Pre-college Electrical Engineering Instruction: The Impact of Abstract vs. Contextualized Representation and Practice on Learning

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BACKGROUND
While engineering instructional materials and practice problems for pre-college students are often presented in the context of real-life situations, college-level texts are typically written in abstract form.

PURPOSE (HYPOTHESIS)
The goal of this study was to jointly examine the impact of contextualizing engineering instruction and varying the number of practice opportunities on pre-college students' learning and learning perceptions.

DESIGN/METHOD
Using a 3 × 2 factorial design, students were randomly assigned to learn about electrical circuit analysis with an instructional program that represented problems in abstract, contextualized, or both forms, either with two practice problems or four practice problems. The abstract problems were devoid of any real-life context and represented with standard abstract electrical circuit diagrams. The contextualized problems were anchored around real-life scenarios and represented with life-like images. The combined contextualized-abstract condition added abstract circuit diagrams to the contextualized representation. To measure learning, students were given a problem-solving near-transfer post-test. Learning perceptions were measured using a program-rating survey where students had to rate the instructional program's diagrams, helpfulness, and difficulty.

RESULTS
Students in the combined contextualized-abstract condition scored higher on the post-test, produced better problem representations, and rated the program's diagrams and helpfulness higher than their counterparts. Students who were given two practice problems gave higher program diagram and helpfulness ratings than those given four practice problems.

CONCLUSIONS
These findings suggest that pre-college engineering instruction should consider anchoring learning in real-life contexts and providing students with abstract problem representations that can be transferred to a variety of problems.

KEYWORDS
practice, problem representation, problem solving

I. INTRODUCTION

Effective pre-college engineering education that helps increase the performance and enthusiasm of K-12 students in engineering has emerged as a key challenge for engineering education (Orsak, 2003). Engineering learning materials for pre-college students represent the engineering concepts typically in the context of real-world examples that are often illustrated with life-like images (Orsak et al., 2004). In contrast, engineering learning materials for college students, such as electrical circuit textbooks, represent the concepts in abstract form, often with standard engineering symbols and abstract diagrams (Alexander and Sadiku, 2004; Irvin and Nelms, 2005). A fundamental question is whether the contextualized representation of engineering concepts and problems is indeed helpful for pre-college students; or, whether abstract representations similar to college-level materials would result in better learning and more positive perceptions of the learning experience.

Past studies have examined the effects of the level of realism of illustrations in science learning materials. In an extensive series of studies, Dwyer and colleagues (Dwyer, 1968; Dwyer, 1969; Joseph and Dwyer, 1984) have studied the impact of varying levels of realism in depictions of the human heart. Although the results were mixed, the research found a tendency for simple line drawings to improve student performance on a set of post-tests including drawing tasks (where students had to draw a human heart and place parts of the heart in the diagram), identification tasks (where students had to identify heart parts in a heart diagram), and comprehension tasks (which tested student comprehension of simultaneous phenomena in the heart's functioning). Another study in the same domain compared instruction using text only, instruction using text and simplified diagrams, and instruction using text and more elaborate diagrams. The results showed that instruction using simplified diagrams was most conducive to improving the students' mental model of the heart (as a double loop model with correct blood paths), as well as the students' factual knowledge of the human heart and memory of the instructional text (Butcher, 2006). A recent study showed that realistic contextualized representations are suitable for learning relatively easy concepts but abstract representations are more advantageous for learning complex concepts in algebra (Koedinger, Alibani, and Nathan, 2008). The first goal of this study was to examine whether middle school students acquire better problem solving skills in elementary electrical circuit analysis when the concepts and practice problems are represented in abstract or contextualized form.

Another important aspect of instructional design for pre-college engineering education is practice of the taught concepts. Practice with appropriate feedback generally improves skill acquisition (Newell and Rosenbloom, 1981; Symonds and Chase, 1929). The second goal of this study was to examine the impact of more practice on solving electrical circuit analysis problems.

The impact of abstract vs. contextualized representation and the impact of practice are largely unexplored in engineering education. A few studies on science education have considered instructional materials that are related to engineering. For instance, one study compared electrical circuit diagrams with the components represented with the standard engineering symbols and a letter against diagrams with components represented with a square and a letter (Winn, 1988). It was found that the more detailed representation with the symbols better fostered writing a list of all components in the circuit. On the other hand, the less detailed square representation better fostered the drawing of the circuit, which required that students remember the spatial arrangement of the components in the circuit. Another study compared diagrams combining contextualized pictures with text labels and diagrams combining abstract rectangular or circular shapes with text labels; both depicting the cycles of water and gases in the natural environment. It was found that for students with low verbal ability, the diagrams with the contextualized pictures led to higher scores on a retention multiple-choice post-test than the diagrams with the abstract shapes (Holliday, Bruner, and Donais, 1977). One study examined how experts and novices read complex electronics schematics that use abstract engineering conventions. It was found that experts exploited the abstract conventions for effective reading of the diagrams whereas novices struggled to identify the most relevant parts of the diagrams (Petre and Green, 1993).

A recent study compared instruction using only abstract representations to instruction using only contextualized instruction, whereby both representation conditions had two practice problems (Moreno, Reisslein, and Ozogul, 2009b). The Moreno, Reisslein, and Ozogul (2009b) study found that learning how to solve parallel electrical circuits with abstract circuit diagrams led to increased performance on near-transfer problems, i.e., problems with the same underlying structure but different surface characteristics than the problems in the instructional module, and better representation of novel problems as compared to learning with realistic diagrams. The present study expands on this recent study by adding a third representation type that combines contextualized with abstract representations and by considering two amounts of practice (two or four practice problems) as well as by replicating the experimental evaluation of the abstract and contextualized representation types for two practice problems with new participants.

The first contribution of the present study is to extend engineering education research by examining the impact of abstract vs. contextualized representations on the acquisition of engineering problem solving skills for pre-college students. The second contribution of this research is to add to the empirical knowledge base about the impact of practice on the acquisition of engineering problem solving skill. In summary, this research seeks to address the following two research questions:

(1) Does contextualizing instruction promote better problem-solving, better representation of novel problems, and more positive learning perceptions?
(2) Does more practice promote better problem-solving, better representation of novel problems, and more positive learning perceptions?

To answer these questions, we asked a group of middle-school students to learn about parallel electrical circuit analysis with the help of an instructional computer program in a 3 $\times$ 2 factorial design in which the first factor was the type of representation (abstract, contextualized, contextualized-abstract) and the second factor was amount of practice problems (2 versus 4).

Problem-solving was measured by a near-transfer post-test in which students were asked to apply the electrical circuit principles learned to solve a set of problems that had the same structure as those presented during the practice session but which differed in their surface characteristics. In addition, learning perceptions were measured using a program-rating survey where students had to rate the instructional program's diagrams, helpfulness, and difficulty. This study did not seek to identify the students' learning approach, which is characterized by the learners' strategies and intentions (Case and Marshall, 2004). Examining the learner strategies and intentions as they relate to representation type and practice amount are interesting directions for future research. In the next sections, we summarize the existing research on problem representations and practice that guided our study and formulate a set of hypotheses.

A. Contextualized Representations

By presenting contextualized cover stories and representations during instruction, novice learners can relate the new problems to their prior knowledge and experiences. Thus, contextualized representations may promote problem solving by activating the learner's prior knowledge (Brown, Collins, and Duguid, 1989; Cognition and Technology Group at Vanderbilt, 1993; Cordova and Lepper, 1996; Koedinger and Nathan, 2004). Although abstract representations attempt to depict a close correspondence between the diagram and the concrete objects that they intend to represent, they rely significantly more on knowledge conventions for their interpretation than contextualized representations (Hegarty, Carpenter, and Just, 1991). Therefore, contextualized instruction should be easier to understand than abstract instruction and promote better problem solving, better problem representations of novel problems, and more positive learning perceptions.

B. Abstract Representations

Abstract problem cover stories and representations can help the learners focus on the relevant underlying structures because they avoid the irrelevant superficial information that changes from problem to problem (Moreno, Reisslein, and Ozogul, 2009b). Studies have shown that one of the main obstacles to successful problem solving is that contextualized problem representations may divert attention to irrelevant details or may highlight superficial aspects of the problem at the expense of information that is necessary to accomplish the task (Elia, Gagatsis, and Demetriou, 2007; Goldstone and Sakamoto, 2003; Kaminski, Sloutsky, and Heckler, 2008; Presmeg, 1986; Sloutsky, Kaminski, and Heckler, 2005), especially for concepts that are relatively complex (Koedinger, Alibali, and Nathan, 2008). Therefore, instruction with abstract representations should be easier to understand and promote better problem solving and representations of novel problems, as well as more positive perceptions about the learning experience than instruction in contextualized form.

C. Combined Contextualized and Abstract Representations

Attempts to bridge the two representation types by simultaneously presenting contextualized and abstract representations are relatively rare. One study compared the following representations of the human heart: first, a hybrid representation where an abstract

Representation		Practice score on Problems 1 and 2 *(max. 6)*	Practice score on Problems 3 and 4 *(max. 6)*
Abstract (A)	*M*	1.88	2.83
(*N* = 24)	*SD*	1.70	2.12
Context. (C)	*M*	1.21	2.54
(*N* = 24)	*SD*	1.18	2.19
Context.-Abstract (CA)	*M*	1.93	3.04
(*N* = 27)	*SD*	1.82	2.21
Total	*M*	1.68	2.81
(*N* = 75)	*SD*	1.61	2.15

Table 1. Means and standard deviations for sum of scores on practice problems 1 and 2 and sum of scores on practice problems 3 and 4 for students with four practice problems.

line drawing was embedded in a photograph of the human heart; second, a combined representation providing a photograph and line drawing side by side; third, a representation using only photographs; and fourth, a representation using only line drawings. It was found that learners with a medium level of prior knowledge benefited from the hybrid and combined representations (Joseph and Dwyer, 1984).

A study of a tutoring system for algebra word problems compared students' learning in the following four conditions: learning only with mathematical equations; learning by constructing abstract algebraic representations of the word problems; learning by simultaneously constructing abstract algebraic representations and static contextualized representations of the word problems; and learning by constructing abstract algebraic representations and contextualized representations of the word problems and then animating the contextualized representation (Nathan, Kintsch, and Young, 1992). Students in the latter group showed a significantly higher gain in problem solving when compared to the rest of the groups.

In sum, the few studies that have used a combination of depictive detailed representations with abstract representations suggests that the combined contextualized-abstract representations will promote better learning, problem representations, and learner perceptions than abstract or contextualized representations alone.

D. The Role of Practice

The adage "practice makes perfect" is broadly supported by research. The classical study by Symonds and Chase (1929, p. 289) summarized experimental findings in the domain of English language usage by stating: "No devices offer more hope for increasing learning than those which give each individual pupil more opportunity to practice." In fact, recent studies in a variety of domains, such as quantitative methods in social sciences (Peladeau, Forget, and Gagne, 2003), teaching strategies (Schnackenberg et al., 1998), and introductory statistics (Shute, Gawlick, and Gluck, 1998), have shown that more practice generally improves test performance. In engineering education research, the effects of practice have received relatively little attention. Therefore, this study set out to add to the empirical knowledge base about practice effects by examining whether providing students with more or less opportunities to practice in the three different representation conditions would affect students' learning and perceptions about learning. Consistent with the literature on practice effects, we hypothesized that students who were given more opportunities to practice would report higher helpfulness and lower difficulty ratings, and produce higher scores in the post-test than those who were given fewer practice problems.

II. Method

A. Participants and Design

Participants were a total of 148 students in 8th grade in a middle school in the Southwestern U.S., 69 females and 79 males. The mean age of the participants was 14.40 years ($SD = 2.64$ years). Fifty-nine (39.9 percent) reported that they were Caucasian, forty-eight (32.4 percent) of the students reported that they were Hispanic American, twelve (8.1 percent) reported they have multiple ethnicities, nine students (6.1 percent) reported being of other ethnicities, nine (6.1 percent) reported being African American, six (4.1 percent) reported being Native American, and five (3.4 percent) reported Asian American as ethnicity. The students had completed the same school instruction in math and science and had not received any school instruction on electrical circuits prior to participating in this study.

The study had a 3×2 factorial design with the first factor being the representation type (abstract, contextualized, contextualized-abstract) and the second factor being the amount of problem-solving practice (2 practice-problems versus 4 practice-problems). There were 48 students in the abstract representation treatment, 49 students in the contextualized representation condition, and 51 students in the contextualized-abstract representation condition. There were 73 students in the 2-practice problem condition and 75 students in the 4-practice problem conditions. The participant distribution over the individual cells is given in Table 2.

Comparisons were made among the groups on performance on post-test, performance on problem representations, and program ratings.

B. Materials and Apparatus

1) Computerized materials: For each participant, the computerized materials consisted 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) an instructional session providing a conceptual overview of electrical circuit analysis; (3) a problem-solving practice session, and (4) a program rating questionnaire. Next, we describe each of these sections in detail.

The instructional session presented the students with the meanings and units of electrical current, voltage, and resistance followed by a worked-out problem showing 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, the worked example included the following 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

Representation	Practice Probs.		Post-test score	Representation score	Diagram rating	Helpfulness rating
			(max. 9)	(max. 9)	(max. 4)	(max. 4)
Abstract	2	*M*	3.07	2.08	2.80	3.02
(A)	(*N* = 24)	*SD*	3.40	2.48	0.80	0.78
	4	*M*	2.36	1.92	2.38	2.83
	(*N* = 24)	*SD*	3.47	2.86	1.19	0.93
	Totals	*M*	2.72	2.00	2.59	2.93
	(*N* = 48)	*SD*	3.42	2.65	1.02	0.86
Context.	2	*M*	1.77	2.80	2.89	3.02
(C)	(*N* = 25)	*SD*	2.48	2.45	1.08	1.03
	4	*M*	3.60	1.67	2.51	2.47
	(*N* = 24)	*SD*	4.01	2.26	1.12	1.27
	Totals	*M*	2.66	2.24	2.70	2.75
	(*N* = 49)	*SD*	3.41	2.40	1.11	1.17
Context.-	2	*M*	4.19	3.96	3.18	3.34
Abstract	(*N* = 24)	*SD*	3.60	2.68	0.64	0.48
(CA)						
	4	*M*	4.70	3.00	2.83	3.17
	(*N* =27)	*SD*	3.99	2.90	1.04	0.78
	Totals	*M*	4.46	3.45	3.00	3.25
	(*N* = 51)	*SD*	3.78	2.81	0.89	0.66
Totals	2	*M*	2.99	2.95	2.96	3.13
	(*N* = 73)	*SD*	3.30	2.62	0.87	0.80
	4	*M*	3.60	2.23	2.58	2.84
	(*N* = 75)	*SD*	3.91	2.72	1.12	1.03

Table 2. Means and standard deviations for post-test score, problem representation score, diagram ratings, and helpfulness ratings by representation type and amount of practice.

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 that were demonstrated 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 practice session contained two practice problems in the two problem condition and four practice problems in the four problem condition. The instructional session and practice session portions of the program had three different representation versions, one for each of the three representation conditions used in this study, which are illustrated in Figure 1 (i), (ii), and (iii), respectively.

In the abstract representation condition (A), the electrical circuit elements (such as voltage source and resistors) in the circuit diagrams were represented with the abstract symbols that are standard in electrical engineering. In addition, the word problems were presented in abstract terms, e.g., "Consider two resistors connected in parallel to a voltage source."

In contrast, in the contextualized representation condition (C), the circuit elements in the circuit diagrams were represented with life-like images, as illustrated in Figure 1(ii). In similar fashion, the word problems were presented in the context of real-life scenarios, e.g., "Consider two light bulbs connected in parallel to a battery."

Finally, in the contextualized-abstract representation condition (CA) each circuit diagram combined both the contextualized version and the abstract version, as illustrated in Figure 1(iii) and the word problems were contextualized, as in the contextualized representation condition.

The worked example in the instructional session and all practice problems in the problem solving practice session were isomorphic, i.e., they had the same underlying structure but different surface characteristics.

The last section in the computer program included a program rating questionnaire, which was an 11-item Likert instrument asking participants to rate their learning perceptions on a 5-point scale which ranged from 0 (strongly disagree) to 4 (strongly agree). The questionnaire was a revised version of a 16-item survey that the authors had developed in collaboration with experts in computer-based engineering education (Moreno, Reisslein, and Delgoda, 2006). The original instrument included three subscales corresponding to students' interest in engineering, the perceived program helpfulness, and the perceived cognitive load (a scale previously developed by Paas and Van Merrienboer (1994)). Based on the research questions of the present study, the original questionnaire was revised to exclude the engineering interest subscale (a construct not related to our research questions) and to include an additional subscale for the perceived usefulness of the program's diagrams. The survey items for the diagram helpfulness subscale were developed by the authors. Following Aiken (1997), the construct validity of the revised survey was assessed with the judgment of subject matter experts in electrical engineering instruction. The new survey had been used in a preliminary study (Moreno, Reisslein, and Ozogul, 2009b) and found to have factorial validity and reliability by way of traditional factor analysis.

To examine the reliability of the instrument in the present study, we conducted a factor analysis using principal axis estimation. The findings showed that three factors accounted for 67.6 percent of the variance of student ratings. Similar to the results of our preliminary study, the three factors related to the usefulness of the program diagrams (four items, such as "The pictures made the lesson easier to understand." and "I liked the pictures in the program." with coefficient factors between 0.75 and 0.84), the helpfulness of the instructional program (five items, such as "The examples in the program helped me learn." and "Getting feedback as I solved problems helped me learn." with factor coefficients between 0.75 and 0.83), and students' perceived learning difficulty (two items, "The lesson was difficult." and "Learning the materials in the lesson required a lot of effort." with factor coefficients 0.88 and 0.90) . The internal reliabilities of the diagram, helpfulness, and difficulty rating scales measured by Cronbach alpha (Allen et al., 2008; Cronbach, 1951) were 0.90, 0.84, and 0.90, respectively, indicating relatively high reliabilities. The attitude survey was administered by the computer-based module, and data were collected by the computer.

2) Paper and pencil materials: The paper and pencil materials consisted of a post-test with three problems (Cronbach's alpha = 0.90, a high level of reliability). The problem statements on the tests were in contextualized form, as is common for real-life engineering problem settings. The problem statements were scaffolded, i.e., asked students to (a) draw a circuit diagram, (b) calculate the individual currents, (c) calculate the total current, and (d) calculate the total resistance. The post-test was designed to assess students' ability to transfer their problem solving skills to an isomorphic set of problems, i.e., the three problems had the same underlying structure but different surface characteristics than the worked example in the instructional session and the problems presented during the practice session. Two engineering instructors who were blind to the experimental conditions scored the post-test (inter-rater reliability 98.5 percent) assigning one point each for the correct solution of tasks (b), (c), and (d) for a maximum score of three points per problem and a maximum post-test score of nine points.

The circuit diagrams drawn for task (a) of the post-test problems were scored using a rubric developed by an experienced electrical engineering instructor. The rubric assigned points for drawing a closed electrical circuit with parallel resistors that correctly reflect the problem statement, for including a voltage source in parallel to the resistors, and for indicating individual current flows in the individual branches of the parallel circuit. The maximum score for each circuit diagram was three points, leading to a maximum representation score of nine points for the three problem representations. The post-test rubric was not shared with the students because we considered that students had sufficient practice with feedback on

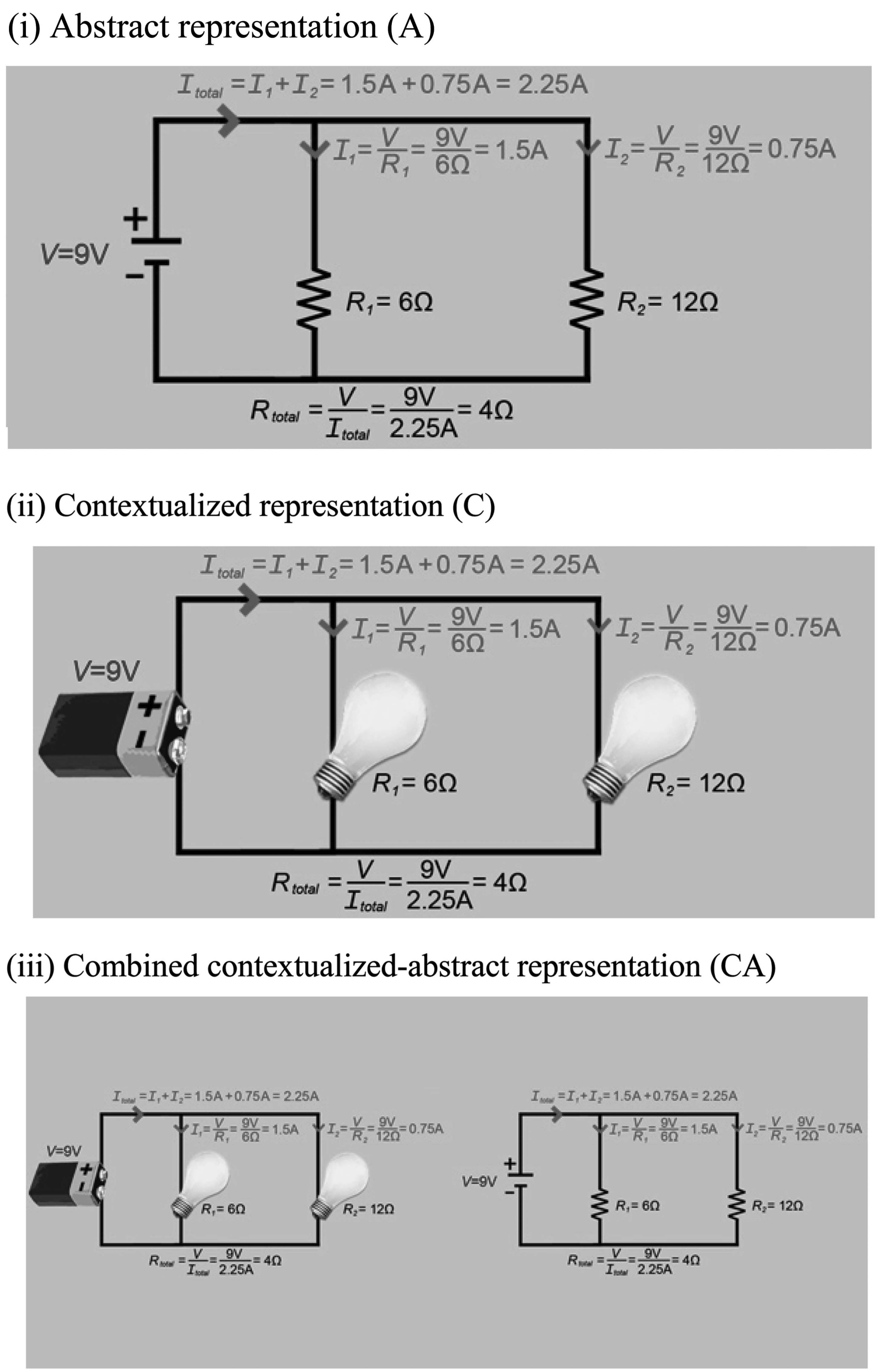

Figure 1. Sample images from the three representation conditions.

similar problems. Two instructors who were blind to the experimental conditions scored the diagrams (inter-rater reliability 97.9 percent).

3) 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 set of laptop computer systems, each with a screen size of 1680 x 1050 pixels, and headphones.

C. Procedure

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, practice session, and program rating questionnaire). Once the computer program was over, participants completed the paper-based post-test.

III. Results

In all statistical tests, alpha was set at 0.05 and an appropriate adjustment was made, i.e., Bonferroni, when conducting multiple tests. Two separate Analyses of Variance (ANOVAs) for the aggregate scores from practice problems 1 and 2, and the aggregate scores from problems 3 and 4 revealed that there was no significant difference between the representation conditions ($p = 0.22$ and $p = 0.72$, respectively). A repeated measures ANOVA showed that the total mean scores increased significantly from practice problems 1 and 2 to problems 3 and 4, $F(2, 72) = 37.05$, $MSE = 1.30$, $p < 0.001$, $\eta^2 = 0.34$. Table 1 shows the means and standard deviations of the numbers of correct responses produced during the practice session for a total of four problems.

The post-test scores, problem representation scores, and program ratings were subjected to two-factor analyses of variance (ANOVAs) with representation type (A, C, or CA) and practice amount (2 or 4 practice problems) as between-subject factors.

The ANOVAs revealed that there was no significant interaction between the representation type and practice amount on post-test scores ($p = 0.21$), nor a significant interaction between the representation type and practice amount on representation scores ($p = 0.63$), nor significant interactions on the diagram ratings ($p = 0.98$), the helpfulness rating ($p = 0.49$), or difficulty rating ($p = 0.78$). Next, we present the main effect results by research question.

1) Research Question 1: Does contextualizing instruction promote better problem-solving, better representation of novel problems, and more positive learning perceptions?

The two-factor ANOVA with students' post-test scores as dependent variable revealed a significant main treatment effect of representation type on post-test score, $F(2, 142) = 4.08$, $MSE = 12.49$, $p = 0.02$, $\eta^2 = 0.05$. Follow-up tests showed that students in the CA group had significantly higher scores than students in the A group ($p = 0.015$) and students in the C group ($p = 0.012$). Furthermore, there was no significant difference between the A and C groups ($p = 0.94$).

The ANOVA for students' problem representation scores showed a significant main treatment effect, $F(2, 142) = 4.60$, $MSE = 6.86$, $p = 0.01$, $\eta^2 = 0.06$. Post-hoc tests revealed that the representation scores of the CA group were significantly higher than those of the A group ($p = 0.007$) and the C group ($p = 0.023$). There was no significant difference between the A and C groups ($p = 0.65$).

The ANOVAs for the program survey subscales (diagram, helpfulness, and difficulty ratings) revealed a marginally significant main effect on ratings of the program diagrams, $F(2, 142) = 2.38$, $MSE = 1.00$, $p = 0.10$, $\eta^2 = 0.03$, with the CA group giving more favorable ratings than the A group ($p = 0.043$). There was no significant difference between the CA and C groups ($p = 0.14$), nor a significant difference between the A and C groups ($p = 0.57$). There was a significant main effect for helpfulness ratings, $F(2, 142) = 4.05$, $MSE = 0.83$, $p = 0.02$, $\eta^2 = 0.05$, with the CA group giving significantly higher helpfulness ratings than the C group ($p = 0.007$) and marginally significantly higher helpfulness ratings than the A group ($p = 0.077$). There was no significant difference between the A and C groups ($p = 0.35$). There were no significant differences among the three representation conditions on the difficulty ratings ($p = 0.65$).

2) Research Question 2: Does more practice promote better problem-solving, better representation of novel problems, and more positive learning perceptions?

The two-factor ANOVA for post-test scores revealed no significant main treatment effect for the amount of practice ($p = 0.35$). Although the interaction between representation type and amount of practice was not significant, a one-way ANOVA showed that the post-test score of the C group was marginally higher with four practice problems than with two practice problems, $F(1, 47) = 3.73$, $MSE = 11.00$, $p = 0.059$, $\eta^2 = 0.07$.

The two-factor ANOVA for representation scores showed a marginally significant main effect of the number of practice problems, $F(1, 142) = 3.05$, $MSE = 6.86$, $p = 0.08$, $\eta^2 = 0.02$, with two practice problems leading to higher representation scores than four practice problems. Further, a one sample Chi-square analysis found that the proportion of students that entirely skipped the problem representation in a diagram for all three post-test problems was significantly higher for the group with four practice problems than for the group with two practice problems, Pearson $\chi^2 = (1, N = 148) = 16.99$, $p < 0.01$.

Finally, the ANOVA for the diagram ratings revealed a significant main effect for amount of practice, $F(1, 142) = 5.53$, $MSE = 1.00$, $p = 0.02$, $\eta^2 = 0.04$ in that the groups presented with two practice problems gave significantly more positive ratings for the diagrams than the groups presented with four practice problems. There was also a significant main effect on the helpfulness ratings, $F(1, 142) = 4.12$, MSE $= 0.83$, $p = 0.04$, $\eta^2 = 0.03$, whereby the students presented with two practice problems rated the program helpfulness significantly higher than those presented with four practice problems. No significant differences on difficulty ratings were found ($p = 0.40$).

IV. Discussion

The present study sought to examine the effects of contextualization and practice on pre-college engineering instruction. To this end, we compared the problem solving and learning perceptions of pre-college students who were randomly assigned to learn about electrical circuit analysis with a learning program that included contextualized instruction and problems (group C), abstract instruction and problems that lacked anchors to real-life scenarios (group A), or instruction and problems that were anchored to real-life scenarios and provided both contextualized and abstract diagrams (group CA). These three types of representation were combined with two levels of practice (2 practice problems or 4 practice problems) to examine the impact of practice.

A. The Impact of Problem Representation (A vs. C vs. CA)

This research is significant because it tested the conflicting hypotheses that contextualized or abstract representations promote better learning. Realistic problem-solving scenarios and representations may be more likely to facilitate learning because their meaning can be more readily accessed in long-term memory (Cognition and Technology Group at Vanderbilt, 1993). On the other hand, abstract problem-solving scenarios may promote better learning by helping learners to focus their attention on the relevant structural information underlying problems rather than on their superficial information.

Our findings indicate that the two representation types employing exclusively contextualized or abstract representations resulted in equivalent post-test performance and problem representation scores. This result is in contrast to an earlier study (Moreno, Reisslein, and Ozogul, 2009b) that found that students learning with abstract representations outperformed students learning with contextualized representations on the post-test. It is instructive to note, however, that the earlier study considered two practice problems and that the results of the present study for the group with two practice problems indicate a tendency for abstract representation to give higher post-test scores ($M = 3.07$, $SD = 3.40$) than contextualized representation ($M = 1.77$, $SD = 2.48$); this difference, however, did not reach the level of statistical significance ($p = 0.13$). A possible explanation for the different results is that the students in the earlier study were slightly older ($M = 15.4$ years, $SD = 1.4$ years) and included more English language learners (40.2 percent) than the students in the present study ($M = 14.4$ years, $SD = 2.6$ years; 14.5 percent English language learners); more research to investigate effective engineering representations across the full K-12 age range for both native English speakers and English language learners could shed further light on this issue.

Considering that in the present study, all groups were given an identical post-test where the problem stories were contextualized, it is still noteworthy that group A performed as well as group C. According to the well-known psychological phenomenon called encoding specificity (Tulving and Osler, 1968) retrieval of information is enhanced when the conditions at retrieval (i.e., assessment) match those at encoding (i.e., instruction). Because students who learned with abstract problems were provided with abstract problems during encoding but contextualized problems during the post-test, this group of students was at a disadvantage.

The key finding of this study is that instruction that combines contextualized and abstract representations results in higher transfer of the electrical principles learned and better representation of novel isomorphic problems than instruction that uses only abstract or contextualized representations. The learners in the CA conditions were in the best of both worlds. First, instruction on the electrical circuit principles and the practice problems were anchored to real-life scenarios and complemented with life-like depictions of the main circuit elements. Second, they could compare side-by-side the real-life depictions with the corresponding abstract representations in the abstract circuit diagram, which is a transferable tool for representing any contextualized circuit problem. It is important to note that the design of this study does not allow us to distinguish between the effects of the real-life scenarios described in the word problems and the side-by-side comparison of the circuit diagrams. Future research should examine the separate contributions of both factors to the CA instructional condition.

In addition, the combination of contextualized and abstract representations promoted more favorable learning perceptions. Specifically, the CA group rated the diagrams marginally higher than the A group, while the diagram ratings by the C group were not significantly different. Furthermore, the CA group gave significantly higher helpfulness ratings than the C group and marginally higher helpfulness ratings than the A group. These program ratings provide additional indication of the benefits of the CA representation.

Taken together, the post-test scores, problem representation scores, and survey findings support the use of hybrid representations to promote learning electrical circuit analysis. By combining contextualized instruction with abstract circuit diagrams, novice students who are in the beginning stage of problem-solving skill acquisition benefit in two important ways. First, they benefit from the anchors to real-life situations that the contextualized representations provide. Second, they benefit from the concise universal representation that the abstract circuit diagrams provide. The abstract representations help the learners focus their attention on relevant problem information and develop effective problem solving skills (Moreno and Mayer, 2000). Providing only contextualized representations hinders the problem solving of the novice students who tend to focus on superficial rather than structural problem information (Harp and Mayer, 1998; Mayer, Heiser, and Lonn, 2001; Moreno, 2007; Quilici and Mayer, 1996). As noted above, future research is needed to examine in detail how the benefits from anchors to real-life situations and from the universal representation in abstract circuit diagrams contribute to the superior performance of the CA representation observed in this study.

B. The Impact of Practice

While the group that learned with four practice problems had a slightly higher mean post-test score than the group that learned with two practice problems, the increase did not reach the level of statistical significance. However, it is noteworthy that the group with four practice problems significantly improved its scores on the practice problems from the first two problems to the last two problems. Thus, the additional two problems helped the group with four practice problems to significantly improve their correct problem solving while practicing in the program, but did not translate into a significant improvement in post-test performance compared to the group with two practice problems. A possible explanation for these results is that the problems in the practice session provided feedback after attempting each problem step whereas the post-test required the solution of the three same steps without the benefit of the feedback. Future research could examine the joint impact of type of representation (abstract or contextualized, or combination thereof), number of practice problems, and form of feedback. For instance, a study could examine a feedback reduction (fading) strategy where students initially receive feedback on each problem step as in this study. After completing a few practice problems, the feedback could be reduced to summative feedback requiring students to attempt all problem steps before receiving feedback (Moreno, Reisslein, and Ozogul, 2009a). Such feedback fading could help transition students to independent problem solving without feedback.

Interestingly, the mean representation score was marginally lower for the group with four practice problems than for the group with two practice problems. A possible explanation is that the students who had experienced four practice problems had automated their problem solving steps better and thus did not need to rely as much on the problem representation in a diagram. After all, the representation of a word problem in a diagram is especially helpful when the problem is challenging. More practice on isomorphic problems had somewhat reduced the difficulty of the task for the students with four practice problems. Even though the problem statement asked the participants to represent the word problem in a diagram as an intermediate solution step, the proportion of students who skipped the graphical problem representation and proceeded directly to the calculation of the resistance of the parallel circuit was significantly higher for the group with four practice problems than for the groups with two practice problems. This result suggests that a higher proportion of the students with four practice problems felt that they could skip the problem representation in a diagram and instead work out their more automated three-step solution procedure.

It is similarly interesting that the program rating scores for the program's diagrams and helpfulness were significantly lower for the group with four practice problems than for the group with two practice problems. The learners who experienced only two practice problems may have felt that these few practice opportunities with their accompanying graphical representations were quite important, whereas the more abundant practice opportunities may have diminished their relative importance for the learners with four practice problems.

C. Interactions between Representation Type and Practice

Although the interactions between representation type and amount of practice did not reach the level of statistical significance, it is instructive to examine the interaction trends for the post-test scores. As we observe from Table 2, the mean post-test score dropped for the A group with increased practice, whereas it approximately doubled for the C group (a marginally statistically significant increase when comparing the C group with two practice problems to the C group with four practice problems), and increased slightly for the CA group. The first trend appears to indicate a drop in interest in the A group as they experienced more abstract representations; indeed, they had rated the program's diagrams and helpfulness significantly lower than the CA group.

The doubling of the post-test score with increased practice for the C group suggests that instruction using only contextualized representation may pose an unnecessary challenge to learning the problem solving steps for novices. Because the contextualized representations are specific to any given problem, they may distract the novice learners from the underlying problem solving steps. In contrast, the abstract representation allows the novice learners to focus on the problem solving steps and provides an easily transferable schema that can be employed to represent and solve a variety of problem scenarios. Instead of being explicitly provided with a transferable representation schema (the abstract circuit diagram), the learners in the C group had to infer themselves a transferable solution schema, which required a relatively larger number of practice problems.

D. Limitations and Practical Implications for Engineering Education

The reported study has important practical implications for engineering education. When reviewing introductory electrical engineering textbooks for pre-college students and college students, we found that those for the younger audience typically present problems in the context of real-world examples (Orsak et al., 2004). In contrast, college-level textbooks mostly rely on abstract problem representations and only a few selected problems are presented in real-world contexts. Examples are the Comprehensive Problems in Alexander and Sadiku (2004) and the Application Problems in Irwin and Nelms (2005). To our knowledge, the research base for contextualizing problems for pre-college students learning engineering is limited. The findings of the present study, although preliminary, suggest that pre-college engineering instruction should also focus on providing abstract problem representations and solution strategies for real-life problems. Because pre-college students have reached the cognitive development necessary to engage in abstract thinking, this practical implication is developmentally appropriate for this age (Meece, 2002; Miller, 2002).

Nevertheless, it is important to note that our study is limited because we chose to focus on one specific student population (i.e., pre-college students who were novices in engineering), domain (i.e., electrical circuit analysis), and learning environment (i.e., instructional program). Moreover, the experimental conditions used in this research do not allow us to generalize the results to other, more authentic learning situations in which students spend several days learning with materials that are embedded in their curriculum. Finally, an important limitation of our study is that due to the brief nature of our school intervention, we used few problem examples that were very similar in structure to learn how to apply electrical circuit analysis principles to solve novel problems.

An important direction for future research is to conduct more laboratory and field studies using other engineering education materials with pre-college and college students in order to extend and generalize our results. Another interesting direction for future research is to examine instructional designs that transition the learner from contextualized problem representation to abstract representation, or vice versa. A few recent studies have examined instructional sequences where an instructional phase with contextualized presentation is followed by an instructional phase with abstract presentation, or an abstract presentation phase is followed by a contextualized presentation phase. More specifically, such instructional sequences were studied for the domain of competitive specialization in Goldstone and Son (2005) and for the domain of cell biology in Scheiter et al. (2009). Further, a study on how learners analyze long sequences of interlocking gears discovered that learners tend to transition from depictive representations of the gears with cogs to abstract circles as they gain experience in reasoning about the gear systems (Schwartz and Black, 1996). A future study on instructional sequences in engineering education could initially provide an anchor to the past experiences of the novice learner by presenting real-life contextualized engineering problems and then transition to presenting abstract problems.

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