Student Perceptions of Technological Literacy Learning with Cumulative and Stepwise

Integration of Equations into Engineering Diagrams

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Abstract

Teaching basic engineering principles and problem solving with equations and schematic diagrams to non-engineering students is a basic goal of technological literacy education. The goals of this experimental study were to investigate the effects of the integration of equations into diagrams on the engineering learning and learning perceptions of non-engineering undergraduate students. Three integration designs were compared: cumulative integration where equations were cumulatively integrated into the circuit diagram, step-wise integration where only the equations relevant to the present step of the problem were integrated into the circuit diagram, and non-integrated presentation where all equations were displayed in an adjacent frame. Student learning was measured with a problem-solving near-transfer and far-transfer posttest (and reported in detail in a recent article). This paper focuses on the student perceptions of the helpfulness of the diagrams and difficulty of the instructional program and the open-ended student feedback. Results indicated that students in the cumulative integrated condition rated the diagrams significantly more positively and significantly more frequently expressed liking of the engineering domain in the open-ended feedback than students in the non-integrated condition. Overall, the findings of this study indicate that engineering instruction for non-engineering students should integrate equations into diagrams in a cumulative fashion so as to avoid the split-attention effect and frustrations due to mapping between diagrams and separate equation displays.

Introduction

Engineering Education for Non-Engineers

Introducing the general populace to technological literacy, that is, a basic understanding of engineering and technological principles, has been widely recognized as an important education goal (ASEE Technological Literacy Constituent Committee, 2011; Krupczak & Ollis, 2005; Pearson &Young, 2002; Wulf, 2002). While the curricula for undergraduate university courses that introduce non-engineering majors to the basics of engineering and technology have received significant attention (Krupczak, et al., 2007), the instructional design of learning materials for effective teaching of engineering to non-majors is largely an open research problem. In this study, we examine the effects of the integration of equations characterizing engineering quantities into schematic diagrams on the engineering learning of psychology undergraduate students. In a recent article (Ozogul, Johnson, Moreno, & Reisslein, 2012), we reported on the learning outcomes form this study. In the present paper, we focus on the perceptions of the learning experience, while briefly reviewing the learning outcomes to provide the context for the reported learning perceptions.

The learning materials of many popular non-technical undergraduate programs, such as communication, journalism, and psychology, consist primarily of text. In contrast, engineering learning materials extensively rely on schematic diagrams and

mathematical equations characterizing engineering quantities for representing engineering concepts and problem scenarios. For instance, introductory engineering texts (Brockman, 2008; Holtzapple & Reece, 2002; Kosky, Balmer, Keat, & Wise, 2009), which are employed in some technological literacy courses (Krupczak, et al., 2007), consist of text explanations, mathematical equations embedded in the text explanations, and schematic engineering diagrams. Since majors from non-technical undergraduate programs are often unaccustomed to learning materials containing equations and diagrams, the instructional design relating to equations and diagrams for these learners has potentially profound effects on their engineering learning.

In general, the field of multimedia learning (Mayer 2009; Meij & de Jong, 2006; Schnotz & Bannert, 2003; Van Lehn et al., 2005) examines the educational and cognitive psychology aspects of learning from combinations of multiple representations of information. In subsequent references to "representation", unless explicitly noted, "representation" refers to external, i.e., provided, representations. Engineering materials consisting of text, equations, and diagrams are one specific instance of such a combination of multiple representations. The cognitive processes involved in learning from multiple representations are commonly modeled and interpreted based on the theories of working memory (Baddeley, 1986) and cognitive load theory (Chandler & Sweller, 1991), which we briefly review in the following subsection. Subsequently, we review the split-attention effect (Chandler & Sweller, 1992; Ginns, 2006), i.e., the effect of learning from spatially separate versus spatially integrated representations of the learning material. We then review the existing studies on learning from integrated equations and diagrams.

Working Memory and Cognitive Load Theories

Baddeley (1986) presents working memory as 1) limited in capacity and 2) subdivided into the visual-spatial sketch pad and the phonological loop. The visual-spatial sketchpad processes visual information and the phonological loop processes auditory information. Building on the assumption of limited working memory capacity, according to cognitive load theory, every instructional condition places a particular burden (load) on the working memory. The total cognitive load experienced at any given time is comprised of three distinct types: 1) intrinsic cognitive load; 2) extraneous cognitive load; and 3) germane cognitive load (Sweller, Van Merrienboer, & Paas, 1998).

Intrinsic cognitive load can be thought of as the natural demand imposed by the learning material for a particular domain (e.g., electrical engineering), per se (Holmes, 2009). Extraneous cognitive load encompasses the unnecessary processing demands placed on the cognitive system as a result of the format of instruction, rather than the learning task itself. Extraneous load does not contribute to learning and can detract from learning. Germane cognitive load refers to the conscious effort made by the learner to use appropriate cognitive processes in an attempt to construct internal (mental) representations of the material (Sweller et al., 1998). The three types of cognitive load are assumed to be additive and the intrinsic load of a specific domain, for any given learner, is fixed. Therefore, a learning environment which has high extraneous cognitive load can overburden a learners' working memory capacity, reducing cognitive resources for germane (productive) cognitive processing.

Split Attention Effect

Combinations of multiple representations can support cognitive processes for deep conceptual learning (Moreno & Mayer, 2007). However, the multiple representations impose the cognitive burden of comprehending and integrating the separate external representations (Ainsworth, 2006; Goldman, 2003). The split-attention effect (Chandler & Sweller, 1992) is the effect of visually switching between two spatially separate sources of information and is widely viewed as the primary challenge when learning from multiple representations (Moreno & Mayer, 1999). The inverse of the split-attention effect, i.e., the effect of physical integration of the multiple sources of information is commonly referred to as the spatial-contiguity effect (Ginns, 2006). The split-source format requires the learner to retain information from one representation in working memory while searching the accompanying representation for relevant information. This information retention increases the extraneous cognitive load (Cierniak, Scheiter, & Gerjets, 2009; Kalyuga, Chandler, & Sweller, 1999), reducing available cognitive resources for germane processing.

The research on mitigating the split-attention effect can be categorized into instructional designs that integrate multiple representations so as to avoid splitting information into separate sources (Chandler & Sweller, 1991; Cierniak, Scheiter, & Gerjets, 2009; Moreno & Mayer, 1999) and designs that facilitate the processing of multiple representation, e.g., through color-coding corresponding elements (Kalyuga, Chandler, & Sweller, 1999; Ozcelik, Karakus, Kursun, & Cagiltay, 2009), attention guidance (Jamet, Gavota, & Quiereau, 2008; Moreno, Reisslein, & Ozogul, 2010), connecting lines or hyperlinks (Seufert & Brunken, 2006; Huk & Steinke, 2007), or presenting verbal information through narration (enabling temporal-contiguity; Moreno

& Mayer, 1999). In this study, we focus on integrated instructional designs; specifically, the integration of mathematical equations into schematic engineering diagrams.

Integrated Instructional Designs

Integrated instructional designs physically integrate multiple representations of information into one integrated presentation (i.e., achieve spatial contiguity), e.g., through the physical integration of text or equations into diagrams (Chandler & Sweller, 1991). Most existing studies of integrated instructional designs have focused on the integration of textual comments into diagrams (Aleven & Koedinger, 2002; Bartholome & Bromme, 2009; Bobis, Sweller, & Cooper, 1993; Florax & Ploetzner, 2010; Kalyuga, Chandler, & Sweller, 1998; Kester, Kirschner, & van Merrienboer, 2005; Sweller & Chandler, 1994).

To the best of our knowledge only two prior studies have examined the integration of equations into diagrams, namely the studies by Sweller, Chandler, Tierney, and Cooper (1990) and by Tarmizi and Sweller (1988). Sweller et al. (1990) studied the integration of equations for the evaluation of slopes and intersection points of straight lines into a diagrammatic representation of the lines in a coordinate system with 9th grade students. Tarmizi and Sweller (1988, Experiments 4 and 5) investigated the effects of integrating given and calculated angle values in a worked example on cyclic quadrilaterals on the geometry learning of 8th and 9th grade students.

Overall, a meta-analysis by Ginns (2006), which considered 37 studies on the spatial-contiguity effect, found an average effect size of $d = .72$.

We are not aware of prior studies examining the integration of equations in diagrams in the engineering domain. However, for completeness, we note that for

specific engineering knowledge domains there have been efforts to represent

mathematical equations characterizing engineering systems in graphical form (Cheng,

2002; Reisslein, Seeling, and Reisslein, 2005). For instance, Cheng (2002) developed and

evaluated law encoding diagrams, specifically Amps, Volts, Ohms, Watts diagrams that

express the equations (laws) relating these electrical quantities in graphical form.

Present Experiment: Cumulative or Step-Wise Integration of Equations in

Engineering Diagrams

The goal of the present experiment was to examine the relative benefits of two

distinct instructional designs of the integration of equations into diagrams on the

engineering learning of students from non-engineering majors. In particular, this study

strived to answer the open research question whether integrated information in diagrams

should accumulate and remain visible within the diagram following its introduction

(cumulative integration), or whether each piece of information should only remain

integrated in the diagram during discussion of a specific problem step (stepwise

integration). In particular, in engineering education, should we employ a cumulative

integrated design where the equations for a particular problem step are accumulated in

the diagram as the problem solution progresses? Or, should we employ a stepwise

integrated design where the relevant equations only remain integrated in the engineering

diagram during the particular problem step? Two competing hypotheses can be offered

for these two integration designs.

Learners may need all information to remain embedded in the diagram for the

remainder of the problem, in order to refer back to previous problem-solving steps and

the associated equations and diagram components. In this case, the cumulative integration

design, which maintains all equations in the diagram, would result in more effective learning, more positive perceptions of the diagrams, and lower cognitive load than the stepwise integration and a non-integrated design.

On the other hand, during each step of the problem presented, learners may have difficulty allocating attention to the diagram area and corresponding equation relevant for the present problem step. Accumulating equations within the diagram may distract learners' attention away from the equation and corresponding diagram area that are relevant for the present problem step. In this case, the stepwise integration design, which moves each successive formulaic step from the diagram to a nearby display box when introducing the next step, would result in improved learning, more positive perceptions of the diagrams, and lower cognitive load compared to the cumulative integration and a non-integrated design.

Method

Participants and Design

Participants were a total of 165 college students (73% female) who were enrolled in an introductory psychology course at a large public university in the southwestern United States. The mean age of the participants was 25.62 years (SD = 8.49 years). Seventy-three (44.2 %) of the students reported that they were Caucasian, 68 (41.2 %) reported that they were Hispanic, eleven (6.7 %) reported that they were Native American, eight (4.8 %) reported being of other ethnicities, three students (1.8 %) reported that they have multiple ethnicities, one student (0.6 %) reported African American, and one student (0.6 %) reported Asian as ethnicity. There were 54 students in the cumulative integrated condition, 56 students in the stepwise integrated condition

and 55 students in the non-integrated 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; (4) a problem-solving practice session, and (5) a program rating questionnaire. Next, we describe each of these sections in detail.

  The pretest consisting of 3 multiple-choice questions and 3 open-ended single-resistor problems was designed to measure the participant's domain-specific prior knowledge before entering the instructional session. The pretest had an internal reliability as measured by Cronbach's α of .68 (Allen, Reed-Rhoads, Terry, Murphy, & Stone, 2008).

  The instructional session presented the students with the meanings and units of 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 two electrical circuit problems which asked students 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 and provided feedback.

[Insert Figure 1 here]

The instructional session and practice session portion of the program had three different versions, one for each of the three treatments used in this study, which are illustrated in Figure 1. In the integrated condition, all equations, i.e., both the equations specifying the given parameter values (i.e., given battery voltage and resistance values) and equations evaluating the intermediate and final results (i.e., individual currents, total current, and total resistance), were integrated into the circuit diagram. This integration was cumulative, that is, as the instructional session on a given circuit or a given practice problem solution progressed, the equations were cumulatively added to the circuit diagram. For example, in the second solution step, the equation for the total current was added to the circuit diagram, which previously contained the equations specifying the given parameter values from the problem statement and the equations characterizing the individual currents from the first solution step, as depicted in Fig. 1(a).

In contrast, in the stepwise condition, only equations that were relevant for the present step of the instruction or problem solution were integrated into the circuit diagram; previously displayed equations were moved to a box to the right of the circuit diagram and recorded there. For instance, in the second solution step, which is illustrated in Fig. 1(b), only the equation characterizing the total current was included in the circuit diagram; the equations for the given parameter values and the individual currents were

moved to the box, while the symbols for the given parameters and individual currents remained in the circuit diagram.

In the non-integrated condition, only the symbols for the electrical quantities were included in the circuit diagram, while the equations were cumulatively added only into the box right to the circuit diagram, as illustrated for the second step of a practice problem in Fig. 1(c).

Recent empirical research has demonstrated that learners are able to report useful perceptions of the quality and helpfulness of the instructional strategies of computer-based learning environments (Antonietti, Colombo, & Lozotsev, 2008). Therefore, the last section in the computer program included a program rating questionnaire, which was a 4-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. Items were adapted from an earlier survey instrument developed by the authors in collaboration with experts in computer-based engineering instruction (Reisslein, Moreno, & Ozogul, 2010). This earlier instrument included three subscales for perceived general program helpfulness, diagram helpfulness, and perceived cognitive load (a scale previously developed by Paas and Van Merrienboer (1994)). Following Aiken (1997), the construct validity of the subscales had been verified with the judgment of experts in electrical engineering instruction and their factorial validity and reliability had been assessed with traditional factor analysis. The general program helpfulness subscale was excluded for the present study, which primarily manipulated the diagrams.

The reliability of the survey instrument in the present study was examined with a factor analysis using principal axis estimation, which showed that two factors accounted

for 87.1 percent of the variance of subject ratings. Similar to the findings for the earlier survey instrument (Reisslein, Moreno, & Ozogul, 2010), one factor related to learner perceptions of the diagram helpfulness (two items, e.g., "The pictures in the program helped me solve the problems"; with factor coefficients .85 and .86), while another factor related to perceived cognitive load (two items, e.g., "Learning the material in the lesson required a lot of effort"; with coefficients .85 and .86). High internal reliabilities of the subscales were demonstrated for both the diagram helpfulness subscale (Cronbach's α = .85) and cognitive load subscale (Cronbach's α = .85).

The program rating questionnaire also included two open-ended questions to capture what students liked best and least about the computer-based instructional module. The questionnaire was administered by the computer-based module, and data were collected by the computer. Responses to the open-ended items were categorized according to which features of the instructional module were noted. Nine categories emerged from examination of the two open-ended responses: issues related to *diagrams* (e.g., "Circuit diagrams were clear"); *examples* (e.g., "I liked that it gave examples throughout"); *feedback* ("I liked the immediate feedback"); *domain* (e.g., "I liked that I learned how to calculate circuits"); *the use of two modalities* (e.g., "I liked the fact that it provided a visual and an audio"); *pace of instruction* (e.g., "The pace was pretty good for me"); *practice* ("I liked the problems I had to solve"); *voice* (e.g., I liked the speaking part of the lesson"); and *interface* (e.g., "There was not a lot going on on the screen to distract you").

Paper and pencil materials. The paper and pencil materials consisted of three near-transfer questions and three far-transfer questions as presented in detail in (Ozogul, Johnson, Moreno, & Reisslein, 2012).

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

Before participants entered the lab, each computer was set up with a randomly assigned treatment (cumulative integrated, stepwise integrated, or non-integrated) within individual cubicles. After signing consent forms, participants were randomly assigned to a cubicle and were given a calculator. Participants were tested in groups of 1-7 students per session. Once seated, participants began the computer module where they were first asked to complete the demographic questionnaire. Second, participants completed the pretest. From there, participants moved into the instructional aspect of the program. At the conclusion of the instruction, participants completed the ratings questionnaire. Following the questionnaire, participants were given the paper-based posttest and a pencil without an eraser.

Results

A preliminary analysis of variance (ANOVA) of the pretest scores indicated no difference among the groups in prior domain-specific knowledge, $F(2, 162) = 1.13$, $MSE = 1.70$, $p = .33$. Also, an ANOVA showed that there was no significant difference in time taken to complete the instructional and practice sessions, $F(2, 162) = 0.02$, $MSE = 1.18$ x

10^{-8}, $p = .98$. As reported in (Ozogul, Johnson, Moreno, & Reisslein, 2012), an analysis of covariance (ANCOVA) revealed a significant main effect of experimental condition on posttest near-transfer performance, when controlling for pretest performance, F (2, 161) = 3.84, $MSE = 13.43$, $p = .02$, $\eta^2 = .05$. Least significant difference (LSD) post-hoc pairwise comparisons indicated that the cumulative integrated condition had significantly higher near-transfer scores, compared to both the non-integrated condition ($p = .02$) and the step-wise integrated condition ($p = .02$). Furthermore, an ANCOVA conducted on the far-transfer score, using pretest score as covariate, indicated a marginally significant effect of experimental condition on total far-transfer score, when controlling for pretest performance, F (2, 161) = 2.81, $MSE = 12.99$, $p = .06$, $\eta^2 = .03$. LSD pairwise comparisons demonstrated that the cumulative integrated condition had significantly higher far-transfer scores than the step-wise condition ($p = .03$), and marginally significantly higher far-transfer scores than the non-integrated condition ($p = .08$).

An ANOVA indicated a significant effect of experimental condition on participants' ratings of the diagram helpfulness, $F(2, 162) = 3.34$, $MSE = 0.70$ $p = .034$, $\eta^2 = .04$. LSD pairwise comparisons revealed that the cumulative integrated condition had significantly higher ratings of the diagram helpfulness than the non-integrated condition ($p = .01$). No other comparisons were significant. No significant differences were revealed in participants' perceived cognitive load, F (2, 162) = 1.77, $MSE = 1.14$, $p = .17$. Descriptive statistics for participant rating are displayed in Table 1.

[Insert Table 1 here]

The open-ended responses concerning which feature of the instructional program the participants liked best were coded in nine variables representing the categories of

program features (i.e., diagrams, examples, etc.); similarly, the liked least feature was

coded in nine variables. Specifically, participants were coded according to whether or not

they noted a particular feature as their most or least favorite aspect. Chi-square tests of

independence were used to determine differences in the distribution of participants noting

liking and dislike for the nine categories of program features. First, a series of 3

(experimental condition) x 2 (participant noted feature as *most* liked aspect: yes or no)

chi-square tests of independence were conducted to explore the relationship between

experimental condition and participants' *liking* for these features. Results indicated a

marginally significant relationship between experimental condition and learners' liking of

the instructional domain, $\chi^2(2) = 3.70$, $p = .16$. A series of three follow-up 2

(experimental condition a vs. experimental condition b) x 2 (noted or did not note liking)

chi-square tests were used to determine which conditions differed in the liking of the

instructional domain. Results from these analyses indicated that more participants in the

cumulative integrated condition liked the domain, compared to the non-integrated

condition, $\chi^2(1) = 3.14$, $p = .076$ (marginally significant). No other follow up

comparisons were statistically significant. Also, no other significant relationships

between experimental condition and participant liking or disliking of features were

revealed. See Table 2 for frequencies.

[Insert Table 2 here]

Discussion

In the current study, we investigated the relative impact of three instructional

designs using equations and diagrams to teach basic engineering principles and problem

solving to non-engineering majors. We compared instructional designs with non-

integrated equations and diagrams, cumulative integration of equations and diagrams, and stepwise integration of equations and diagrams. We examined these conditions through testing differences in learning outcomes, i.e., near and far transfer, as well as self-reported cognitive load and diagram helpfulness ratings and open-ended comments.

We first discuss the results for the comparison between the cumulative integrated condition, where all equations are cumulatively integrated into the diagram, and the non-integrated (control) condition, where the equations are accumulated in a list separate from the diagram. Then, we discuss the results for the comparisons between the stepwise integrated condition, where the equation relevant for the present problem step is integrated into the diagram and the earlier equations are in a separate list, and the other conditions. We conclude by outlining the limitations of the present study and future research directions.

Cumulative Integrated Equations vs. Non-integrated Equations

Learners in the cumulative integrated condition had significantly higher near-transfer posttest scores and marginally significantly higher far-transfer posttest scores compared to learners in the non-integrated condition. The superior efficacy of the cumulative integrated design compared to the non-integrated design suggests that integrating equations within the diagrams in a cumulative fashion reduces demands placed on the limited capacity of working memory (i.e., extraneous load; Sweller et al., 1998) as learners in the cumulative integrated condition were not required to visually switch back and forth between the two separate representations. Also, the integrated format clearly indicated the correspondences between the multiple representations through their close proximity. This close physical proximity linked circuit components in

the diagram to their corresponding engineering notations (symbols) and characterizing equations. Selecting the relevant portions of diagrammatic representations that correspond to segments of symbolic representations (e.g., text, equations) is often challenging for learners. Thus, manipulations that assist in locating corresponding elements can lead to more effective use of attention and increased learning outcomes (Ozcelik, Karakus, Kursun, & Cagiltay, 2009).

The diagram helpfulness ratings in the cumulative integrated condition were significantly higher compared to the non-integrated condition. Learners in the non-integrated design were forced to split visual attention between diagrams and equations. The switching between the separated diagrams and equations may have frustrated these learners. On the other hand, with the cumulative integrated design, learners are no longer required to switch back and forth between spatially separated diagrams and equations and do not need to search diagrams for elements which correspond to the equations. The higher learner-perceived diagram helpfulness; thus, indicates that the cumulative integrated design is more beneficial for learning perceptions than the non-integrated design.

The learners' self-reported cognitive load rating on the scale adopted from Paas and Van Merrienboer (1994) did not differ among conditions. However, cumulative integration led to significantly improved learning and significantly more positive perceptions of the learning experience. It is therefore likely that similarly to the recent study by Cierniak et al. (2009), the integrated design reduced extraneous load while increasing germane load such that the total cognitive load remained unchanged. Indeed, the scale from Paas and Van Merrienboer (1994) commonly measures total cognitive load

(Schnotz & Kurschner, 2007; Van Gog & Paas, 2008). Developing and validating measures that distinguish the different types of cognitive load and employing such detailed cognitive load measures for the integration of equations and diagrams is an important direction for future research.

More learners in the cumulative integrated condition noted in the open-ended responses that the domain was their most favorite part of the instructional module, although this was a marginally significant finding. Considering that learners in the cumulative integrated condition had higher posttest scores, their positive perceptions may stem to some degree from positive feelings of self-efficacy in the domain. Generally, technological literacy education faces the challenge of introducing the engineering domain with its extensive reliance on diagrams and equations to learners that have chosen other areas of study or career paths. The result for the open-ended responses indicates that the cumulative integrated design is more likely to foster positive perceptions of the engineering domain by learners from non-engineering majors.

In summary, aside from increased learning outcomes, the cumulative integrated design increased positive perceptions of the learning experience and made the engineering domain more appealing for the non-engineering students.

Stepwise Integrated Equations vs. Cumulative Integrated and Non-integrated Equations

The stepwise integrated condition led to significant lower near-transfer and far-transfer scores compared to the cumulative integrated condition. The stepwise integrated condition did not differ from the non-integrated condition for near-transfer or far-transfer scores. These results indicate that an integrated format that integrates equations into the

diagram, but removes each successive formulaic step from the diagram when introducing the next step, is not effective in promoting learners' mental integration of the two representations. Learners may be re-inspecting preceding equations and their corresponding diagram components in an effort to mentally simulate the successive solution steps (Hegarty, 1992; 2004). Thus, all equations should be cumulatively added to the circuit diagram so that learners can refer back to earlier solution steps.

These learning outcome results are underscored by the learner ratings of the diagram helpfulness. While there is no statistically significant difference between the diagram ratings for the step-wise integrated condition and either of the two other conditions, descriptively the diagram rating for the step-wise integrated condition ($M =$ 3.07, $SD = 0.78$) is between the ratings for the non-integrated condition ($M = 2.85$, $SD = $ 1.00) and the cumulative integrated condition ($M = 3.27$, $SD = 0.71$). This indicates that the step-wise integrated condition has a tendency to be perceived as less frustrating then the non-integrated condition. With the step-wise integrated condition, the equations for the present solution step are integrated in the diagram, thus somewhat alleviating the need to split attention between the diagram and equation listing. However, the effect of this integration of only the equations for the present step was not strong enough to lead to a significant difference from the non-integrated condition.

The analysis of the open-ended comments did not reveal any significant improvement of student perceptions with step-wise integration compared to the non-integrated design. Thus, overall, the results indicate that the integration of equations into diagrams has no significant benefits if only the equations for the present solution step are integrated into the diagram.

Limitations and Future Directions

The conclusions drawn from our study on effective strategies for designing engineering learning materials with equations and schematic diagrams for technical literacy education for non-engineering students are limited due to the limited selection of subjects (psychology students) and the domain (electrical circuits). Also, our experiment only examined the effects of the manipulations on the products of learning (e.g., posttest scores) and self-reported learning perceptions. More in-depth analysis of the processes involved in learning, through concurrent verbal reporting, eye-tracking, or detailed online cognitive load reporting, would allow more explanatory conclusions regarding the cognitive mechanisms involved in the effect.

An important direction for future research on technical literacy education is to conduct studies with students from other popular non-engineering majors and with basic engineering principles from other engineering domains. Another interesting direction for future research is to examine the integration of engineering equations and diagrams in the context of instructional strategies based on worked examples, which have received growing interest in engineering (Azemi, Toto, & Litzinger, 2010; Doering & Mu, 2009; Moreno, Ozogul, & Reisslein, 2009; Reisslein, Seeling, & Reisslein, 2006; Reisslein, Sullivan, & Reisslein, 2007).

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Figure 1. Sample images from the three treatment conditions.

(a)   cumulative integrated condition
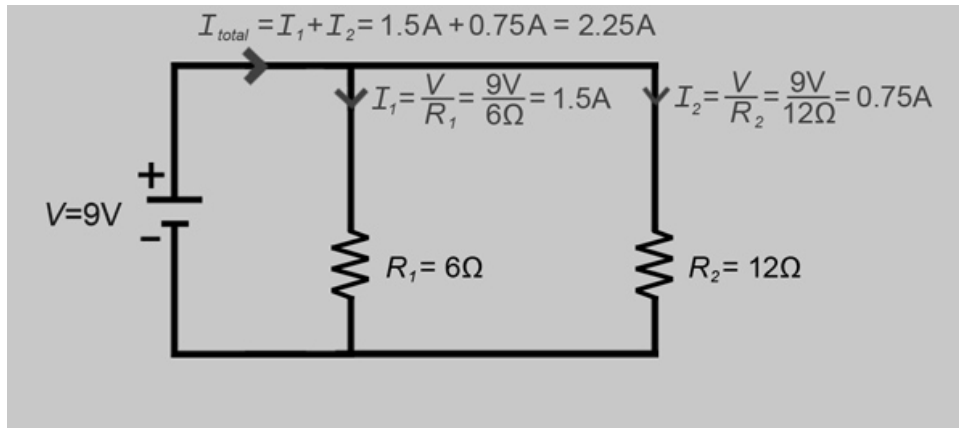
(b)   step-wise integrated condition
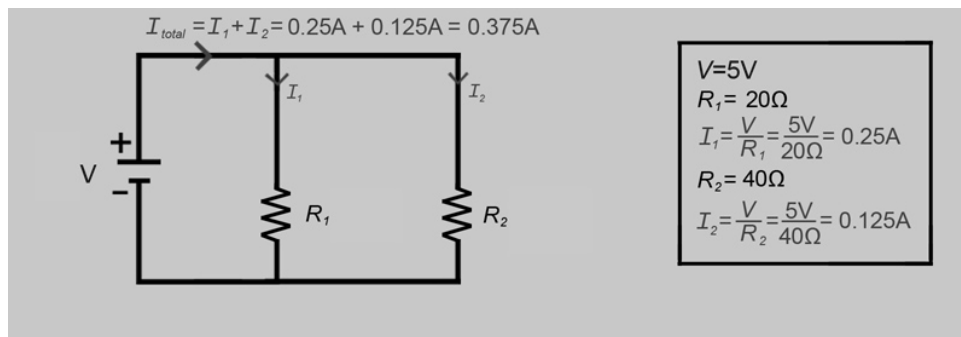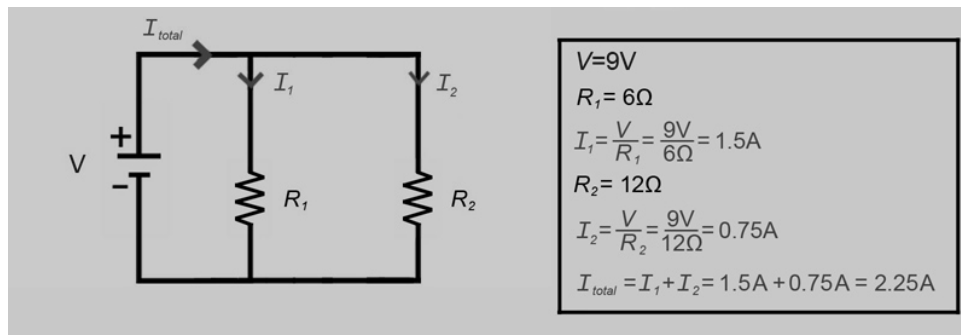

(c)   non-integrated condition

Table 1

Descriptive statistics for dependent variables, by experimental condition

Group	N	Diagram Rating (Max: 4)		Cognitive Load Rating (Max: 4)	
		M	SD	M	SD
Cumulative Integrated	54	3.27[a]	0.71	1.73	1.07
Step-wise Integrated	56	3.07	0.78	1.79	1.12
Non-integrated	55	2.85	1.00	1.44	1.01

Notes: [a] The cumulative integrated condition significantly outperformed the non-integrated condition.

Table 2

Number of participants who noted instructional domain as most favorite feature, by experimental condition

	Condition		
	Integrated	Stepwise	Non-integrated
Noted liked best	3ϕ	1	0
Did not indicate	51	55	55

ϕ Note: Frequency is significantly higher than non-integrated condition ($p < .05$)