AC 2012-3625: REPRESENTATION GUIDANCE WITH ABSTRACT AND CONTEXTUALIZED REPRESENTATION: EFFECTS ON ENGINEERING LEARNING PERFORMANCE IN TECHNOLOGICAL LITERACY EDUCATION

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Representation guidance with abstract and contextualized representation: Effects on engineering learning performance in technological literacy education

Abstract

An experiment explored the impact of explicit guidance (instruction) on the use of abstract symbols or life-like depictions to represent engineering problems. The study examines the effects of guiding learners in the use of abstract or contextualized representations of engineering problems. The study had a 2 (representation conditions: abstract text with abstract diagrams (AA) and contextualized text with contextualized diagram (CC)) x 2 (no guidance or guidance) design. Instruction was provided by a computer-based module that taught the analysis of parallel electrical circuits by using the respective combination of representation and guidance/no guidance on the representation of the electrical circuit components. Among conditions without guidance, the AA representation had significantly higher near-transfer posttest scores compared to the CC representation. These results indicate that novices to engineering (such as high school students and undergraduate non-engineering majors that are unfamiliar with the abstract engineering symbols), learn better with abstract symbol representations than with representations with life-like depictions of engineering system components. Comparing guidance conditions to no guidance conditions revealed that the CC representation with guidance significantly outperformed the CC representation without guidance. This result indicates that guidance on the use of life-like depictions to represent electrical circuit components aided in generating problem solving schemata that allowed the learners to more effectively transfer their problem solving skill to novel contextualized problem settings.

Introduction

Basic understanding of engineering and technological principles among the general populace, i.e., technological literacy, has been highlighted as an essential educational goal[1-4]. Although emphasis has been placed on introducing non-engineering majors to basic engineering and technology concepts[5], researchers have yet to establish the most effective means of representing elementary engineering problems to non-majors. In this study, we examine the effects of representation format and representation guidance on electric circuit problem solving of psychology undergraduate students.

Students demonstrate difficulty solving story problems in mathematics, especially when a problem includes irrelevant information[6]. When posed with such problems, the ability to discriminate between relevant and irrelevant information is essential to successful problem solving[7]. Often, the difference between successful and unsuccessful problem solvers lies in the role that preexisting mental representations (i.e., schemas) play during problem solving. When confronted with a new problem, experts are able to recognize the correspondence between the configuration of the current problem and problems he/she has previously encountered and solved[8]. Existing knowledge of the problem structure resides in mental representations called schemas; the schemas further provide students with the necessary information to select appropriate steps leading to a goal[9]. In contrast, novice students lack appropriate schemas to allow them to focus on underlying concepts within a problem and plan a successful solution approach[10]. As a result, these learners tend to rely on surface features of visual representations and are unable to solve the problems[11,12].

The processes used during problem-solving depend upon the problem solver's understanding and representation of the problem type[13]. It is clear from expertise studies that experts and novices differ significantly in the way they make use of visual representations[14-18]. Visual representations may include features that are primarily schematic (i.e., abstract) or realistic (i.e., concrete) representations of the problem at hand, or may be a combination of both concrete and abstract elements. When experts are observed solving problems, they plan solutions at a more abstract level, focus on key steps, and skip less important ones[15]. Unlike experts, novices do not possess relevant schemas and must attempt to interpret a provided problem in piecemeal. Thus, presenting novices with visual representations which structure the problem and guide their attention may improve learning outcomes. Early introduction of new concepts and principles to-be-learned should be designed to activate and build on novices' existing knowledge[19,20].

Use of visual representations during problem solving

Expertise studies in a variety of domains demonstrate that visual representations are a fundamental tool used in the reasoning and problem solving of experts[14,16-18]. Available empirical work indicates that experts are better equipped to disregard irrelevant or nonessential information and focus on relevant information within visual representations[15,21,22]. In order to bridge the divide between expert and novice learners, several researchers have investigated manipulations to learning materials intended to facilitate the problem-solving and learning processes for novice learners.

The presence of illustrations can promote learning of instructional material consisting of text and equations. Visual representations are thought to facilitate learning through specifying key features and spatial relationships that may remain explicit in sentential form[23,24]. However, learning from text with depictive representations also poses unique cognitive demands on learners[25]. The comprehension of an illustrated document requires the selection of the relevant elements, their organization, the activation of prior knowledge, and the construction of links between the verbal and illustrated information[26]. Schnotz[27] posits that, in order for successful text-picture integration to occur, relevant text and images must be selected, processed, and then integrated for mental model construction. The ability to integrate and process the information contained in the text and visual representations is a critical condition for learning to take place[28,29].

We proceed to review specific relevant prior studies examining the use of visual representations to support problem solving. Winn, Li & Schill[30] found that university students performed significantly better while solving word problems related to family relationships when they were presented with tree figures instead of statements only, showing that conceptual relationships expressed through spatial arrangement permit more rapid problem solving than equivalent texts. Similarly, Butcher & Aleven[31] found that teaching geometry with diagram interactions had robust benefits for students learning. These interactions with diagrams supported long-term retention of practiced problem-solving skills and promoted student success with transfer tasks that required meaningful connections between geometry rules and diagrams.

Supporting the use of visual representations

Although the inclusion of illustrations or diagrams can facilitate problem solving, translating between representations is a difficult task for novice students that are still in the process of acquiring an understanding of the underlying concepts[32]. Multimedia learning environments provide combinations of representations such as text, diagrams, and graphs. These external representations are understood when an observer constructs internal mental representations of the content described in the text or shown in the diagram, but learners often underestimate the informational content of representations and believe a glance is sufficient for understanding and extracting relevant information[27]. When used properly, external representations can contribute to students' understanding of scientific concepts; however, students do not always use, understand, interpret or value these representations as their instructors intended[33]. Learning materials which provide support for learning processes required to translate from one representation to another may enhance learners' ability to link visual information to the relevant quantitative information, thus students may interpret representations more easily[34].

Schwonke, Berthold, and Renkl[35] investigated students' difficulties in using multiple representations, and whether students require instructional support to utilize the potentials of multiple representations. A preliminary study, investigating students' allocation of visual attention, in relation to learning and learners' beliefs on the representation functions, showed that students were not aware of the functions of diagrams. They found that informing students about the functions of tree diagrams had a substantial positive effect on learning about probability theory. Berthold and Renkl[36] investigated the effects of multiple representations (pictorial only, arithmetic only, or both pictorial and arithmetic), color coding to signal correspondences between representations, and prompts to self-explain during learning about probability theory. Results indicated that, although using both pictorial and arithmetic information did not promote learning; color coding and self-explanation prompts increased student learning.

Seufert[37] investigated the moderating effects of domain knowledge on the beneficial impact of help in locating corresponding elements within text and diagrams. Results indicated that low prior knowledge learners were not able to use the given help for structure mapping; for these learners, the help did not significantly impact recall or comprehension of the material. On the other hand, for medium prior-knowledge students, the help appeared to reduced demands on working memory for successful structure mapping processes; medium prior-knowledge students had higher recall and performance when provided help in relating representations. For the high prior-knowledge students, help had an effect on recall but not on comprehension of the material. Butcher and Aleven[38] investigated the effects of integrated visual-verbal learning materials on student problem solving. Students either entered numeric values (answers) to geometry problems in a table isolated from the geometry diagram or interacted with the diagram to enter their answers. Results showed that the integrated format guided students' attention to key features of the visual representation during problem solving, supported longer-term retention, and improved transfer performance. This finding is consistent with extensive research on the advantage of integrated formats over split-source formats of provided representations (for review[39]).

The results from the reviewed research suggest that although problem solving 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 provided. This assistance can come in the form of prompts for active learning processes[36], visual indicators of correspondences between representations[36], verbal guidance on correspondences between representations[35,37], or integrating representations within one another[38]. The first goal of this study was to determine whether college students would develop better problem solving skills in electrical circuit analysis when provided with verbal guidance on correspondences between text and diagrams.

Contextualized vs. abstract visual representations

The ability to use multiple representations for the same concept, and the ability to easily switch from one representation system to another, is essential for successful scientific thinking[40]. 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 perceptually rich, concrete knowledge representations[41]. 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[42].

Contextualized representations

A potential benefit to providing contextualized (or concrete) representations within instruction is that novice learners can more easily relate new problems 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[43-46]. Positive results have been reported by several researchers who studied the value of concrete (realistic) representations in promoting learning. Jennings, Jennings, Richey, and Dixon-Kraus[47] investigated use of contextualized stories while teaching kindergarten students math problem solving. The results showed that the students who learned with the stories had significantly higher test scores of early mathematics ability compared to students who learned with the regular curriculum. Yang, Greenbowe, and Andre[48] investigated the use of familiar objects (a battery and flashlight) for exploring student beliefs about electrochemical concepts and electric circuits. The authors concluded that introducing the concepts of electrochemistry using the familiar context of a flashlight and battery system improved students’ understanding of electrochemistry more than when using abstract, simple cells to introduce the concepts. Tiancheng and Jonnasen[49] investigated the effectiveness of concept-based versus 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.

Abstract representations

Providing learners with abstract representations may lead to better learning outcomes because an abstract format may guide learners to focus on the underlying structure of the problem, rather than superficial elements which may change from problem to problem[50,51]. Positive effects of abstract representation format have been found in mathematics[52,53]. De Bock et al.[52] reported that while teaching to solve word problems about area and volume, realistic contextual presentation of instruction yielded a significantly lower achievement compared to other groups. In a study conducted with gifted high-school students by Moreno, Reisslein, and Ozogul[50], students who learned about electrical circuit analysis with abstract diagrams produced higher transfer scores and better problem representations after instruction than those who learned with diagrams that included life-like images of the circuit elements. Within a different domain, Dwyer and colleagues[54-56] have studied the impact of varying levels of realism in depictions of the human heart. The authors reported a trend that simple line drawings improved student performance on a set of post-tests including drawing tasks, identification tasks, and comprehension tasks. Butcher[57] conducted research in the same domain, comparing instruction using text only, text and simplified (abstract) diagrams, and text and more elaborate (realistic) diagrams. The results showed that instruction using simplified diagrams was most effective in improving the students' mental model of the heart and also improving students' factual knowledge of the human heart and memory of the instructional text.

The second goal of this study was to contribute to our developing understanding about representation formats by examining whether abstract text and diagrams or contextualized text and diagrams would impact student learning and perceptions of the materials.

Method

Participants and design

Participants were a total of 98 students (79 females and 19 males) enrolled in an educational psychology introductory course, given 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.

The study had a 2 x 2 factorial design, with the first factor being the representation type (abstract text and diagram or contextualized text and diagram) and the second factor being the guidance provided on correspondences between text and diagram (with guidance versus without guidance). There were 24 students in the abstract-text with abstract-diagrams without guidance (AA) condition, 25 students in the contextualized-text with contextualized-diagram without guidance (CC) condition, 24 students in abstract-text with abstract diagrams with guidance (AAG) condition, and 25 students in the contextualized-text with contextualized diagrams with guidance (CCG) condition. Comparisons were made among the groups on performance on posttest, performance on practice, and program ratings.

Materials

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) an instructional session providing a conceptual overview of electrical circuit analysis; and (4) a problem-solving practice session.

The pretest 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 instructional session. The instructional session 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 using the fundamental properties of voltages and currents in parallel circuits and Ohm's Law in three steps: *(i)* note that the voltage is the same over each individual resistor and calculate the value of the current flowing through each individual resistor using Ohm's Law, *(ii)* calculate the total current flowing in the circuit by summing up the currents flowing through the individual resistors, and *(iii)* calculate the total resistance of the parallel circuit by applying Ohm's Law to the entire circuit.

The practice session presented 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 was self-paced. After completing each solution step, participants received feedback. Specifically, if the solution was correct, the program confirmed the correctness of the solution. If the solution was incorrect, the program presented an explanation about how to solve the step correctly as well as the correct solution. After studying the explanatory feedback, students could click on the "Continue" button to proceed to the next solution step while the correct solution for the preceding step remained on the screen. After all three steps in a problem were completed, students could click on the "Next Problem" button to move to the next practice problem. Once the participants had submitted their answers, they were not allowed to return to previous steps or problems.

The instruction and practice session portions of the program had two representation conditions, namely abstract text with abstract diagrams (AA) or contextualized text with contextualized diagrams (CC). Each representation condition had a version without guidance and a version with guidance (G). The abstract diagrams represented the electrical circuit elements, e.g., voltage source and resistor, with the standard abstract engineering symbols, as illustrated in Fig. 1(a).

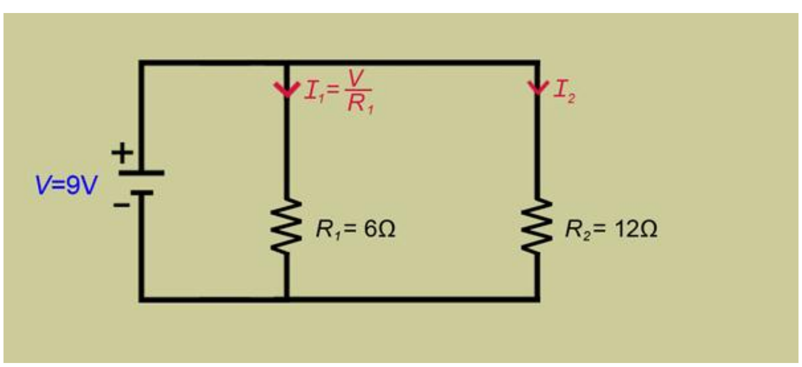

Figure 1(a). Sample abstract diagram

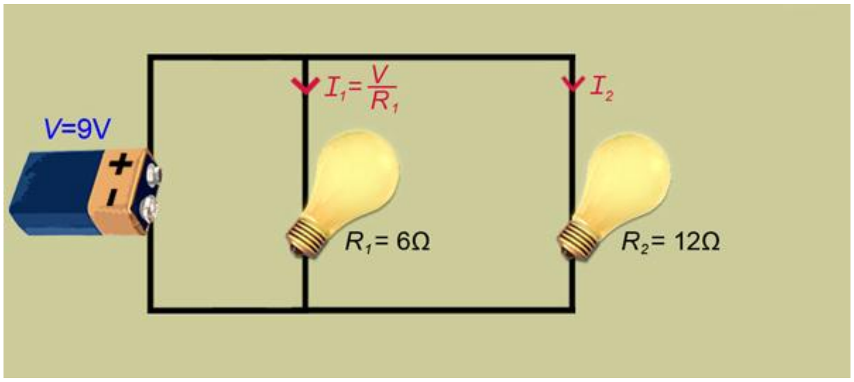

Figure 1b. Sample contextualized diagram

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 R2= 12 Ω in parallel to the first electrical device that you already had with a resistance of R1 = 6 Ω
>
> [Look at the new diagram and try to find the second electrical device.]
>
> Let's call the current flowing through the first electrical device I1, and the current flowing through the second electrical device I2.

In contrast, the contextualized diagrams represented the electrical circuit components with life-like images, as illustrated in Fig. 1(b). 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 R2= 12 Ω in parallel to the first light bulb that you already had with a resistance of R1 = 6 Ω
>
> [Look at the new diagram and try to find the second light bulb]
>
> Let's call the current flowing through the first light bulb I1, and the current flowing through the second light bulb I2.

The guidance provided students with verbal indicators to the correspondence between the text and the diagrams. This guidance was designed to ease the transition between the verbal information and the diagrams, i.e., to help students learn the correspondence between the text and the diagrams. For instance, in the text excerpts above, the guidance is provided by the text in the square brackets, which guides the student's attention to specific parts of the diagrams. The text in square brackets was omitted in the conditions without guidance.

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 instructional session. Two engineering instructors (inter-rater reliability 99.8 %) scored the far transfer test questions

Apparatus

The computer program used in the study 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 x 1050 pixels, and headphones.

Procedure

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

Results

To determine the separate effects and possible interaction effects of representation and guidance, we conducted two separate 2x2 analyses of variance, with near transfer posttest score and far transfer posttest score as the dependent variables and both the representation factor and guidance factor as between subjects variables. For near transfer items, results indicated no significant main effect of representation type, F (1,94) = 0.97, p = .33, and no significant main effect of guidance, F (1,94) = 0.13, p = .72. There was a significant interaction between the representation and guidance factors, F (1,94) = 6.30, MSE = 10.3, p = .014, η_p^2 = .06. Separate independent sample t-tests among the four conditions revealed differences among conditions. We report only comparisons between representation conditions within each level of the guidance factor and between levels of the guidance factor within each level of the representation factor. Comparisons were not made between conditions which had different guidance condition *and* different representation condition. For example, we do not report potential differences between AA and CCG. First, the AA condition had significantly higher posttest scores compared to the CC condition, t (47) = 2.73, p = .009. Although the CCG condition had descriptively higher near transfer scores than the AAG condition, this difference was not statistically significant, t (47) = 0.99, p = .33. Next, the CCG condition significantly outperformed the CC condition, t (48) = 2.12, p = .04. Although the AA condition had descriptively higher near transfer scores than the AAG condition, this difference was not statistically significant, t (46) = 1.46, p = .15. See Table 1 for descriptive statistics.

The analysis of variance on far transfer items did not reveal a significant main effect of representation type, F (1,94) = 0.33, p = .57, nor a significant main effect of guidance, F (1,94) = 1.06, p = .31. Additionally, results did not demonstrate a significant interaction between representation and guidance factors, F (1,94) = 1.29, p = .26.

Table 1

Descriptive Statistics for Posttest Near Transfer Score, and Far Transfer Score, by Experimental Condition

Guidance and Representation Type	Near Transfer Score (max. 9)		Far Transfer Score (max. 9)	
	M	*SD*	*M*	*SD*
No Guidance	6.53	3.10	3.96	3.98
AA (*N* = 24)	7.69	2.65	4.67	4.35
CC (*N* = 25)	5.42	3.14	3.28	3.54
Guidance	6.80	3.48	4.82	4.05
AAG (*N* = 24)	6.29	3.87	4.58	4.14
CCG (*N* = 25)	7.28	3.06	5.04	4.04

Discussion

This study was designed to explore the effects of different forms of representation (both text and diagrammatic representations) and guidance in locating correspondences between representations on student learning outcomes from multimedia instruction on electric circuit analysis. To address these issues, we compared the problem solving performance of naïve college participants who were randomly assigned to learn about electric circuit analysis with abstract text and abstract diagrams (AA condition) or contextualized text and contextualized diagrams (CC condition). The two types of representations were presented either with or without guidance on identifying correspondences between text and diagram.

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 AA condition had significantly higher near-transfer performance, compared to the CC condition. This result mirrors previous results from[50,] which utilized a two-group design, comparing contextualized text and diagrams to abstract text and diagrams. These earlier findings revealed that learners had better near transfer performance after learning with abstract text and diagrams than contextualized text and diagrams.

The current results also reflect earlier findings from[58,] in which the AA condition performed significantly better than the CC condition. Overall, these results support the notion that abstract representations foster learning through allowing learners to focus on the underlying structure of the problem at hand, rather than the superficial elements of each individual problem. Thus, these learners do not observe worked-example problems considering, for example, a battery and a light bulb, rather noting that any type of voltage source and any type of electrical device could be present. Since these college students, although novices to electric circuit analysis, have the requisite experience to know what objects can serve as electrical devices and voltage sources respectively, the use of contextualized posttest problems does not hinder their ability to successfully reach the solution.

Our results suggest that, when guidance is provided to learners about how to make links between text and diagram, different representation formats perform equally well. No significant difference was found between the two guidance conditions, indicating that when guidance was available, the representation format did not have a significant impact on learning. The results indicate that the guidance essentially elevates the performance of the CC condition to meet the learning attained in the AA condition.

The effect of guidance

Similarly to the findings on representation type, there was not a significant main effect of guidance on near-transfer or far-transfer performance. 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 contextualized diagram participants benefitted from the inclusion of guidance on correspondences between representations, whereas the abstract condition did not benefit from the guidance. This appears at first counterintuitive, considering that contextualized text references (e.g., 'battery') to diagram elements should be most easily interpreted and correspondences most easily determined under this condition. However, without the explicit guidance, the learners may have only briefly glanced at the diagram with the familiar life-like images, and thus may have missed the relevant structural information about the circuit[27]. The guidance in the contextualized text and diagram condition may serve as a prompt to learners to more thoroughly examine the underlying structure of the electrical circuits. 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). Thus, these learners are facilitated in building more accurate and accessible mental representations of electric circuits. This may enable the transition from interpreting concrete 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 the abstract representation without guidance is sufficient to form internal representations necessary for solving isomorphic problems. The abstract diagrams alone with their conventional engineering symbols, which were unfamiliar to the naïve learners, elicited attention and supported the formation of effective schemas for circuit analysis.

It is also important to recall the result that differences between representation conditions were resolved through the use of guidance. This suggests that the guidance serves as a means to place different representation formats at an even position. This could be critical when attempting to sequence instruction, transitioning between different representation types[59].

Limitations and future directions

It is important to note that our study is limited because we focused on one specific instructional context, namely technological literacy education of college undergraduates who were novices in engineering, domain (i.e., electrical circuit analysis), and learning environment (i.e., instructional program). Further, the experiment was conducted in a laboratory environment, not in situ (i.e., classroom). Future research should examine the experimental design used in this study in other instructional contexts, domains, and learning environments.

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 concrete examples, followed by more abstract representations, can be beneficial to transfer of knowledge to novel situations[59] and that learners tend to naturally transition from representing a domain in a concrete manner to a more abstract manner[60]. Sequences of different combinations of representation types from the current experiment can be experimentally tested to determine an optimal sequence for engineering education.

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