Computers in Human Behavior 29 (2013) 2239–2247

Contents lists available at SciVerse ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Learning from abstract and contextualized representations: The effect of verbal guidance

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ARTICLE INFO

Article history:
Available online 4 June 2013

Keywords:
Multiple external representations
Visual representations
Text–diagram integration
Attention guidance
Problem-solving

ABSTRACT

An experiment examined the effects of providing explicit verbal guidance to learners in integrating information with abstract or contextualized representations during computer-based learning of engineering. Verbal guidance supported learners in identifying correspondences and making mental connections among multiple textual and diagrammatic representations. Results from a 2 (abstract (A) or contextualized (C) representation) × 2 (no guidance or guidance) design showed that without guidance, abstract representations led to better transfer than contextualized representations. Moreover, learners in the contextualized representation group benefitted from the guidance, while the abstract representation group did not benefit from guidance. These findings suggest that abstract representations promote the development of deep, transferrable knowledge and that verbal guidance denoting correspondences among representations can facilitate learning when less effective representational formats are utilized.

1. Introduction

The majority of STEM (science, technology, engineering, and mathematics) computer-based learning environments are replete with multiple external representations (MERs) such as text, diagrams, and formulas. Computer-based learning environments with MERs can be a double-edged sword. Although learners can benefit from the unique advantages of visual and verbal representations and the complementary information contained among them (Ainsworth, 1999; Larkin & Simon, 1987), translating among MERs can be a difficult task for learners, imposing additional load on limited working memory (Baddeley, 1986; Chandler & Sweller, 1991; Goldman, 2003; Sweller, van Merrienboer, & Paas, 1998). Researchers have discovered many ways to support the cognitive processes associated with learning from MERs, including presenting verbal and visual information concurrently and in close proximity (Mayer & Anderson, 1991; Moreno & Mayer, 1999), removing redundant or unnecessary information (Kalyuga, Chandler, & Sweller, 1999; Mayer, Heiser, & Lonn, 2001), and using narration rather than printed text (Mayer & Moreno, 1998). However, the research literature is less clear when attempting to synthesize prescriptions regarding the optimal representational format (i.e., abstract or contextualized) to support novice learners, and the effect of guidance or cues that assist learners in coordinating across MERs. The current experiment examines the effects of varied representation formats and coordination guidance on developing novice learners' problem-solving skills during computer-based learning with MERs.

1.1. Learning with multiple external representations

Ainsworth (1999, 2006) asserts that MERs play three major roles in learning. First, they support complementary processes and provide complementary information to the learner (e.g., include non-redundant or only partially redundant information). Second, one representation can constrain possible interpretations of another proximate representation through familiar properties or by inherent properties (e.g., a familiar diagram of a simple electric circuit can constrain interpretation of a less familiar mathematical equation). Finally, multiple representations aid learners in constructing a deeper understanding of material by supporting abstraction, by promoting generalization to novel situations, and by demonstrating relations among representations. Diagrams are a common form of MERs and are thought to facilitate learning by specifying key features and spatial relationships that may remain implicit in sentential form (Larkin & Simon, 1987; Winn & Solomon, 1993). However, learning from text with diagrams also poses unique cognitive demands on learners (Schroeder et al., 2011) because learners must process the visual information in addition to the verbal content.

The comprehension of MERs requires the *selection* of relevant elements, *organization* of visual and verbal information, and the

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http://dx.doi.org/10.1016/j.chb.2013.05.002

integration of new verbal and visual information together and with prior knowledge (Mayer, 2001, 2005; Mayer & Moreno, 2002; Schnotz, 2005). Seufert (2003) claims that effective learning from MERs occurs through processes related to intra-representational and inter-representational coherence formation. Intra-representational coherence formation involves identifying relevant information and relevant relationships between elements within one representation (e.g., a text or diagram). Inter-representational coherence formation involves identifying corresponding elements between two or more representations (e.g., text and diagram) and constructing the mental associations between those elements. Learners' ability to extract relevant information from MERs and integrate this information into meaningful mental representations is driven by the comprehensiveness and accuracy of their own existing prior knowledge *and* the format and configuration of the provided MERs.

Available empirical work indicates that experts are better equipped to disregard irrelevant or nonessential information and focus on relevant information within and among representations (Canham & Hegarty, 2010; Jarodzka, Scheiter, Gerjets, & van Gog, 2010; Koedinger & Anderson, 1990). Novice learners often focus their attention on one type of representation, rather than exploiting the unique advantages of each of the MERs (Tabachnek-Schijf, Leonardo, & Simon, 1997). Furthermore, novices' inadequate mental representations cause them to attend to surface features of external representations, or perceptually salient elements that are not central to domain concepts (Kozma & Russell, 1997; Lowe, 1999, 2003). Attending to perceptually-salient but conceptually-irrelevant information ultimately inhibits students' ability to acquire new, coherent schemas necessary for successful problem-solving. The distinction of expert and novice focus on conceptual vs. perceptual saliency may help explain why some research has found that spatial abilities predict early achievement in STEM disciplines, but spatial abilities are less predictive of STEM success as expertise in the domain develops (Uttal & Cohen, 2012). In order to assist novice learners, materials that incorporate MERs as students learn new problem-solving concepts and procedures should include features that direct students' attention to conceptually-meaningful aspects of the MERs. This type of guidance during use of MERs should promote deeper reasoning with the visual representations and stronger learning outcomes.

1.2. Cognitive load theory

According to Cognitive Load Theory (CLT), every instructional condition places a certain burden (load) on working memory capacity. This load is subdivided into three distinct types: (1) intrinsic cognitive load; (2) extraneous cognitive load; and (3) germane cognitive load (Ayres & Van Gog, 2009; Paas, Renkl, & Sweller, 2003; Paas, van Gog, & Sweller, 2010; Schnotz & Kurschner, 2007; Sweller et al., 1998). Intrinsic cognitive load is the natural demand imposed by the inherent difficulty of the learning material (e.g., physics, body systems). Sweller et al. (1998) state that this type of cognitive load depends on the amount of 'element interactivity' in a particular task; that is, the degree to which multiple aspects (or "elements") of the material must be processed in combination in order to understand the material. Materials with high element interactivity contain concepts, ideas, or information that cannot be learned in isolation (see Sweller, 2010 for a discussion). To the extent the MERs may constrain and influence learning, materials containing MERs likely are high in element interactivity. Element interactivity further depends on the expertise of the learner; more sophisticated mental schemas permit chunking of elements, thereby reducing intrinsic cognitive load. Extraneous load relates to unnecessary cognitive processes which do not contribute to (and can detract from) learning. For example, an instructional condition which includes irrelevant information can divert attention from conceptually relevant elements, increasing extraneous (nonessential) cognitive load. Germane load relates to essential cognitive processes which lead to construction and modification of internal mental representations of the learning material. Because working memory is limited, instruction should reduce extraneous cognitive load to free up resources that can be dedicated to processing germane load.

In order to bridge the divide between expert and novice learners and capitalize on available cognitive resources, it is critical to understand how manipulations of learning materials can facilitate effective learning processes for novices. Previous research has found that manipulating learning materials in order to provide additional learner guidance can reduce extraneous load during learning. For example, because novice learners lack adequate mental schemas to guide problem solving, the use of worked-examples can avoid the cognitive overload which may occur during problem solving (Renkl, 2005; Sweller & Cooper, 1985; Sweller et al., 1998). Worked examples can focus learners' attention on the problem steps, thereby fostering the abstraction of underlying principles and promoting the development of problem-solving skills. Presenting worked examples in an integrated format (where relevant numerical and visual elements are presented in close proximity) can further improve the value of a worked example, likely by guiding students to coordinate information from varied sources (Tarmizi & Sweller, 1988). Although this previous study provided visual guidance for coordination, it is likely that verbal guidance on correspondences among representations has the potential to reduce extraneous cognitive load related to visual search processes as well.

When learning with MERs, selecting and coordinating across relevant elements represents a significant source of extraneous cognitive load. Thus, deeper understanding likely will be supported by instructional supports that assist novice learners in (1) identifying relevant information within representations, (2) finding corresponding elements between representations, and (3) attending to multiple representations, rather than focusing on one. In the current research, we provide verbal guidance designed to ease selection and coordination between MERs in a computerized learning environment, thereby reducing extraneous (unnecessary) cognitive load (Sweller et al., 1998). To the extent that such guidance can reduce extraneous load, students who receive guidance should demonstrate deeper understanding of problem-solving concepts and procedures following use of a computerized learning module containing MERs.

Although providing guidance across MERs should facilitate processing across the representations, the nature of the representations may also play a significant role in determining how successful the learner is in coordinating them during learning. That is, as discussed in the following section, the representational format of the MERs can influence students' learning outcomes.

1.3. Contextualized vs. abstract visual representations

In STEM instruction, text and diagrams can be presented in a contextualized format, using specific real-life objects (e.g., battery), or abstract format, using conventional symbols to represent universal system elements (e.g., two parallel lines with a plus and minus sign to represent a voltage source). Even if the instructional goal is to develop abstract knowledge in a domain, some research suggests that abstractions can be most effectively learned through initial experience with contextualized representations (Goldstone & Sakamoto, 2003). This suggestion is consistent with earlier research showing that abstract representations (i.e., "secondary notations") must be learned before individuals can understand and make use of them (Petre & Green, 1993).

1.3.1. Contextualized representations

A potential benefit of contextualized representations is that novice learners can more easily relate the to-be-learned content to their own experiences and prior knowledge. Learners can draw upon their own prior knowledge of real-life objects (e.g., battery and light bulb) and situations, thus promoting learning (Brown, Collins, & Duguid, 1989; Cognition & Technology Group at Vanderbilt, 1993; Cordova & Lepper, 1996; Koedinger & Nathan, 2004). Positive results have been reported by several researchers who studied the value of contextualized representations in instructional materials. Jennings, Jennings, Richey, and Dixon-Krauss (1992) demonstrated that students who learned math problem-solving with contextualized stories had significantly higher test scores of early mathematics ability compared to students who learned with regular curriculum, without contextualized stories. Yang, Greenbowe, and Andre (2004) provided evidence that introducing the concepts of electrochemistry using the familiar context of a flashlight and battery system improved students' understanding of electrochemistry more than using abstract, simple cells to introduce the concepts. Tiancheng and Jonassen (1996) investigated the effectiveness of concept-based vs. case-based structures on an interdepartmental information system lesson. The authors found that the students performed equally well while solving problems, but when making inferences from given information, students who learned with the case-based structure performed better than the students who learned with concept-based structure.

1.3.2. Abstract representations

Although some evidence shows benefits of using concrete representations during instruction, providing learners with abstract representations may lead to better learning outcomes because an abstract format can guide learners to focus on the underlying structure of the problem, rather than superficial elements which may differ from problem to problem (McNeil, Uttal, Jarvin, & Sternberg, 2009; Reisslein, Moreno, & Ozogul, 2010). Positive effects of abstract representation format have been found in mathematics (De Bock, Verschaffel, Van Dooren, Deprez, & Roelens, 2011; Kaminski, Sloutsky, & Heckler, 2008), science (Butcher, 2006; Dwyer, 1968, 1969; Joseph & Dwyer, 1984), and engineering (Moreno, Ozogul, & Reisslein, 2011). Within a different domain (Dwyer, 1968, 1969; Joseph & Dwyer, 1984) found that simple line drawings of the human heart improved student performance on a set of post-tests including drawing tasks, identification tasks, and comprehension tasks. Similarly, Butcher (2006) compared learning with a computerized module using text only, text and simplified (abstract) diagrams, and text and more elaborate (realistic) diagrams of the human heart. The results showed that instruction using simplified diagrams was most effective in improving the students' mental model of the heart, increasing students' factual knowledge of the human heart and memory of the instructional text, and in promoting inferences that integrated across the instructional materials.

1.3.3. Summary of earlier findings

Taken together, the results from prior studies on abstract vs. contextualized formats provide conflicting conclusions about the optimal representational format for novices, and suggests that the issue of optimal representational format is more complicated than identifying either abstract or contextualized representations as optimal for learning. The selection and coordination processes required for learning with MERs (e.g., identifying relevant information within representations and finding corresponding element between representations) should be analyzed in conjunction with representational format. That is, we must examine the ways in which instructional supports designed to facilitate selection and coordination with MERs may be mediated by the format of the representations themselves. A better understanding of these issues has strong potential impact for the design of computerized educational materials, since many instructional technologies (e.g., problem-solving systems, intelligent tutoring systems, multimedia modules) must include MERs.

When learning with MERs, learners may be better equipped to identify corresponding elements if contextualized representations are used. Specifically, when a particular system component is mentioned within a text, learners may experience less difficulty locating the corresponding diagram element when it is contextualized (e.g., battery) than when it is abstract (e.g., a voltage source). The following section examines instructional supports to reduce unnecessary cognitive load during learning with multiple representations.

1.4. Supporting the use of MERs

When used properly, MERs can contribute to students' understanding of scientific concepts; however, students do not always use, understand, interpret or value these representations as their instructors intended (Orgill & Crippen, 2010) and may believe a glance at a diagram is sufficient for understanding and extracting relevant information (Schnotz, 2002). Materials that support the learning processes required for coherence formation may enhance learners' ability to link visual information to relevant quantitative information; as a consequence, students may interpret representations more easily (Shah & Hoeffner, 2002). Compared to experts, novices cannot effectively allocate visual attention to relevant information (Canham & Hegarty, 2010; Jarodzka et al., 2010; Koedinger & Anderson, 1990); thus, presenting novices with visual representations that guide their attention to relevant features and directing learners' focus to diagram elements and the spatial relationships among the elements may improve learning outcomes.

Bertohold and Renkl (2009) found that, although presenting both pictorial and arithmetic information (compared to single representation formats) did not promote learning, color coding to denote correspondences between representations and self-explanation prompts increased student learning about probability theory. Earlier research also has shown beneficial effects of color coding correspondences among representations (Kalyuga, Chandler, & Sweller, 1998). Techniques to guide visual attention are assumed to positively impact learning by reducing extraneous (unnecessary) cognitive load associated with visual search processes required to locate relevant information within and corresponding information among representations (Sweller et al., 1998). Eye-tracking data has provided converging evidence that such techniques assist learners in locating corresponding information (Ozcelik, Karakus, Kursun, & Cagiltay, 2009). Seufert (2003) studied verbal prompts and showed that student domain knowledge moderates the beneficial impact of help in locating corresponding elements within text and diagrams. Results indicated that help was not beneficial to low prior knowledge students, but led to better recall and performance for medium prior knowledge students and better recall for the high prior knowledge students.

The results from the reviewed research suggest that although learning can sometimes be facilitated through the use of multiple visual representations, learners often benefit more from two or more representations when assistance in translating between them is available. This assistance can be provided in the form of prompts for active learning processes (Bertohold & Renkl, 2009), visual indicators of correspondences between representations (Bertohold & Renkl, 2009; Kalyuga et al., 1998; Ozcelik et al., 2009), or verbal guidance on correspondences between representations (Seufert, 2003). The goals of the current experiment were twofold. First, we sought to determine whether college students would develop better problem-solving skills following learning with a computerized multimedia module when provided with verbal guidance on correspondences between text and diagrams. Second, we sought to examine whether the potential benefits of guidance are dependent on the representational format used in the computer module.

1.5. Research questions and hypotheses

RQ 1. Do learners develop better problem-solving skills using abstract or contextualized representations?

Because of conflicting evidence from prior studies on representational format (Butcher, 2006; De Bock et al., 2011; Dwyer, 1968, 1969; Jennings et al., 1992; Joseph & Dywer, 1984; Kaminski et al., 2008; Moreno, Reisslein, & Ozogul, 2009; Tiancheng & Jonassen, 1996; Yang et al., 2004), a primary goal was to contribute to our developing understanding about representation formats by examining whether abstract text and diagrams or contextualized text and diagrams would better support student learning. Competing hypotheses were offered based on the theoretical and empirical background related to representational format. *Hypothesis* 1a. Abstract representations will lead to better acquisition of problem-solving skills because learners can more easily focus on conceptually-relevant information. *Hypothesis* 1b. Contextualized representations will lead to better acquisition of problem-solving skills because learners can more easily relate presented information to their own everyday experiences.

RQ 2. Do learners develop better engineering problem-solving skills when provided verbal guidance on correspondences across representations?

The second goal was to investigate the effectiveness of verbal guidance designed to assist learners in connecting MERs. The experiment examined the impact of verbal attention guidance to visual elements in diagrams, supporting students' selection of relevant and corresponding information. We predicted that verbal guidance would reduce extraneous cognitive load related to visual search processes for locating relevant information within visual representations and to connecting elements across the verbal and visual representations (Sweller et al., 1998). *Hypothesis* 2. Verbal guidance conditions will lead to better problem solving skills by directing learners' attention to relevant and corresponding information.

RQ 3. Does the impact of verbal guidance depend on the representational format utilized?

The third goal of the experiment was to explore whether the efficacy of verbal guidance in connecting MERs is dependent on the representational format utilized. On the one hand, contextualized representations may permit more straightforward identification of corresponding information, so verbal guidance may assist learners only when using abstract representations. On the other hand, because learners tend to underestimate the importance of diagrams and believe that superficial inspection is sufficient (Schnotz, 2002), verbal guidance may lead to more effortful inspection of the more familiar contextualized representations and thus may assist learners only when using contextualized representations.

2. Method

2.1. Design and participants

The experiment utilized a 2 × 2 between-subjects factorial design, with the first factor being the representation type (abstract [A] or contextualized [C]) and the second factor being the guidance provided on correspondences between text and diagram (guidance [G] vs. no guidance [NG]).

Participants were a total of 98 students (79 females and 19 males) enrolled in introductory educational psychology courses at a large public university in the southwestern United States; students received credit towards their final grade for their participation in the research. The mean age of the participants was 26.20 years (*SD* = 9.21 years). Fifty-six (57.1%) of the students reported that they were Caucasian, 35 (35.7%) reported that they were Hispanic, four students (4.1%) reported "other" as their ethnicity, one (1.0%) responded as Native American, one (1.0%) as multiple ethnicities, and one (1.0%) as Asian American. Participants were randomly assigned to experimental conditions. There were 24 students in the abstract text and diagrams without guidance (A–NG) condition, 25 students in the contextualized text and diagrams without guidance (C–NG) condition, 24 students in abstract text and diagrams with guidance (A–G) condition, and 25 students in the contextualized text and diagrams with guidance (C–G) condition. Comparisons were made among the groups on performance on posttest and practice problems.

2.2. Materials

2.2.1. Computerized materials

Each participant received the computerized materials consisting of an interactive program that included the following sections: (1) a demographic information questionnaire in which students were asked to report their gender, age, and ethnicity; (2) a pretest; (3) a computer module providing a conceptual overview of electrical circuit analysis; and (4) a computerized problem-solving practice session.

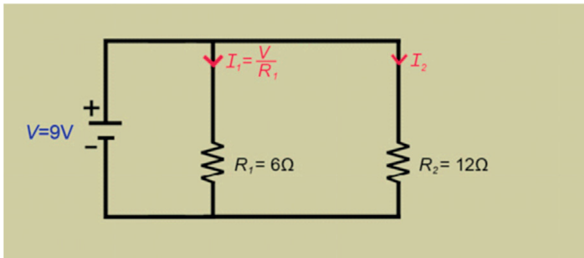
The pretest (Section 2) consisted of 12 multiple-choice questions (internal reliability of .79). It was designed to measure the participant's knowledge of the topic before entering the computer module.

The computer module (Section 3) presented the students with the meanings and units of the elementary electrical quantities, namely electrical current, voltage, and resistance. Furthermore, the session presented how to calculate the total resistance of a parallel circuit with given source voltage and individual resistance values (Ozogul, Johnson, Moreno, & Reisslein, 2012a). For each screen of the instruction, the program displayed the circuit diagram with cumulatively integrated equations (Ozogul et al., 2012b), illustrated in Fig. 1, in the top half of the screen and played the audio narration of the instructional text. According to Levin and colleagues (Carney & Levin, 2002; Levin, 1981; Levin, Anglin, & Carney, 1987), illustrations in text can serve five primary functions: (1) decorational; (2) representational; (3) organizational; (4) interpretational; or (5) transformational. The diagrams in our computer instruction served the interpretational function, to assist the learner's understanding of how the electric circuit works. The computer module was self-paced.

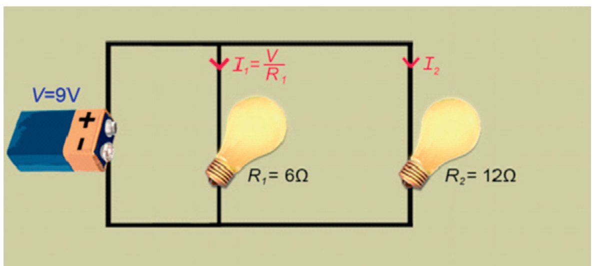
The computerized practice session (Section 4) presented two electrical circuit problems in which students were asked to compute the total resistance of a parallel circuit by applying the three solution steps taught in the instructional portion of the program. The practice part of the module also was self-paced and corrective feedback was provided immediately after students completed each problem step (Moreno et al., 2009). Learners received one point for each correct answer provided for the practice problem step. The program logged a practice problem score from 0 to 6.

The computer module and computerized practice session portions of the program had two representation conditions, namely abstract text and diagrams (A) or contextualized text and diagrams (C). Each representation condition had a version without guidance (A–NG and C–NG) and a version with guidance (A–G and C–G).

2.2.1.1. Abstract representation. The abstract diagrams represented the electrical circuit elements, e.g., voltage source and resistor, with the standard abstract engineering symbols, as illustrated in



(a) Abstract representation (A)



(b) Contextualized representation (C)

Fig. 1. Sample circuit diagrams, abstract (A) and contextualized (C) conditions.

Fig. 1a. The abstract text explained the elementary electrical quantities and circuit components (voltage source and electrical device) and presented the total resistance calculation and practice problems in abstract terms, as illustrated in the following excerpt corresponding to the parallel circuit in Fig. 1 (ignoring for now the text in the square brackets):

Imagine that you connect a second electrical device with a resistance $R_2 = 12\,\Omega$ in parallel to the first electrical device that you already had with a resistance of $R_1 = 6\,\Omega$.

[Look at the new diagram and try to find the second electrical device.]

Let us call the current flowing through the first electrical device I_1, and the current flowing through the second electrical device I_2.

2.2.1.2. Contextualized representation. In contrast, the contextualized diagrams represented the electrical circuit components with life-like images, as illustrated in Fig. 1b. The contextualized text presented the electrical quantities and circuit components as well as total resistance calculation and practice problems in the context of real-life scenarios, as illustrated by the following excerpt corresponding to Fig. 1:

Imagine that you connect a second light bulb with a resistance $R_2 = 12\,\Omega$ in parallel to the first light bulb that you already had with a resistance of $R_1 = 6\,\Omega$.

[Look at the new diagram and try to find the second light bulb.]

Let us call the current flowing through the first light bulb I_1, and the current flowing through the second light bulb I_2.

2.2.1.3. Guidance conditions. The two guidance conditions (A–G and C–G) provided students with verbal cues regarding the correspondence between the text and the diagrams. This guidance was designed to facilitate coordination across the verbal information and the diagrams, i.e., to help students identify and process the correspondences between the text and the diagrams. For instance, the conditions without guidance introduced the concept of voltage without referring to the circuit diagram. In contrast, the abstract representation with guidance (A–G) condition had additional narration stating that the voltage source is represented by two parallel lines with a plus and minus sign in the diagram (see Fig. 1a) and prompted students to look at the diagram and to find the voltage source. The verbal guidance can be considered as providing specific processing guidelines which require more effortful inspection of the diagrams (Peeck, 1993).

Analogously, the contextualized representation with guidance (C–G) condition had additional narration to prompt students to look at the circuit diagram (see Fig. 1b) to find the battery, which provides the voltage for the circuit. An additional example of guidance is provided in the text excerpts above introducing the second electrical device/light bulb in parallel to the first electrical device/light bulb. The guidance is provided by the added text in the square brackets and guides the student's attention to specific parts of the diagrams, namely the second electrical device/light bulb in parallel to the first one.

2.2.2. Paper and pencil materials

The paper and pencil materials consisted of a posttest with three near-transfer questions and three far-transfer questions. The problem statements on the test were in contextualized form, as is common for real-life engineering problem settings. The near-transfer test was designed to assess students' ability to transfer their problem-solving skills to solve an isomorphic set of problems. In particular, the near-transfer portion consisted of three problems that had the same underlying structure but different surface characteristics than the problems presented during the practice session of the program. Two engineering instructors scored the near-transfer test questions (inter-rater reliability 98.5%).

The far-transfer questions were designed to assess students' ability to transfer their problem-solving skills to solve a novel set of problems. These questions had different underlying structure and different surface features than the practice problems within the computer-based learning environment. Specifically, given the individual resistance values and the current through one of the resistors, the students were asked to calculate the total current in the parallel circuit. In order to solve the far-transfer problems the participants had to apply the same basic principles (Ohm's law, basic properties of voltages and currents in parallel circuits) as in the practice problems, but the sequence in which these principles were employed and the circuit element to which Ohm's Law was applied varied from the practice problems and from the solution steps presented in the computer module and computerized practice. Two engineering instructors scored the far transfer test questions (99.8% inter-rater agreement; calculated as percentage agreement between instructors across transfer questions).

2.3. Apparatus

The computer program used in the experiment was developed using Adobe Flash CS3 software, an authoring tool for creating web-based and standalone multimedia programs. The apparatus consisted of a desktop computer system, with a screen size of 1680×1050 pixels, and headphones.

2.4. Procedure

After completing informed consent, participants were randomly assigned to a treatment group and seated in front of a Windows-based desktop computer. Then, the experimenter started the assigned version of the computer program and instructed participants to work independently on all sections of the program (demographic survey, pretest, computer module, and computerized practice session). Once the computer program was over, participants completed the paper-based posttest.

3. Results

Preliminary analyses were run to determine that learners did not spend more or less instructional time learning depending on the learning condition, and to ascertain that prior knowledge was equivalent among groups. A 2 (representation type: C or A) × 2 (guidance: G or NG) ANOVA, with instructional time as dependent variable did not indicate a main effect of representation type or guidance on learning time. There also was not a significant interaction between the two factors. However, the parallel ANOVA on pretest showed a significant difference in pretest scores between abstract and contextualized groups, $F(1,94) = 6.51,\ p < .05$.

Table 1 provides descriptive statistics for pretest scores, near- and far-transfer posttest scores, and practice problem scores, by representation type and guidance condition. In order to determine potential main effects of representation type and guidance as well as interactions between these two factors, a series of 2 (representation type) × 2 (guidance) analyses of covariance (ANCOVAs) were conducted, with each of the student learning and practice measures as dependent variables, representation type and guidance as between subjects variables, and pretest score as covariate (due to the significant difference between pretest scores of the abstract and contextualized groups).

3.1. Learning outcomes

The analysis on near transfer items indicated no significant main effect of representation type, $F(1,93) = 1.83$, $p = .183$, and no significant main effect of guidance, $F(1,93) < 1$. However, there was a significant interaction between the representation and guidance factors, $F(1,93) = 6.44$, $MSE = 10.1$, $p = .013$, $\eta_p^2 = .07$. Separate independent sample *t*-tests were conducted to identify the simple main effects underlying the interaction. First, the A–NG condition had significantly higher near-transfer posttest scores compared to the C–NG condition, $t(47) = 2.73$, $p = .009$. Although the C–G condition had descriptively higher near-transfer scores than the A–G condition, this difference was not statistically significant, $t(47) = 0.99$, $p = .33$. Next, the C–G condition significantly outperformed the C–NG condition, $t(48) = 2.12$, $p = .04$. Although the A–NG condition had descriptively higher near-transfer scores than the A–G condition, this difference was not statistically significant, $t(46) = 1.46$, $p = .15$.

The analysis on far-transfer items did not reveal a significant main effect of representation type, $F(1,93) = 1.02$, $p = .32$, nor a significant main effect of guidance, $F(1,93) < 1$. Additionally, results did not demonstrate a significant interaction between representation and guidance factors, $F(1,93) = 1.34$, $p = .25$.

3.2. Practice problems

The analysis on the practice problems embedded within the computer module demonstrated the main effect of guidance on total practice problem score was not statistically significant, $F(1,93) < 1$. Results also indicated that practice performance was not significantly impacted by the representation type, $F(1,93) < 1$, and there was not a significant interaction between representation type and guidance, $F(1,93) = 2.21$, $p = .14$.

4. Discussion

This experiment was designed to explore the effects of different forms of representations and guidance in locating correspondences between representations on student learning outcomes following multimedia instruction on electric circuit analysis. To address these issues, we compared the problem-solving performance of novice college participants who were randomly assigned to learn about electric circuit analysis with abstract text and abstract diagrams (A conditions) or contextualized text and contextualized diagrams (C conditions). The two types of representations were presented either with verbal guidance (G) or no guidance (NG) on identifying correspondences between text and diagram.

4.1. The effect of representation type

Results from the experiment indicate that the question of optimal representation types for learning is not a simple one. The interaction observed between representation type and guidance indicates that the most effective format of representation depends on whether guidance is provided in relating text and diagram. Comparing representation type within the two levels of the guidance factor established that when learners do not receive any guidance on determining the correspondence between text and diagram, the most effective representation format is the combination of abstract text and abstract diagram. This is demonstrated by the finding that the A–NG condition had significantly higher near-transfer performance, compared to the C–NG condition. This result mirrors previous results from Moreno et al. (2011) in which the A condition performed significantly better than the C condition.

Overall, these results support a modification of our Hypothesis 1a that predicates the absence of verbal guidance. If no verbal guidance is provided, abstract representations foster learning by allowing learners to focus on the underlying structure of the problem at hand, rather than being distracted by the superficial elements of each individual problem. Learners who were provided with abstract representations did not focus on specific instantiations (e.g., a battery and a light bulb) as they observed worked-example problems; rather, these learners could focus on the underlying

Table 1
Means and standard deviations for pretest, near- and far-transfer posttest, and practice score, by representation type and guidance condition.

Representation type	Guidance condition	Pretest (max = 12) *M* (*SD*)	Near transfer (max = 9) *M* (*SD*)	Far transfer (max = 9) *M* (*SD*)	Practice score (max = 6) *M* (*SD*)
Abstract (A)	–NG No guidance (*N* = 24)	1.29 (1.81)	7.69 (2.65)[a]	4.67 (4.35)	4.46 (1.25)
	–G Guidance (*N* = 24)	1.54 (1.96)	6.29 (3.87)	4.58 (4.14)	4.25 (1.29)
	Total (*N* = 48)	1.42 (1.87)	6.99 (3.36)	4.63 (4.20)	4.35 (1.26)
Contextualized (C)	–NG No guidance (*N* = 25)	2.52 (2.62)	5.42 (3.14)	3.28 (3.54)	4.24 (1.29)
	–G Guidance (*N* = 25)	2.72 (2.78)	7.28 (3.06)[a]	5.04 (4.04)	4.80 (1.15)
	Total (*N* = 50)	2.62 (2.67)	6.35 (3.20)	4.16 (3.86)	4.52 (1.33)
Totals	No guidance (*N* = 49)	1.92 (2.32)	6.53 (3.10)	3.96 (3.98)	4.35 (1.35)
	Guidance (*N* = 49)	2.14 (2.46)	6.80 (3.48)	4.82 (4.05)	4.53 (1.24)

[a] Significantly higher than the C–NG (contextualized representation without guidance) condition.

problem structures. Since novice students have difficulty selecting conceptually-relevant information in MERs (Kozma & Russell, 1997; Lowe, 1999, 2003), inclusion of abstract representations may assist novice students by eliminating perceptually salient information which changes across problems and can misdirect students' processing. Thus, abstract representations may reduce extraneous load associated with processing perceptually-salient but conceptually-irrelevant information (Harp & Mayer, 1997; Mayer et al., 2001; Sweller et al., 1998). Although the college student participants in this work were novices to electric circuit analysis, they likely have the requisite experience to know what objects can serve as electrical devices and voltage sources respectively. Accordingly, they likely did not need contextualized training in order to apply their knowledge to contextualized problems at posttest. Thus, in learning contexts where students should be able to successfully connect abstract representations to prior knowledge, abstract representations should be used to facilitate knowledge transfer to new situations.

4.2. The effect of guidance

Similar to findings on representation type, there was not a significant main effect of guidance on near-transfer or far-transfer performance. Hypothesis 2 was not supported by the results of the experiment. However, the interaction between representation type and guidance revealed that the benefit of guidance is dependent on the format of the representations used. When considering each representation type separately, the results demonstrated that the contextualized text and diagram participants benefitted from the inclusion of guidance, whereas the abstract representation condition did not benefit from the guidance. At first this appears to be counterintuitive, considering that contextualized text references (e.g., 'battery') to diagram elements should be most easily interpreted and correspondences most easily determined under the contextualized condition. However, without the explicit guidance, the familiarity of the contextualized representations may have caused learners to overestimate their initial understanding of the diagrams. That is, learners may have only briefly glanced at the diagram with the familiar life-like images, and thus missed the relevant structural information about the circuit (Schnotz, 2002).

The guidance in the contextualized text and diagram condition may serve as a prompt for learners to more frequently and/or thoroughly examine the diagrams, making it more likely that they will process the underlying structure of the electrical circuits. Examination of the drawings constructed by learners substantiates this conclusion. The drawings were scored using a rubric developed by an experienced electrical engineering instructor. The rubric assigned points for conceptually correctly drawings of the circuits resulting in a maximum drawing score of 18 points. Learners in the C–G condition produced conceptually more correct drawings (drawing score $M = 9.77$, *Std. Error* = 1.84) of the circuits compared to the C–NG learners ($M = 8.14$, *Std. Error* = 1.84), although the trend was not statistically significant.

The guidance on correspondences between text and diagram can direct learners' attention to the diagram as a whole, leading to more careful inspection of the configuration of diagram elements (i.e., circuit components). Specifically, prompting learners to examine diagram elements may support the intra-representational coherence formation processes (Seufert, 2003) of identifying relevant information and relevant relationships between elements within the diagrams. Thus, these learners are facilitated in building more accurate and accessible mental representations of electric circuits. This may enable the transition from interpreting contextualized representations to developing the abstract internal representation of circuits necessary to solve new isomorphic problems with the same structure.

Our results indicated that for the abstract text and abstract diagrams, learning was not promoted through the use of guidance on correspondences between representations. More specifically, the results indicate that, for our learning materials, presenting abstract representation without guidance is sufficient to form internal representations necessary for solving new (near transfer) problems. The conventional engineering symbols in the abstract diagrams, which were unfamiliar to novice learners, may have elicited students' attention and supported the formation of effective schemas for circuit analysis.

4.3. Implications

When considering the implications of this work for the design of computer-based learning modules, it is important to remember that differences between representation conditions were resolved through the use of guidance. No significant difference was found between the two conditions with guidance, indicating that when guidance was available, the representation format did not have a significant impact on learning. The results suggest that the guidance essentially elevates the performance of the C condition to that attained in the A condition. Stated in another way, providing guidance in an instructional module promotes learning with contextualized representations but does not compromise learning with abstract representations. Therefore, instructional modules utilizing MERs may be well-advised to make use of guidance as a strategy to promote learning. This finding also has implications for the design of systems that transition between different representation types (Goldstone & Son, 2005); it is possible that guidance may negate the previously observed benefits of moving from contextualized to abstract representations.

5. Conclusions

The results of our study support the use of abstract representations in instructional materials designed for novices in engineering domains. We conclude that an abstract representation format allows students to focus on the underlying structure of the presented problems, rather than the superficial elements which may change from problem to problem. By detecting that each example problem shares a similar configuration and encoding this configuration into internal mental representations, learners are better able to recognize a similar problem configuration in test problems, even when they are posed in contextualized format.

The experiment demonstrated that verbal guidance on correspondences across representations may be necessary when the representational format is difficult to generalize to domain principles. Therefore, if instruction is designed to include early contextualized examples, it may require support features which assist learners in attending to relevant information and, as a result, processing the (domain-general) structural information present in the representation.

5.1. Limitations and future directions

Although the current research offers important new information to consider when designing instructional environments, there are limitations to this work. We focused on one specific instructional domain, namely engineering (i.e., electrical circuit analysis), implanted in a single learning environment (i.e., computer-based multimedia instructional program). Further, the experiments were conducted in a laboratory environment, not in situ (i.e., classroom). Future research should examine the experimental manipulations in other instructional contexts, domains, and learning environments.

The results did not indicate significant main effects or interactions for the students' far transfer or practice scores, although descriptive statistics suggested a similar trend for both of these dependent variables as for the near transfer scores. Prior research has demonstrated smaller effect sizes for far transfer than for near transfer performance (Karbach & Kray, 2009; Lipsey & Wilson, 1993); it is possible that a larger sample size would reveal a statistically significant interaction for the far transfer measure. Practice, i.e., attempting to solve isomorphic problems as in the conceptual overview (demonstration phase) and receiving immediate feedback, may be required for the earlier germane processes enacted during the demonstration phase to fulfill their potential. That is, small differences in understanding of the concepts and solution procedure after the demonstration phase with different guidance conditions may be amplified through subsequent practice with feedback. Future studies may examine the impact of varying amounts of practice on subsequent posttest performance.

A critical next step in investigating the influence of representation type and representation guidance is to explore different sequences of these representations. As has been shown in other domains, the use of contextualized examples followed by more abstract representations can be support knowledge transfer to novel situations (Goldstone & Son, 2005). Moreover, learners tend to transition naturally from representing a domain in a concrete manner to a more abstract manner (Schwartz & Black, 1996). Sequences of different combinations of representation types from the current experiment should be tested experimentally to determine an optimal sequence for engineering education. Moreover, subsequent research examining representation transitions should employ appropriate experimental designs to understand how representational guidance may influence optimal sequence. Additionally, follow-up research should examine the impact of representational guidance on learning from mixed representational pairs – that is, with abstract text and contextualized diagrams or vice versa.

Acknowledgments

This article is based on work supported by the National Science Foundation under awards 0648568 and 1025163. Any opinions, findings, and conclusions or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the National Science Foundation. This work was inspired by Dr. Roxana Moreno who passed away in 2010.

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