nodes and links between locations in a website is all that is necessary to decrease the level of disorientation learners experience when they navigate a site, because the map serves to decrease the learners’ disorientation enough to increase their surface level retention of the website material. Our data revealed supporting results, suggesting that both of our maps provided enough orientation cues to reduce the cognitive load induced by the disorientation phenomenon. However, we also found that while the presence of navigational maps was a necessary condition for benefiting comprehension due to the reduction of cognitive load, the reduction of disorientation was an insufficient condition for incurring deep-level comprehension of website content. That is, our data revealed that deep level comprehension was differentially affected by the maps we used, with the type of map incurring the mediating effects of metacognitive skills.

For deeper comprehension of the website material, we were guided in our expectations by the findings obtained by Nilsson and Mayer (2002). In their investigation, using maps to navigate a website resulted in incomplete construction of conceptual frameworks of the material because their learners were only able to handle a portion of the website due to cognitive load. Our results were similar in that our learners showed an increase in cognitive load. However, they were dissimilar in that the type of load generated by our experimental maps differed. In our investigation, cognitive load was germane to the instructional goals of the task in the spatial/semantic condition, but extraneous when the map contained only spatial—locational cues. In Nilsson and Mayer (2002), the type of cognitive load was not manipulated, since only one type of map was used. Thus, our findings revealed that when cognitive load is germane to the task, learners must summon additional cognitive regulatory mechanisms to meet their instructional goals when navigating a website. When cognitive load is extraneous, learners derive little if any utility from the regulatory processes they employ—processes which serve to degrade and consequently reduce their learning performance.

Thus, the findings we obtained were more consistent with the results of Schwartz et al. (2004). In their investigation, learners showed deeper comprehension of web-based material, but only under conditions where a navigational platform induced learners to use their metacognitive skills. Indeed, when our learners navigated the website in the spatial/semantic condition, the data revealed deeper level comprehension—but only for those learners with high levels of metacognitive skills. We believe that the finding demonstrates that metacognitive evaluation and monitoring are essential for proper use of complex navigational maps for constructing a mental model of the structure of, and material found within, a hypermedia environment. If a learner uses a map that is not useful for his/her specific instructional goals—as in the spatial only condition—metacognitive skills are of no value for constructing the model necessary for representing deep levels of comprehension. Therefore, those learners in the spatial only condition with high metacognitive skills were at a disadvantage because their skills were unnecessary for the use of a simple map under complex instructional goals. In short, the spatial/semantic maps incurred more cognitive load, but cognitive load that was germane to the learning task and hence the instructional goals of the learners with high metacognitive skills.

The findings are theoretically meaningful when explained in the context of the model of text-graphic comprehension proposed by Schnotz and his colleagues. Schnotz et al. (2002) found that descriptive (text-based) and depictive (graphic-based) information are transformed into separate mental models containing both descriptive and depictive information that are shared and integrated during the comprehension process. Thus, the information contained in each influences, and is influenced by, the other for the interpretation and comprehension of both. Schnotz et al. (2002) go on to explain that in text comprehension, the learner (a) constructs a mental representation of the text surface structure through an analysis of symbol structures, (b) generates a propositional representation of the semantic content, and (c) constructs a mental model of the subject matter. In graphic comprehension, the learner (a) creates a visual—mental representation based on initial perception and (b) constructs a mental model through semantic processing and a propositional representation of the subject matter depicted in the graphic (Schnotz et al. 2002).

In the present study, we believe that the learners navigating with the spatial/semantic navigational map had to create separate mental models of the textual information they read as well as the graphical structure of the navigational map they used. In doing so, the learners in the spatial/semantic condition required more cognitive resources to create their depictive cognitive model as there was a great deal of semantic information to process—including how the site information was semantically related. The learners in the spatial only condition, on the other hand, did not have as
much depictive information to cognitively represent, since semantic information was absent within the graphic. According to Schnotz’s model, then, the learners in our investigation presumably created mental models of the information (text-based and graphic-based) and then were able to inspect it later for further use. As Schnotz et al. (2002) point out, the textual information is not only mentally represented as text, but also as graphical information, since graphics are also represented mentally in a depictive and descriptive way. In the present study, we believe that our learners were required to create mental models of both textual and graphical information and later retrieve that information for deep level processing. Because the spatial/semantic condition required more processing of information found in the navigational map, learners with low metacognitive skills were less able to incorporate their descriptive and their depictive mental models. That is, learners in the complex map group without the necessary cognitive skills failed to present with deeper comprehension in their essay answers.

Still, however, Schnotz’s model does not directly explain why different learners would encode and map the web-based information differently. We suggest that our learners with low metacognitive skills were creating incomplete cognitive models of the textual information because their cognitive resources were expended by their attempts to understand and create a mental model for their use of the complex navigational map. That is, the process of creating separate mental models, as suggested in Schnotz’s integrative model of text and picture comprehension, creates a heavier, rather than lighter, load on the working memory system particularly when a map is used with text in a hypermedia environment. Thus, learners in the spatial/semantic map condition were better able to deeply comprehend the information found in the site when they had higher metacognitive abilities. In short, these learners were presumably better able to create a complete mental model of the material.

We believe that combining Schnotz’s model with the concept of cognitive load is beneficial for understanding why learners with different levels of metacognitive abilities are, or are not, able to create complete mental models of the subject matter (whether it is found within a graphic or within text). That is, we believe that the learners with low metacognitive skills were incurring greater extraneous cognitive load while attempting to create a clear mental model of the navigational map, trying to link the map’s semantic function to the textual information present in the site. Indeed, Nilsson and Mayer’s (2002) learners may have experienced a similar problem as well, in that their use of maps to navigate resulted in incomplete mental model construction because of the heavy extraneous cognitive load.

Next, we proposed that the type of cognitive load, germane or extraneous, and the metacognitive skills incurred by this load, are essential to determine in order to be able to make predictions about learning outcomes. Learners with high metacognitive skills incurred high germane cognitive load while navigating with the spatial/semantic navigational map, making deeper comprehension of the material possible. Valko (2002) refers to this type of load as “metacognitive load”—cognitive load that is germane to a task because the task incurs metacognitive skills relevant to it.

Thus, when cognitive load is high under conditions of web-based learning, the explicit monitoring of cognitive processes indigenous to metacognition occurs within the realm of germane cognitive load. We found that, in order to be effective, a website map should engender germane cognitive load and minimize cognitive load that is extraneous. That is, when learners in the spatial/semantic map condition had better developed metacognitive skills, the spatial and semantic information present in the navigational map presumably increased cognitive load germane to the task—in this case, a task requiring learners to apply the website content to a relevant social problem. Since the learners in our investigation presumably assessed the utility of a map as high to the task demands, the load engendered by their evaluation was germane to the task, and therefore utilitarian to their processing. The learners who were high in metacognitive skills then were more likely to be able to evaluate and critique their essays in a more complex way, allowing them to demonstrate that their metacognitive skills were increasing metacognitive load but also deeper comprehension. Only learners high in metacognitive skills showed higher levels of performance when applying website content to the problem posed to them for learning—and only in the spatial/semantic map condition. Thus, for these students, cognitive load was certainly higher, but we contend, germane, because the cognitive resources invoked by the map were capable of assisting them in making semantic associations between content elements contained in the website.

Finally, there are two limitations of this investigation that are important to underscore—the fact that an online measure of metacognition was absent and the possible role visual literacy skills played in performance. With regard to the first, learners endorsed questionnaire items indicating their level of metacognitive skill. Thus, the degree to which learners implemented these skills during processing is indeterminable from the experimental design of this investigation. Still, however, learners reporting higher metacognitive skills significantly outperformed learners reporting comparatively lower skills of metacognition in the spatial/semantic map condition. And, the spatial/semantic map was
designed to incur higher “metacognitive load”. Thus, we suggest that when a navigational map is capable of generating germane metacognitive load, hypermedia learners stand an increased probability of more deeply processing the content contained in the website. Indeed, when a learner did not have the metacognitive skills necessary to process the map and the adjunct text, the presence of the complex map increased extraneous cognitive load, thereby deceptively learning. That is, when the learners found the utility of the map to be low because they did not have high metacognitive skills, the load engendered was extraneous to the task. The use of the navigational map was only effective if the learner had the metacognitive skills to process the breadth of information present in the map and found it useful for the specific instructional goals of the navigational task. Finally, it is possible that the metacognitive load necessary to deploy navigational map skills may have been influenced by learners’ general dearth of “graphical literacy”—skills associated with experience using complex maps since the spatial semantic map was rendered in 3 dimensions. While the present investigation was not designed to make this determination, it is nevertheless important to encourage further research to distinguish between increased load and the specific skills that produce it.

References


