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K-12 ENGINEERING OUTREACH: DESIGN DECISIONS, RATIONALES, AND APPLICATIONS

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Even though engineering outreach to K-12 schools initially seemed to be a simple undertaking, it proved to require complex design solutions related to a variety of issues. The purpose of this design case is to tell the story of our National Science Foundation (NSF) supported engineering outreach project, that took place between the years of 2007-2013. The design problem of this project started with the issue of how to design the engineering instruction, what to provide within the K-12 instruction, how to conduct the outreach, and how to overcome physical limitations of school sites. This design case captures the design process, context, various designs of the computer-mediated learning platform, and the rationales for design iterations. We also describe how the design team, which included experts in instructional design, electrical engineering, and educational psychology, as well as carpenters, teachers, and graphic designers, worked together to accomplish an outreach project that reached over 3,600 K-12 students. In addition to the design processes, we also report the major findings from our evaluation studies of the intructional modules delivered to K-12 students, and how we used these results to iterate and refine our module designs.

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PROJECT OVERVIEW

The project addressed in this design case was focused on engineering outreach, and looking for best design ideas to support K-12 students' learning of engineering. We describe the design and development processes of the project, which were built on a theoretical framework for designing engineering instruction. The project included an initial design of the computer-mediated learning platform, and progressive design refinements based on iterative feedback from the design team. In addition, the module designs incorporated feedback from K-12 students and their teachers, and reflected the learning outcomes (e.g., student performance on knowledge tests after completing the module) from instructional delivery at school sites. Even though we describe these processes and our experiences with them in different sections of this paper, we would like to note that some of these processes occurred simultaneously.

More specifically, the overall design of the K-12 computer-based instructional modules combined a theoretical research-oriented strand, and a practical outreach implementation-oriented strand. The research-oriented strand consisted of a theoretical framework for the instructional design of the outreach modules as well as evaluation studies for three key aspects of the K-12 engineering outreach computer-mediated instruction. Specifically, we wanted to investigate (a) how to best represent engineering content for K-12 students, (b) how to most effectively guide student attention (signaling), and (c) best methods for providing feedback to students related to their problem solving attempts.

The theoretical framework and the evaluation studies of these three instructional design aspects informed the instructional module design. Through the close integration of both the research-oriented strand and the practical implementation strand, we achieved impactful module designs and outreach delivery strategies. The progressive nature of the module designs ensured that the final computer-mediated learning platform has successfully supported learning of elementary engineering concepts. Our evaluations showed that the students were able to relate math and science knowledge from their regular school instruction to everyday engineering problems. At the same time, the students had fun and gained insights into the field of engineering and its career opportunities. Our effective outreach delivery strategies focused on a mobile computer lab, which delivered computer-based instruction to K-12 students in their classrooms.

THEORETICAL FRAMEWORK

In this section, we describe the theoretical framework that guided our project and development of the instructional modules. Before we started our project, we held an initial team meeting to establish solid foundations that were supported by learning theory, and the findings of previous research on design. The team spent two eight-hour days brainstorming the theoretical framework that we could apply to engineering instruction and was suitable to our target audience. At the end of the two-day meeting, we arrived at an initial agreement that research in science, technology, engineering and mathematics (STEM) education must be grounded in precise theories of how students comprehend and process information during learning (Bransford, Brown, & Cocking, 1999; Katehi, Pearson, & Feder, 2009; Lambert & McCombs, 1998). Consequently, we grounded our project on a well-rounded set of learning theories and their related instructional strategies that are highly relevant for teaching elementary engineering problem solving to novices.

The goal of several of the instructional strategies we examined in our project has been to cater to varied and changing needs of the novice learners. The designs had to consider that instructional media or methods might have different effects depending on the individual characteristics of the learner. One of the most popular contemporary cognitive models for learning is the four-stage model proposed by Anderson, Fincham, and Douglass (1997) within Anderson's Adaptive Control of Thought-Rational (ACT-R) framework (Anderson, 1993). In this model, the learner solves problems initially by analogy, that is, by relating problems to known examples. With more experience, the learner advances to the second stage where s/he formulates declarative rules, such as verbalizations of the solution strategy that assist in developing a solution. As experience increases, the learner moves to the third stage in the model. In this third stage, the learner formulates procedural knowledge for problem solving which permit fast problem solving with relatively little mental effort. After having encountered many different varieties of problems, the learner advances to the fourth stage where s/he may have many different examples in long-term memory, which enables the learner to rapidly retrieve a solution from memory. As the learner advances through these four stages of learning, which typically overlap, the relative importance and effectiveness of different instructional strategies, changes.

Because we studied the delivery of instruction by means of an interactive multimedia learning environment, we drew from a cognitive-affective theory of learning with media (Moreno, 2005), which is based on the following assumptions: (a) humans have separate channels for processing different information modalities (Baddeley, 1992); (b) only a few pieces of information can be actively processed at any one time in working memory within each channel (Sweller, 1999); (c) meaningful learning occurs when the learner spends conscious effort in cognitive processes such as selecting, organizing, and integrating new information with existing knowledge (Mayer & Moreno, 2003); (d) long-term memory consists of a dynamic, evolving structure which holds both, a memory for past experiences and a memory for general domain knowledge (Tulving, 1977); (e) motivational factors mediate learning by increasing or decreasing cognitive engagement (Pintrich, 2003); (f) metacognitive factors mediate learning by regulating cognitive processing and affect (McGuinness, 1990); and (g) differences in learners' prior knowledge and abilities may affect how much is learned with specific methods (Kalyuga, Ayres, Chandler, & Sweller, 2003; Moreno, 2004; Moreno & Durán, 2004).

A special challenge of technology-based instruction is to promote meaningful learning by increasing students' active processing of the instructional materials while reducing cognitive load (Sweller, 1999). Therefore, according to a cognitive-affective theory of learning with media, we needed to carefully examine the relationship between the cognitive demands imposed by the learning environment and the desired learning outcomes. To this end, the literature suggests to distinguish between extraneous processing, essential processing, and generative processing during learning (Mayer, 2005; Mayer & Moreno, 2003). It is established in the literature that extraneous processing occurs when students spend their limited resources in mental activities that are not necessary for making sense of the information to-be-learned. Examples of extraneous processing are forcing students to split their visual attention by presenting mutually referring text and graphics in separate computer screens (Ayres & Sweller, 2005; Ginns, 2006), or presenting visual or auditory adjuncts that are not necessary to make the lesson intelligible (Moreno & Mayer, 2000).

Essential processing occurs when students select relevant information and hold it in working memory for further processing. When the learning environment provides too many different paths to construct knowledge, too many representations that need to be integrated with each other, or when the learning materials are unfamiliar to the student, essential processing may suffer (Ainsworth, 2006; de Jong & van Joolingen, 1998; Goldman, 2003; Moreno, 2007).

Generative processing includes mental activities that go beyond selecting relevant information and which promote making sense of the new information. Examples are the processes of mentally organizing the new information into a coherent mental model and integrating the new knowledge representations with prior knowledge. Provided that students are motivated to spend their cognitive resources in the learning task, essential and generative processing results in the creation of a meaningful learning outcome (Moreno & Mayer, 2007).

The design of our K-12 engineering instructional module started with a prototype design based on the above described established theoretical frameworks. We describe the prototype and the underlying research literature in the next section.

In the context of the theoretical framework we investigated specific instructional design aspects for which there was not sufficient guidance provided in the literature to make sound design decisions related to engineering education. Specifically, we investigated the design aspects related to representation of the engineering content as well as signaling of the engineering content and feedback as summarized in the corresponding subsections. We utilized the insights gained from these investigations in the continuous refinement of the engineering instructional module for K-12 students.

LEARNING MODULE DESIGN RATIONALE AND DESIGN PROCESS

Baseline Instructional Module Design

From the broad range of engineering topics, we decided to focus on basic electrical engineering (Helgeland & Rancour, 2006; Ogunfunmi & Rahman, 2010; Sangam & Jesiek, 2015) because electrical engineering is the foundation for many information technologies that students interact with on a daily basis. Furthermore, the challenges of learning electrical engineering are similar in nature to those of learning other engineering disciplines (Slotta & Chi, 2006).

We conducted K-12 engineering outreach with a computer-mediated learning platform because such instructional delivery permits careful control and manipulation of the presentation of the instructional materials. It allows researchers to empirically test their hypotheses while limiting confounding factors (e.g., different personal teaching styles). Also, computer-based learning is highly sought after in K-12 schools as students are increasingly more comfortable learning with technology (such as computers and tablets). Students are expected to become proficient technology users and thus computer-based learning is viewed as an integral part of the education process. The teachers who collaborated with the design team expressed strong preference for computer delivery of the instructional content as students are excited to work on computers. The teachers viewed the computer-mediated learning platform as an opportunity for the students to learn and practice with computers which is an important skill for taking state-mandated standardized assessments.

In addition to computer-based learning, we examined the representation concreteness with hands-on electrical circuit kits. The circuit kits provide an authentic hands-on lab learning environment. Next, we outline the generic features (i.e., the features that are invariant across the various designs) of both the computer-based and the circuit kits learning environment.

We based the design of the computer-based learning platform on empirical principles supported by the chosen theoretical framework. In particular, we applied the cognitive principles for learning in interactive environments derived by Moreno and Mayer's (2007) research program. For example, our design was guided by the multimedia principle: Students learn better from verbal and visual representations than from verbal or visual representations alone; thus, we included both types of representations of the engineering concepts and procedures (Mayer, 2001; Moreno & Durán, 2004; Moreno & Mayer, 1999). In addition, we employed the instructional design principle of modality: Students learn better from words and graphics when words are spoken rather than printed (Mayer & Moreno, 1998; Moreno & Mayer, 2002; Moreno, Mayer, Spires, & Lester, 2001). Accordingly, in our computer-based environment, students learned by listening to narrated explanations as they watched corresponding visual representations of the concepts to be learned. Following the personalization principle (Moreno & Mayer, 2004), the narrations were in conversational rather than monologue style. In line with the temporal contiguity principle: Students learn better with concurrent rather than successive corresponding words and graphics (Mayer & Moreno, 2003), we temporally synchronized the presentation of the engineering knowledge representations, such as equations and engineering diagrams.

To reduce students' cognitive load, we presented essential rather than extraneous or redundant materials. For example, one scenario included lighting inside a tent. The essential information included only images and features directly related to the electrical circuit in the tent as this circuit was the core of the learning domain. While it would have been visually more pleasing to provide a broader context for the tent scenario (e.g., placing the tent in woods, using various

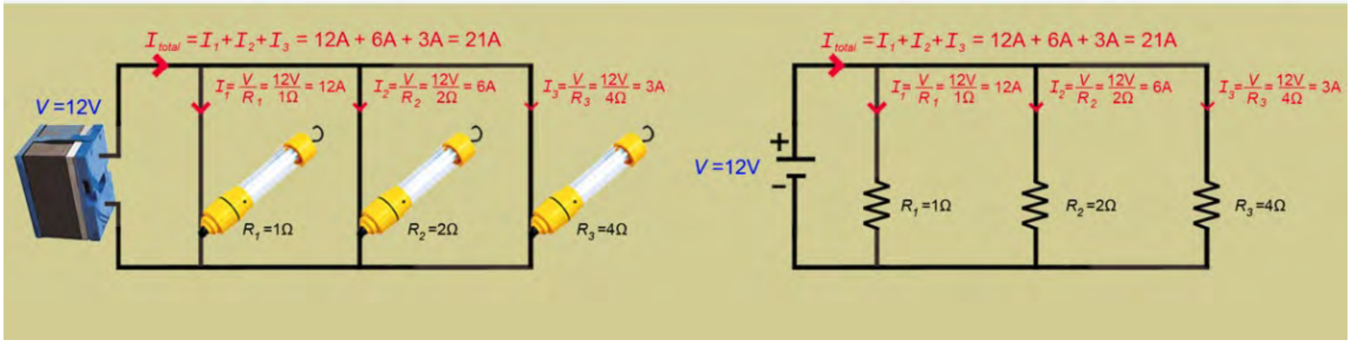


FIGURE 1. Illustration of essential circuit relevant details of tent lighting scenario in module version with contextualized representation (left) vs. abstract representation (right).

colors for the tent, and placing people around the tent), such design decisions would have increased students' cognitive load and placed unnecessary cognitive processing demands on the students. While representing the tent example we only included the circuit relevant aspects, such as energy source, light bulbs, and how they are connected to each other to light the tent as an application of the instructional design principle of coherence (Mayer, Heiser, & Lonn, 2001; Moreno & Mayer, 2000; see Figure 1). Finally, to promote the active processing of the materials, our learning environments applied the guided activity principle by providing the guidance of a pedagogical agent's voice (Moreno, 2004; Moreno & Mayer, 2005). The agent's voice was used to provide verbal explanations and prompted students to interact and reflect on the relationships between the multiple representations during learning (Moreno & Mayer, 2005).

For all learning conditions, the computer-mediated learning platform consisted of four phases:

1. Introductory phase: the pedagogical agent introduced him/herself and explained the learning objectives of the lesson.
2. Theoretical concepts phase: the agent presented and explained the conceptual and procedural knowledge of the lesson.
3. Modeling phase: the agent demonstrated how to apply the theoretical concepts to solve a worked out problem example.
4. Practice phase: the learner was presented with a set of practice problems and attempted their solution followed by agent feedback.

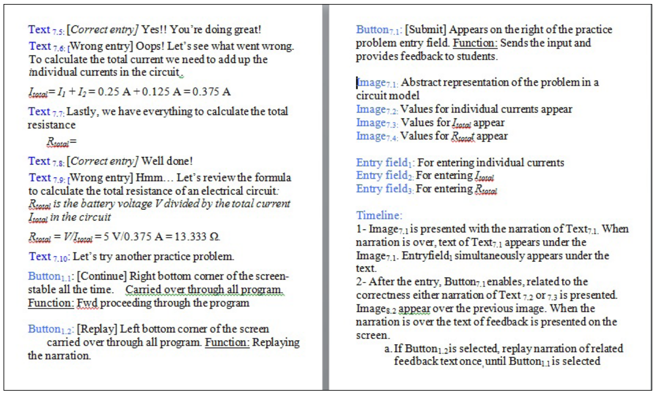
The hands-on learning environment with electric circuit kits was based on commercially available circuit experimentation kits, namely the Snap Circuits Jr.® 100 Electricity Kit from the Elenco line of Snap Circuits kits (http://www.snapcircuits.net), in combination with electronic multimeters for circuit measurements.

Implementation Steps of the Design Process

The goal of the design process was to create a prototype of a computer-mediated learning platform that was grounded in well-established learning and cognitive theories, was age-appropriate for our target audience, and enabled us to evaluate the effectiveness of the different design variables and research hypotheses. The first step in the design process was to create a prototype of the computer-mediated learning platform. The instructional designers solicited the instructional content from the engineering subject matter expert (SME). The SME selected the content based on his prior experience teaching engineering to novice learners. The SME also consulted with teachers to ensure that the selected topic area was suitable for the intended student audience.

Once the learning module design elements (including content, practice problems, graphics, and implementation of theoretical framework) were finalized between the engineering subject matter expert, instructional designers, and educational psychologist for each computer-based module, storyboards were created for each design. The storyboards included two parts: textual description and image sketches. On the textual storyboard, details about each screen design, including the exact written text, narration text, buttons and their functions, entry fields, feedback to appear based on student input, and the image numbers to embed, were given. The textual storyboard also included a timeline of events that explained the exact order of events occurring on each screen (see Figure 2). Additionally, screen-by-screen image sketches were hand drawn to communicate the design clearly to the graphic designer (see Figure 3).

Even though we attempted to maintain this detailed, clear design process throughout the prototype phase, we often encountered issues that needed to be addressed once we saw the design implemented on the actual computer screens. For example, one issue came up concerning to the positioning of images relative to the accompanying text. The team had to discuss if the images should be placed vertically or horizontally on the screen (see Figures 4 and 5). Here are a few examples from the actual communications between



Text $_{7.5:}$ [*Correct entry]* Yes!! You're doing great!

Text $_{7.6:}$ [Wrong entry] Oops! Let's see what went wrong. To calculate the total current we need to add up the individual currents in the circuit.

$I_{total} = I_1 + I_2 = 0.25\text{ A} + 0.125\text{ A} = 0.375\text{ A}$

Text $_{7.7:}$ Lastly, we have everything to calculate the total resistance

$R_{total} =$

Text $_{7.8:}$ [*Correct entry]* Well done!

Text $_{7.9:}$ [Wrong entry] Hmm… Let's review the formula to calculate the total resistance of an electrical circuit: *R_{total} is the battery voltage V divided by the total current I_{total} in the circuit*

$R_{total} = V/I_{total} = 5\text{ V}/0.375\text{ A} = 13.333\ \Omega$

Text $_{7.10}$: Let's try another practice problem.

Button$_{1.1}$: [Continue] Right bottom corner of the screen-stable all the time. Carried over through all program. Function: Fwd proceeding through the program

Button$_{1.2}$: [Replay] Left bottom corner of the screen carried over through all program. Function: Replaying the narration.

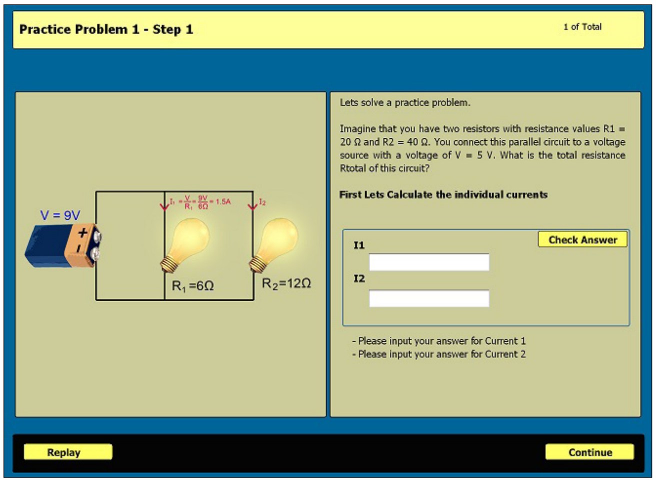
Button$_{7.1}$: [Submit] Appears on the right of the practice problem entry field. Function: Sends the input and provides feedback to students.

Image$_{7.1:}$ Abstract representation of the problem in a circuit model
Image$_{7.2:}$ Values for individual currents appear
Image$_{7.3:}$ Values for I_{total} appear
Image$_{7.4:}$ Values for R_{total} appear

Entry field$_1$: For entering individual currents
Entry field$_{2:}$ For entering I_{total}
Entry field$_{3:}$ For entering R_{total}

Timeline:
1- Image$_{7.1}$ is presented with the narration of Text$_{7.1.}$ When narration is over, text of Text$_{7.1}$ appears under the Image$_{7.1}$. Entryfield$_1$ simultaneously appears under the text.
2- After the entry, Button$_{7.1}$ enables, related to the correctness either narration of Text $_{7.2}$ or $_{7.3}$ is presented. Image$_{8.2}$ appear over the previous image. When the narration is over the text of feedback is presented on the screen.
   a. If Button$_{1.2}$ is selected, replay narration of related feedback text once, until Button$_{1.1}$ is selected

FIGURE 2. Example of textual storyboard with timeline of events for each screen of computer-mediated learning platform.



Lets solve a practice problem.

Imagine that you have two resistors with resistance values R1 = 20 Ω and R2 = 40 Ω. You connect this parallel circuit to a voltage source with a voltage of V = 5 V. What is the total resistance Rtotal of this circuit?

First Lets Calculate the individual currents

- Please input your answer for Current 1
- Please input your answer for Current 2

FIGURE 4. Illustration of vertical layout: Circuit diagram and text are side-by-side.

the engineering subject matter expert, graphic designer, educational psychologist and instructional designer:

> **[ENGINEER SUBJECT MATTER EXPERT]** *"The horizontal layout looks a lot less crowded and it is easier to see the formulas; this is why I suggest the change.*
>
> **[GRAPHIC DESIGNER]** *"thanks for sending the layouts. I agree the horizontal layout has some advantages, but my concern is, isn't it more natural for learners to see the text on the right accompany an image on the left? Maybe our learning psychology expert can address this question?"*
>
> **[LEARNING PSYCHOLOGY EXPERT]** *"There is nothing 'natural' about the position of graphics or word problems. What is important is keeping the layout consistent because students will expect it to be the same throughout the lesson."*
>
> **[ENGINEERING SUBJECT MATTER EXPERT]** *"The horizontal layout seems to be a better use of space because it allows for the largest possible images. Because the images include detailed formulas I think it is important to make them very readable."*

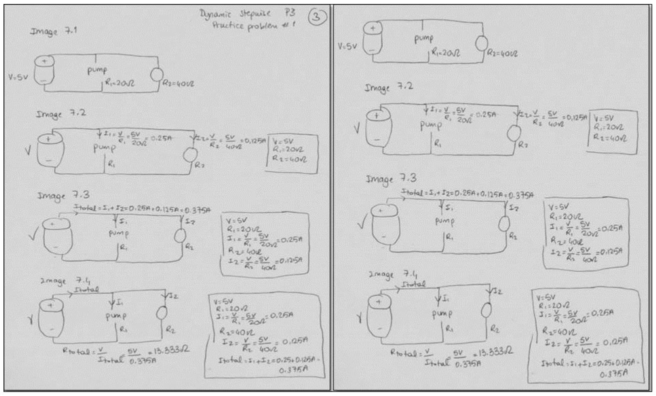
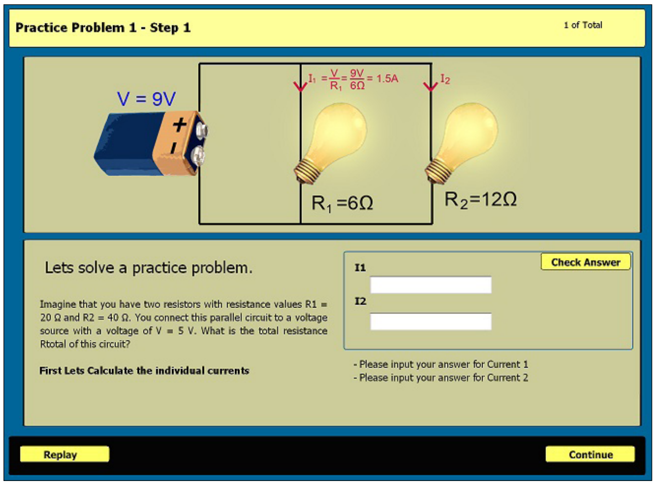


FIGURE 3. Examples of screen-by-screen image sketches.



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First Lets Calculate the individual currents

- Please input your answer for Current 1
- Please input your answer for Current 2

FIGURE 5. Illustration of horizontal layout: The text is underneath the circuit diagram.

Once the decision for the layout was made, display issues related to the transition between desktop (design set-up) to laptop (actual delivery set-up) arose.

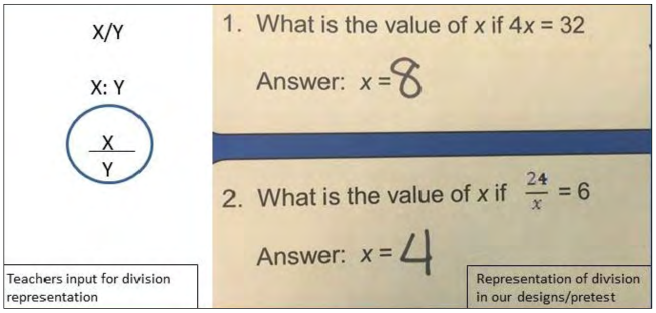
> **[INSTRUCTIONAL DESIGNER]** *"The images still come out pretty small on the screen, especially the font in the formulas is pretty small. There seems to be plenty of free space in the horizontal as well as vertical dimensions to make the images, and thus the equation font, larger. What would be the best way to go about this? The laptops we use have a screen size of approximately 33 x 21 cm. The image part of the screen takes approximately 8.3 cm, suggesting a vertical space of 316 pixels for the image part."*
>
> **[GRAPHIC DESIGNER]** *"Since the width of the screen is 1200, then you don't really need one single image of both equations. All the other files are 600x265, so you could simply place two images side by side."*

Based on this response, the engineering SME checked with the software developer: "This is an interesting idea.—would that work for us?"

As seen from these samples of the actual communications within the team, it took a number of design iterations to finalize the initial prototype, and to create a smooth running instructional module. Each new iteration of the module development (for examining a new instructional design) took four to six months depending on the complexity of the elements. Each module development included numerous tests of usability and functionality, as well as overall testing by all team members and a few representative (pilot) students.

During the design and development phases we included teachers as a part of the design team, and solicited feedback from a few teachers regarding the multimedia module usability and appropriateness of the instructional content for the intended K-12 audience. For example, in one of the communications with the teachers we consulted about how division is taught in middle schools in the state of Arizona, and how it is represented. The instructional designer communicated with the science teachers: "We are finalizing the pretest for middle school students. What do you think, which of the below symbols are students most used to for representing division?" Our partner math teachers provided their input for the most common division representation that middle school students were familiar with, and the research team used that way of representation for all of our engineering materials and modules (see Figure 6).

In another communication between the design team members and the science teachers, the following input was captured: "We should avoid the concept of a mathematical 'function', as the function concept is not taught thoroughly at the middle school level." This was also one main comment from our middle school teacher on the original draft. Another middle school teacher collaborator suggested a couple of language simplifications, for example, instead of "observe the effect on the current", we should use "watch the current." Another example from teacher input that changed our design iteration is: "…put everything in 'you' form. E.g., instead of the present form 'Let's look at the circuit diagram. We see a resistor…', change it to 'Look at the circuit diagram. You see a resistor' …Teachers use this more direct, almost military order- like approach. I am thinking that this direct 'you' form may better prompt and encourage students to learn with the computer program."



1. What is the value of x if $4x = 32$

Answer: $x = 8$

2. What is the value of x if $\frac{24}{x} = 6$

Answer: $x = 4$

FIGURE 6. Teachers' input for division representation in engineering modules and materials.

Also during the development stages we asked for input and feedback on our prototypes from our teacher collaborators. For example, during the development of our initial pedagogical agent prototype, the instructional designer drove to the school site to meet with three teachers and got their input on the design of the pedagogical agent and the initial design of the computer-mediated learning platform. The teachers mostly based their input on their experiences with being around students. They also called several students for validating their inputs during the meeting. Below is one of the summary documents that captures what the teachers and two students said about the pedagogical agents:

- *They all look so angry.*
- *They look at you head-on, it is threatening.*
- *They don't seem approachable.*
- *Tank top shirt is not ok for females, they should be covered up more.*
- *Earrings are not ok.*
- *More hair is needed.*
- *They look green*
- *No hat please, kids do not wear hats at school.*
- *They don't look friendly.*
- *Race-human faces, gender choice, the location of the school and their population, bring lots of issues.*
- *What about a robot…etc, may be more appropriate to electrical engineering, and would avoid all these issues.*

As engineering is a domain that is male-dominated, and often perceived as not cool, we tried to design the agents to look "cool" and friendly with the hat and sunglasses. However, as a result of this interaction, the project team redesigned the agents. Specifically, we took the hat and sun glasses off, redesigned their faces to look friendlier, added more hair, and changed the angle of the faces (See Figures 7 and 8).

PRACTICAL OUTREACH IMPLEMENTATION

Recruitment of Teachers and Students

At the first stages of the project, we applied a systematic process to identify several school districts in the state of Arizona. We were particularly interested in reaching out to schools with a large number of minorities, as these students often lack opportunities to engage in STEM outreach. We also focused on schools receiving Title I funding to increase the awareness and access to engineering for all students.

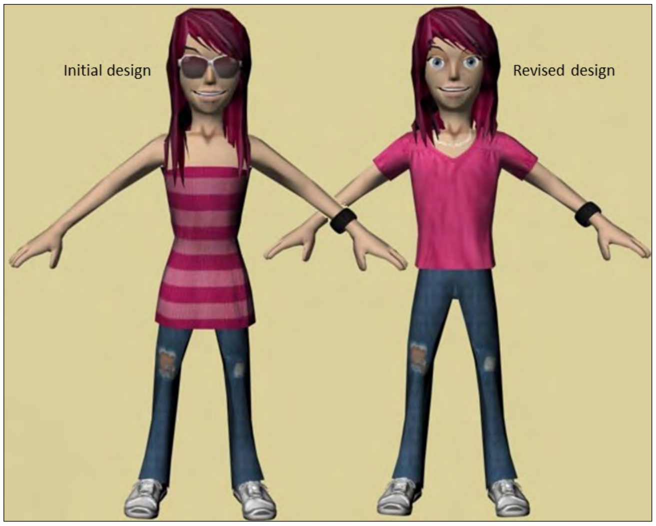


FIGURE 7. Design progression of female pedagogical agent: Initial design (left) and revised design based on teacher and student collaborator feedback (right).

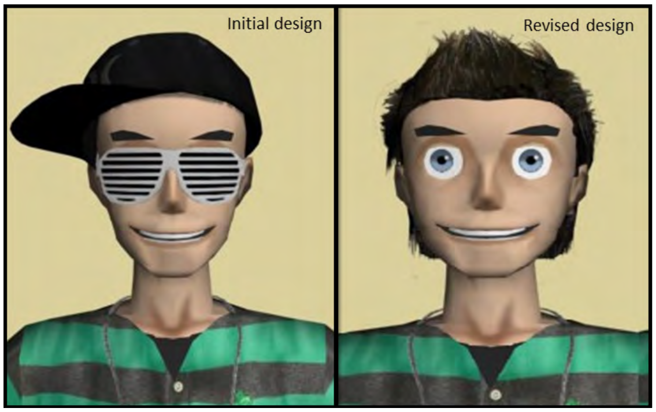
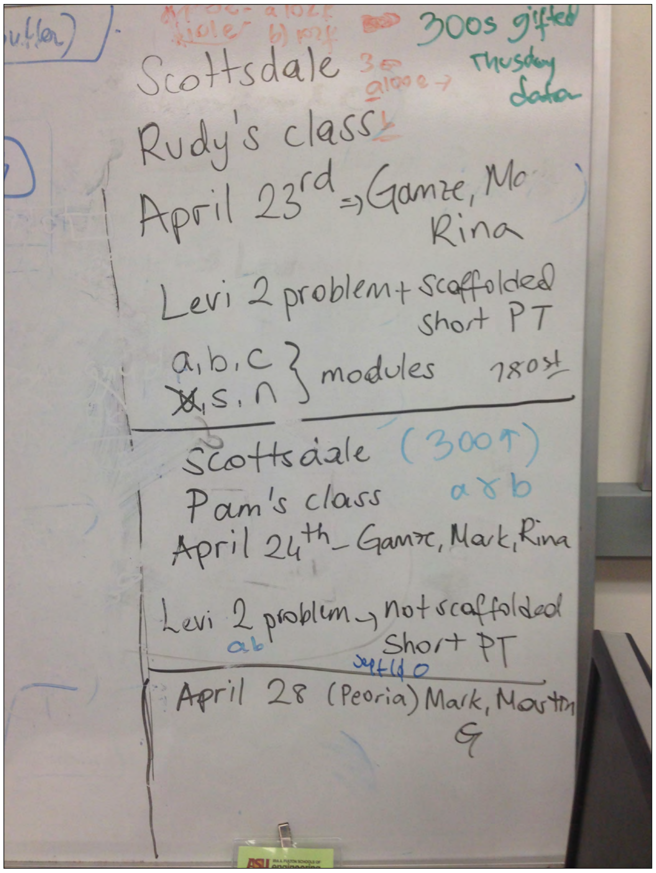


FIGURE 8. Male pedagogical agent designs: Initial design (left) and revised design based on teacher and student collaborator feedback (right).

Once we identified the districts, we located the e-mails of science teachers and/or Principals from school websites. If they were interested, we followed up with a phone call to finalize the visit details. We personally visited several schools and explained the benefits of participating in our engineering outreach project to the science teachers. This step was especially crucial at the high school level where we generally received the least interest from the teachers. This reluctance may have been due to the demanding curriculum already in place and perhaps even the negative engineering stereotypes (e.g., engineering is a difficult subject) that many high school students have.

Later in the project, we had Principals or teachers reach out to us, through the word-of-mouth information they gained from other teachers, or we had teachers ask us to return in subsequent school years. We generally had one to three school visits every month. To keep track we kept the schedule on the white board and updated it every month (see Figure 9).


300s gifted
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Levi 2 problem → not scaffolded
ab Short PT
April 28 (Peoria) Mark, Martin
G

FIGURE 9. Example of a school visit schedule: Visits and organization for month of April.

In the initial phase of the project, once the visit date was finalized the team visited the school site a few times before the actual visit date/s, to ensure the computer-mediated learning platforms ran on the school computers. But later, as described in the next section, after we had changed the outreach model to the mobile computer lab approach, we either visited the school sites once to check the environment for setting up the mobile computer lab, or we visited a few hours before the start of the outreach sessions.

Recruiting students, the majority being minorities and underserved populations, was easy, as most students were eager to interact with the instructional content within the computer-mediated learning platform. The design team had to consider the unique learner characteristics, such as lack of access to quality extra-curricular activities and the socio-economic background of the students' families. The design team had to select instructional examples that were personally relevant to the target audience. For example, the design team could not include references to home WiFi networks as many families could not financially afford such networks.

Mobile Computer Lab Rationale and Design Process

The main purpose of the project was to deliver the engineering outreach by visiting school sites across the state of Arizona and provide instruction through a computer-mediated learning platform, have students interact with engineers, and engage in Q&A sessions. Initially, the team decided to use school computer labs to schedule the outreach days. During the first outreach events using this model, the team had to reschedule the visit a few times due to changes at the school computer lab schedule, high demand of teachers for using the school computer lab, not having enough working school computers to accommodate an entire class, and team needing to visit the school a few times prior to the outreach to assure that the software is compatible and network is working well. Even after all these details were arranged, when the team visited the school sites, they ran into several problems related to numerous computers being out of order on that day, and others freezing on students while they worked on their programs. As a result of this experience, we decided to change the outreach model, and implement the idea of bringing a mobile computer lab to schools for the days of the outreach. Although the idea seemed simple to execute, several design decisions needed to be made to design the mobile computer lab.

We purchased 35 laptops considering the maximum number of students in each class provided by our teachers was 30 for each classroom, and we decided to buy five extra laptops for any unforeseen circumstances, such as the possibility of extra students, or computer failures. In the meantime, the team conducted market research to investigate the possibilities for purchasing laptop carrying cases for delivering the laptops to schools. After examining several options the team abandoned this idea. Transporting the individual carrying cases with the laptops inside would not be feasible due to staff shortage (not enough people on the team to carry 35 laptops and their peripherals, such as power cords and headphones). Additionally, the team needed very sturdy cases that could withstand multiple transport and storage cycles. The team also found the commercially available mobile computing transport/storage solution too costly. The cooperating teachers on the team emphasized the need to have secure (lockable) storage for the laptops, to avoid any damage/loss when the laptops were not in use at the school sites. The team was therefore looking into more personalized and cost-effective solutions. The design team consulted with the university carpenter's office, and searched for the most feasible solution for transporting the laptops to various school sites. After prototypes, and various ideas, the team decided on building wooden four-pack laptop cases (see Figure 10).

There were various design decisions based on a variety of factors. For example, for each wooden case, we decided to include four laptops, based on the weight that each team member could safely lift while loading and unloading the cases. Also, the total height and width of the stack of boxes was to fit a SUV type vehicle that the team was using. Including four laptops in each case, met these requirements. To avoid laptops bouncing during the car ride and while carrying, and to improve the ease of use, we decided to add four slots for laptops within each case that functioned as drawers. A fabric (pull) handle was attached to each slot to easily take each laptop from the drawer. By pulling on the handle, the slot could be easily pulled out, to effortlessly remove and replace the laptop (see Figure 10).

FIGURE 10. Four-pack laptop case.

FIGURE 11. Handles and stacking of laptop cases.

To provide padding for each laptop, we considered bubble wrap or felt. After discussions on durability and considering the anticipated long-term intense use of these custom-made boxes, we decided layering each drawer slot and inside of the door panel of the wooden cases with felt fabric.

Then, we considered how to keep the case doors secure and to avoid laptops sliding off during transportation. We decided to add a lock feature to secure each of the laptop cases. Throughout the use of the cases, the research team also

FIGURE 12. Cord case and design.

discovered that this design element, initially added for safety, served as a signal to the research team during outreach days. In particular, the research team came to recognize the helpful signaling that the lock provided: At a school site if the lock of a case was unlocked it meant that at least one laptop from that case was being used at the moment; if it is locked, it meant that no laptop was being used, or at the end of the day all laptops had been placed in that box and the box was ready for the return transport. This lock system became a check feature for laptops, assuring that all the equipment for the mobile lab was secured in each allocated slot by the end of the outreach day.

Additionally, to ease handling and lifting and to avoid injury, we decided to add handles on the sides of each laptop case (see Figure 11). Additionally, these four-pack cases helped with the mobility of the laptop lab, making it easy to load and unload the laptops into/out of the SUV, transport them on a foldable flat dolly from a parking lot to classrooms at the school sites, and store them in an organized manner when not in use. The sturdiness of the cases allowed them to be stored on top of each other, and protected the laptops from possible damage during transport from one location to another.

Besides the nine four-pack computer cases, two additional similar cases were designed and built to accommodate (a) the cables and extension cords, and (b) the headphones that were needed for the outreach in schools (see Figure 12).

All computer cases were painted with white wood paint due to availability of that color in the carpenters' office free of charge and to bring all the case coloring to look alike, regardless of the various colors of wood being used.

Through this mobile computer lab approach and over a six-year project timeline, we reached out to approximately 3,600 students in grades 4 through 12 across the state of Arizona. In these six years that we used these cases, they preserved their design features, and served as an instrumental part of the mobile computer lab outreach project.

EVALUATION STUDIES INFORMING MODULE DESIGN

Design of Content Representations

Within the design process, we varied how we presented the engineering content. The following subsections outline the design variations that took place in terms of content representations.

Abstract vs. Contextualized Representations

During our initial team discussions, the engineering subject matter expert (SME) brought to our attention the fact that engineering textbooks at the college level typically represent engineering content in abstract form, that is, with generic symbols (Moore, Miller, Lesh, Stohlmann, & Kim, 2013; Nathan et al., 2013). The rest of the team was surprised to learn this, and thought that K-12 students are typically not familiar with these abstract symbols. However, they are familiar with everyday electrical devices, such as smartphones. The teachers on the design team confirmed that students in elementary schools are not formally introduced to abstract symbols (e.g., standard scientific conventions) during science instruction at school. The students might learn conceptual basics of elementary engineering concepts (e.g., electricity) but are not taught any corresponding abstract symbols. The teachers suggested that students in the lower elementary grades might learn better if the instructional examples are concrete as students are developmentally not at the level of abstract thinking and acquiring knowledge from abstract examples. The engineering expert on the team, who had experience teaching more advanced engineering learners, proposed to integrate the abstract content representation in order to avoid formation of any misunderstandings and mis-representations that might negatively impact future learning. Misconceptions that are created during initial learning might be difficult to repair later. The design team had therefore to empirically investigate which of the content representations would be most suitable for the intended target audience.

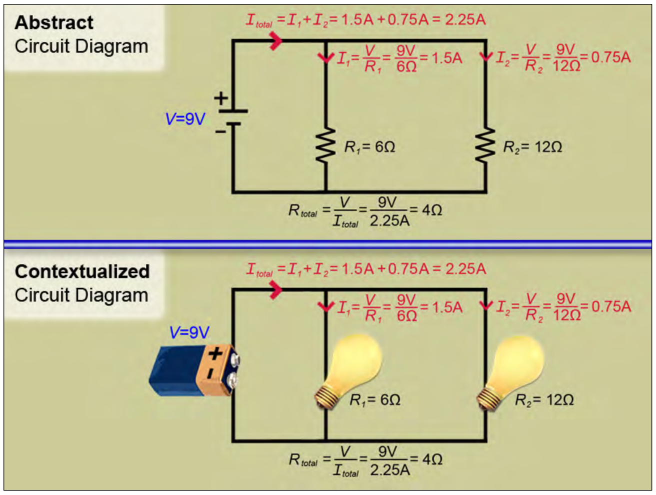


FIGURE 13. An example of abstract and concrete representation images used in the modules.

In summary, the design had to allow for testing of two competing presentation formats: abstract or contextualized electrical circuits.

We modified our module prototype to initially provide two content representations: abstract representation (combining abstract engineering diagrams with abstract text) and contextualized representation (combining contextualized engineering diagrams with contextualized text; see Figure 13). To our surprise we found that abstract representation tended to foster problem solving skills more effectively than contextualized representation for K-12 students. This was an interesting finding in that the middle and high school students were novices to electrical engineering prior to participating in our project. For novice learners, situated learning theory suggests to present instruction in the context of real-life settings that students can relate to. In contrast, information processing models of learning suggest to present new knowledge in a concise manner that emphasizes the underlying structure of the problem solving strategies. Our initial results indicated that emphasizing reasoning about electrical circuits in terms of abstract voltage sources and resistors was more effective for initial engineering learning experiences, even at the middle and high school level. We were very intrigued by this finding and decided to add a third design by combining contextualized and abstract diagrams arranged side-by-side with contextualized text. As we hypothesized we found that the combined condition outperformed both the abstract presentation and the contextualized presentation (Moreno, Ozogul, & Reisslein, 2011; Reisslein, Moreno, & Ozogul, 2010).

Following these findings we discussed ways of helping K-12 students with the transitioning from life-like depictions to the abstract engineering representations. Thus, we augmented the module with additional design elements that would guide the novice learners to the correspondences between the real-life components and their abstract engineering modeling in electrical circuit diagrams and electrical circuit analysis. Specifically, we combined two representation designs (abstract text and diagrams, and contextualized text and diagrams) with three levels of diagrammatic instructional support (none, provided text labels, and interactive text labeling). We tested the student understanding of the engineering concepts and procedures prior, during, and after learning within the computer-mediated learning platform. We discovered that students' posttest performance was better while being taught with abstract representations compared to contextualized representations. Also, the labeling option that asked students to interact with the program and do the labeling on their own resulted in higher posttest scores than both the "no labels" and "provided text labels" designs (Johnson, Butcher, Ozogul, & Reisslein, 2014). Overall, our results supported the cognitive information processing theories (Anderson, Fincham, & Douglass, 1997; Sweller, 1999) in that (a) abstract engineering representations benefit novice learners more than the contextualized format, and (b) learning is positively impacted when learners generate their own labels for circuit diagrams, but not when labels are provided to them.

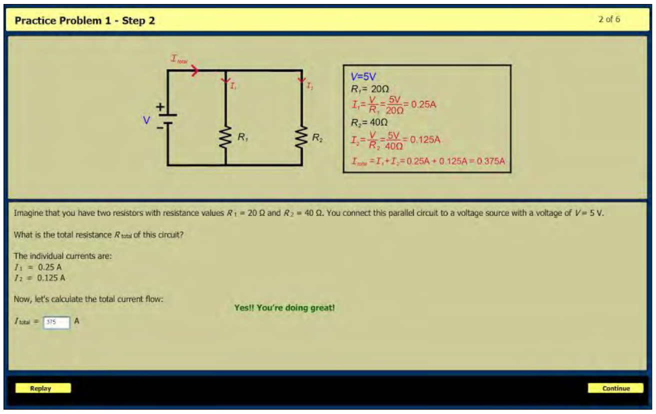
In a related design variation we explored how verbal prompts (verbal instructional support provided, or not provided), alerting the learner to the correspondences between the circuit elements and quantities and their abstract or contextualized representation, could assist the K-12 students. We found a general benefit of using abstract representations with K-12 students. The abstract representation led to the highest learning outcomes (i.e., highest posttest scores) regardless whether verbal support was provided or not (Johnson, Butcher, Ozogul, & Reisslein, 2013). However, the contextualized representation design benefited from instructional support. Overall, these results corroborated our earlier findings that novice learners underestimate the instructional significance of a diagram with familiar depictions, and that explicit verbal pointers can improve learning. For the abstract diagram with the unfamiliar depictions no such instructional support was necessary.

Complementary Hands-On Circuit Kit Design

We complemented these initial experiments conducted with a computer-mediated learning platform with a hands-on lesson to further explore the impact of the representation type. The hands-on lesson was based on an electrical circuit kit, specifically the Snap Circuits kit. In the abstract representation type, the circuit elements were marked with the standard engineering symbols. In the concrete representation type, the circuit elements were familiar to the students, such as batteries and light bulbs. We collected evaluation data for this hands-on experiment with both high school students and elementary school students. Results for the hands-on circuit kit lesson indicated that for elementary school students, the concrete representation led to higher understanding ratings and lower cognitive load ratings than the abstract representation, while there was no difference in student learning between the two representation conditions (Reisslein, et al., 2013). For high school students, there were no significant differences in student perceptions or learning between the two representation conditions. However, male high school students gave significantly higher interest and understanding ratings as well as lower cognitive load ratings than their female counterparts, even though there was no significant difference in student learning between the genders. Unfortunately, many people in our society have negative perceptions regarding engineering. These perceptions may influence attitudes, beliefs, and interests. There is a wide body of literature (Besterfield-Sacre, Moreno, Shuman, & Atman, 2001; Eccles, 2005; Gilmartin, Li, & Aschbacher, 2006; Ing, Aschbacher, & Tsai, 2014) focusing specifically on the negative engineering stereotypes of females. The widely held negative stereotypes of females toward engineering may have influenced the perceptions of the female high school students. The stereotype is that engineering is a hard and male-dominated discipline; therefore, females may have been reasoning that the circuit activity is supposed to provide little enjoyment and be difficult to understand for them. Furthermore, elementary school students reported higher enjoyment for the circuit kit activity and higher cognitive load than the high school students.

Integration of Equations into Diagrams

Our engineering SME pointed out that in all college engineering text-books there are label boxes containing symbol definitions and equations, and the learners need to integrate those while examining a diagram. Within the team we discussed this matter and through these discussions we identified another instructional design issue to explore with K-12 students, namely the split-attention effects between multiple representations (Ginns, 2006). Engineering instruction commonly involves text, diagrams, and equations and therefore poses a unique design challenge (Moore, et al., 2013; Nathan et al., 2013). We explored the existing split-attention studies, and noticed that they had usually only investigated the attention split between text and diagrams (Bartholome & Bromme, 2009; Florax & Ploetzner, 2010; Ginns, 2006) and had not considered equations. Only Sweller, Chandler, Tierney, and Cooper (1990) as well as Tarmizi and Sweller (1988) had previously considered the integration of equations, in the context of mathematical geometry. We explored this design aspect with three module designs, namely (a) non-integrated equations and diagrams; (b) cumulatively integrated equations and diagrams, where all equations are accumulated in the diagram; and (c) stepwise integrated equations and diagrams, where only the equation involved at the current step is embedded in the diagram and the others are accumulated in a side box (see Figures 14, 15, and 16).



Imagine that you have two resistors with resistance values R_1 = 20 Ω and R_2 = 40 Ω. You connect this parallel circuit to a voltage source with a voltage of V = 5 V.

What is the total resistance R_{total} of this circuit?

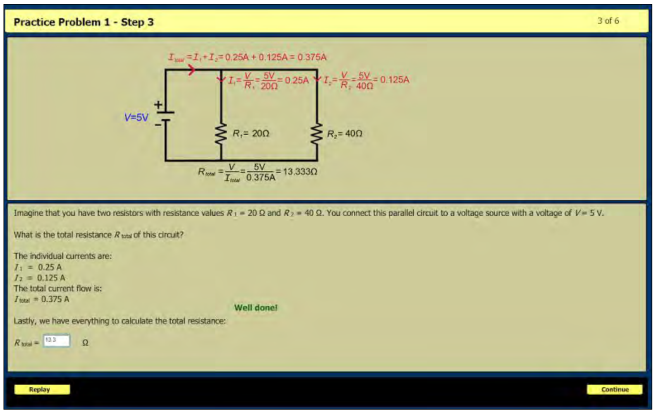
The individual currents are:
I_1 = 0.25 A
I_2 = 0.125 A

Now, let's calculate the total current flow:

I_{total} = 375 A

Yes!! You're doing great!

FIGURE 14. An example of non-integrated representation (all equations are separated outside the circuit diagram).



Imagine that you have two resistors with resistance values R_1 = 20 Ω and R_2 = 40 Ω. You connect this parallel circuit to a voltage source with a voltage of V = 5 V.

What is the total resistance R_{total} of this circuit?

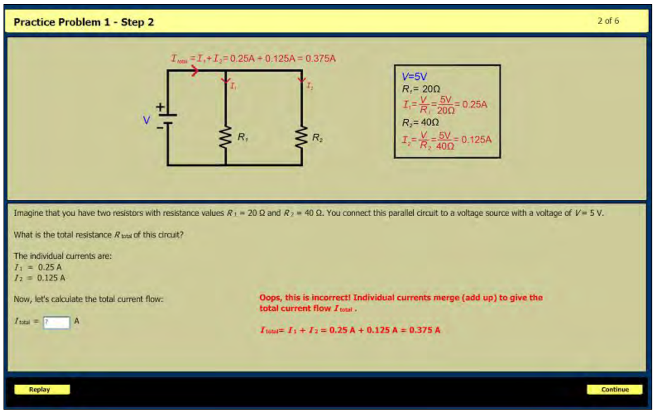
The individual currents are:
I_1 = 0.25 A
I_2 = 0.125 A
The total current flow is:
I_{total} = 0.375 A

Well done!

Lastly, we have everything to calculate the total resistance:

R_{total} = 13.3 Ω

FIGURE 15. An example of cumulative representation (all equations are integrated in the circuit diagram).



Imagine that you have two resistors with resistance values R_1 = 20 Ω and R_2 = 40 Ω. You connect this parallel circuit to a voltage source with a voltage of V = 5 V.

What is the total resistance R_{total} of this circuit?

The individual currents are:
I_1 = 0.25 A
I_2 = 0.125 A

Now, let's calculate the total current flow:

I_{total} = ? A

Oops, this is incorrect! Individual currents merge (add up) to give the total current flow I_{total} .

$I_{total}= I_1 + I_2$ = 0.25 A + 0.125 A = 0.375 A

FIGURE 16. An example of stepwise integrated representation (presently relevant equation is integrated in the circuit diagram; other non-relevant equations are outside the circuit diagram).

We found that learners in the cumulative integrated design scored significantly higher on the near-transfer posttest and higher on the far-transfer posttest, compared to the stepwise and non-integrated designs (Ozogul, Johnson, Moreno, & Reisslein, 2012). The higher learning performance with cumulative integration compared to non-integrated representation is consistent with the spatial contiguity effect, that is, the integrated representation avoids the extraneous cognitive load due to switching attention and mapping between the separated diagram and equations in the non-integrated representation. We concluded that for K-12 students, the split-attention drawback of the stepwise integrated design for the past set of equations outweighs the advantage of signaling the currently-relevant equation. Overall, our findings from the integration study indicated that cumulative integration of equations into engineering diagrams is the most successful instructional strategy for the K-12 audience.

Color Coding

Although the instructional designs that we have examined so far have used a color coding scheme, we had not explicitly examined whether this color coding actually benefitted student learning. Although the colored representation is easy to display without incurring extra cost on a computer screen, producing colored instructional print materials for a paper-based version of our learning platform would incur extra cost for color printing. We decided, therefore, to systematically examine color coding in representations of engineering learning materials. Specifically, we decided to compare black and white representation of the circuit variables (which is conventionally used in some textbooks) with a color-coded representation that consistently employed the same font color for a specific variable, namely ***blue*** for electrical voltage variables, ***red*** for electrical current variables, and ***black*** for electrical resistance variables (see Figures 17 and 18). We brought this design of the electrical circuit analysis module to high school novice learners. We found that the group who had color-coded representations scored significantly higher on posttest scores, and provided higher ratings for liking the instruction and finding it helpful, as well as lower ratings of cognitive load, than the black-font group (Reisslein, Johnson, & Reisslein, 2015). We concluded that color coding of the notations for quantities in electrical circuit diagrams aids the circuit analysis learning of novice K-12 students.

Representation Transitioning

Next we decided to explore whether there are ways that we can help learners transition between representations. The teachers on the team shared their experience teaching K-12 students. When new and difficult material was introduced at school for the first time, the teachers would often use concrete examples and relate the content area to students' prior knowledge. The teachers also observed that with increasing practice their students did not need as much hand holding and were able to comprehend the learning material in more abstract terms. This input prompted the team to design dynamic transitioning of the representations during a computer-based learning session. When we consulted the literature, we found that representation transitioning had only been examined in a few studies that focused on topics areas outside engineering (McNeil & Fyfe, 2012; Scheiter, Gerjets, Huk, Imhof, & Kammerer, 2009; Zacharia & Olympiou, 2011). Towards examining a full representation transitioning sequence, we extended the designs for the abstract and the contextualized representations to form the "end points" of a representation transitioning multimedia instructional module. The extended module dynamically transitioned the learners from an initial (starting point) representation to a target point representation as the instruction progressed. For instance, the contextualized to abstract design transitioned learners from an initially contextualized representation with real-life imagery of light bulbs and batteries to an abstract target representation with engineering symbols. Similarly, we designed and developed an abstract to contextualized design. We delivered these two dynamic transitioning designs as well as the static abstract-only and contextualized-only representation designs to K-12 students. The findings showed that the abstract to contextualized design resulted in better near- and far-transfer than the contextualized to contextualized design, and better near-transfer than the contextualized to abstract design (Johnson, Reisslein,

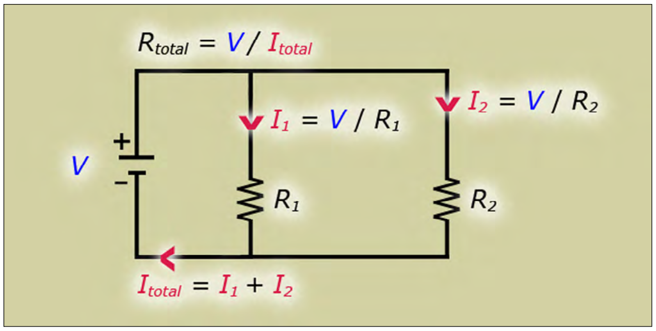
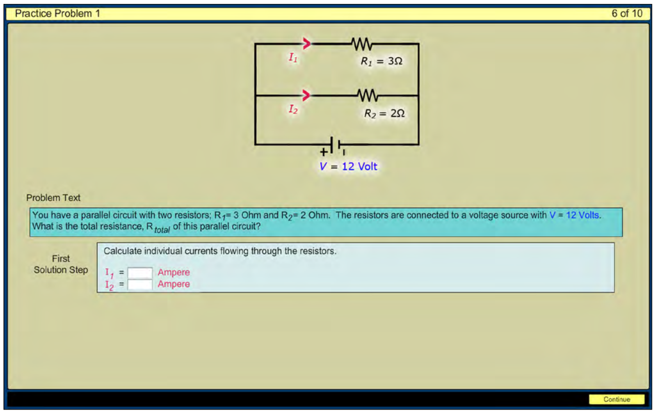


FIGURE 17. Illustration of color coding in a circuit diagram: Voltage variables (V) in blue font, current variables (I_1, I_2, I_{total}) in red font, and resistance variables (R_1, R_2, R_{total}) in black font.



You have a parallel circuit with two resistors; R_1= 3 Ohm and R_2= 2 Ohm. The resistors are connected to a voltage source with V = 12 Volts. What is the total resistance, R_{total} of this parallel circuit?

Calculate individual currents flowing through the resistors.

I_1 = ☐ Ampere
I_2 = ☐ Ampere

FIGURE 18. Illustration of consistent use of color coding for variables across the circuit diagram and the accompanying problem text and solution steps.

& Reisslein, 2014). Based on these transitioning designs, we concluded that the abstract to contextualized transitioning sequence: (a) assists novice learners in focusing on conceptually-relevant information shared across similar problems in initial stages of learning; (b) reduces extraneous cognitive load associated with selecting relevant information; and (c) provides learners with a variety of contextualized problems in later stages of learning, thus assisting in transfer of key principles to novel problem settings.

Signaling (Attention Guidance)

Another key challenge we wanted to address with our designs was that novice students lack the necessary background knowledge to distinguish between what is relevant and what is not relevant in a problem situation, especially when the problem includes multiple representations (Jamet, Gavota, & Quaireau, 2008; Meij & de Jong, 2006; Moreno & Mayer, 2005, 2007). We agreed on designing a module that employed signaling methods to guide students' visual attention to relevant pieces of information during learning. Signaling is especially critical in engineering instruction as engineering learning materials involve multiple descriptive representations, such as text and equations, as well as multiple depictive representations, such as diagrams and plots (Jonassen, Strobel, & Lee, 2006).

We initially investigated how to guide learners' attention in engineering learning modules with three module designs: no signaling, arrow signaling (see Figure 19), and signaling by an animated pedagogical agent (APA; Heidig & Clarebout, 2011; Kim & Baylor, 2006), whereby the agent was a male peer of the middle/high school students (see Figure 20). Through these module deliveries we found a strong agent signaling effect in that signaling with the male peer agent resulted in significantly better problem solving performance than the same signaling with an arrow (Moreno, Reisslein, & Ozogul, 2010).

We then became curious and wanted to see whether the agent characteristics may have had an effect on the students, because of his gender and age. Thus, we decided to follow up on the discovery of the agent signaling effect with a module that provided the same instruction via agents with different age and gender. Specifically, we added designs with a young (peer) female agent, an older (non-peer) female agent, and an older (non-peer) male agent (see Figure 21). We used theater artists to record the voices of the agents. After the delivery of modules to middle and elementary students, we found that the agent signaling effect vanished for an older (non-peer) agent and that a female (peer) agent demonstrated an agent signaling effect only for learners with low prior knowledge (Johnson, Ozogul, Moreno, & Reisslein, 2013). We were surprised by this finding of the reduced effectiveness of the young female agent, and we attributed the finding to the stereotypical views that many pre-college students hold regarding the suitability of females for engineering. Specifically, the biased notions on women in engineering may weaken the perceived importance and/or validity of instructional messages delivered via female agents, especially for those learners who have some pre-existing domain-specific knowledge. The higher effectiveness of the young (peer) agents compared to the older (non-peer) agents is consistent with learning gains observed in peer instruction. We thought that this was because K-12 students may perceive the young agents more similar to themselves than older agents, thereby they were more motivated toward imitation and achievement in the engineering domain. Overall, the findings indicated that a male young (peer) agent was most effective for teaching engineering to pre-college students.

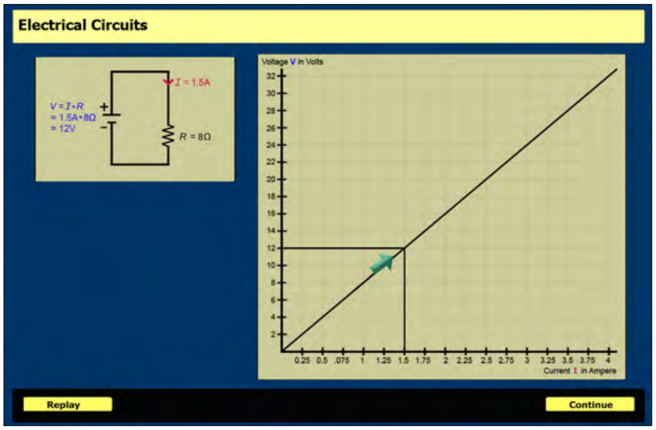


FIGURE 19. Arrow signaling.

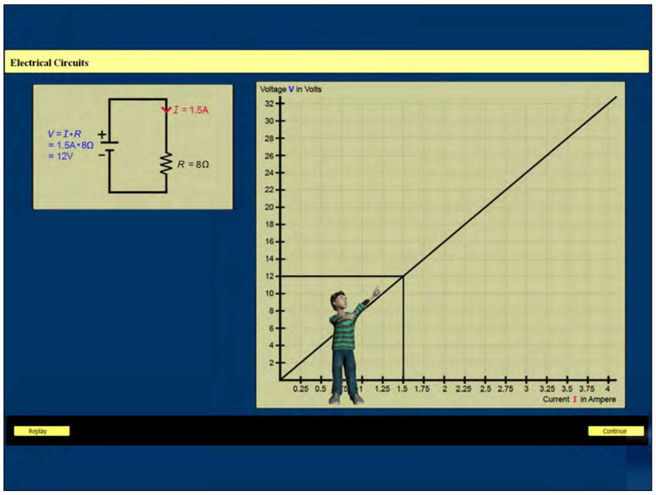


FIGURE 20. Male peer agent (APA) signaling.

We still were interested to investigate a key design issue related to animated pedagogical agents (APAs), namely the individual effects involved in agent signaling: the presence of the agent and the signaling functionality provided by the agent. Isolating these individual effects required a 2 (visual

FIGURE 21. All four agents used for signaling (from left to right): an older (non-peer) male agent, a young (peer) female agent, a young (peer) male agent, and an older (non-peer) female agent.

signaling, no visual signaling) × 2 (visual APA presence, no visual APA presence) design (Johnson, Ozogul, & Reisslein, 2015). Through these deliveries we discovered that high-prior knowledge learners achieved higher posttest scores without the APA. On the other hand, low-prior knowledge learners achieved higher posttest scores when aided by visual signaling. Also, the low-prior knowledge learners had better learning perceptions when a visual APA was present. Overall, our findings indicated that the impact of visual signaling and visual presence of an APA depend on the learner characteristics. The design takeaway from these signaling evaluations is ambiguous. One cannot generalize for all types of learners. Rather it is critical to analyze the target audience prior to any instruction and design the learning environment to reflect the students' prior knowledge.

Feedback

Another area we wanted to investigate was the effect of feedback. Feedback is widely recognized as one of the most powerful influences on students' learning (Hattie & Timperley, 2007). When we explored the literature, previous findings suggested that novice learners benefit from just-in-time information to repair or correct errors immediately after attempting an individual problem solving step (Kester, Kirschner, & Van Merriënboer, 2006). However, immediate feedback requires mental processing of the feedback after each problem solving step. We decided to investigate the learning effects of dynamically varying the frequency of feedback during engineering problem solving practice. We designed modules to give us insights on the effects of different static frequencies of feedback during electrical engineering multimedia instruction (Moreno, Reisslein, & Ozogul, 2009). In particular, we designed a static step-by-step feedback strategy that provided feedback after students attempted each problem solving step throughout their practice session. Additionally, we designed a static summative feedback strategy that provided feedback after having fully completed the same problems in the practice session. We found that the step-by-step feedback strategy showed improved problem solving performance on a posttest.

After exploring static feedback strategies we met with our collaborating teachers to discuss options to better support student learning by utilizing varying feedback options. The teachers described their teaching strategies in the classroom where they adjust their feedback based on the stages of learning and student performance. The design team got a strong sense for the need to tailor instructional feedback to the changing needs of the learners as they progressed through the learning phases. It was not clear what feedback structure would best support the student learning. The design team has therefore decided to investigate how students' learning would be affected by transitional feedback designs. In the literature we found that transitional feedback strategies have been examined by Billings (2012). Specifically, feedback that adaptively transitioned from detailed to general and feedback that was initially general and remained general or transitioned to detailed feedback, was examined in training for simulated military missions.

We developed four varying feedback designs to explore which one best suits the K-12 students and the learning of the engineering domain. Our design discussions centered on the issue of the feedback frequency. The instructional designer proposed more frequent feedback as the students were novice learners and needed more instructional scaffolding. The engineering subject matter expert argued that breaking down the feedback to miniscule subtasks was not necessary because the students need to get a broader understanding of the underlying principles and the frequent feedback would be disruptive. The educational psychologist on the team was also worried about the higher frequency of the feedback as it would impose higher processing demands on the learners during initial stages of knowledge acquisition. All the suggestions and concerns were valid and required empirical evaluation in a systematic manner, in order to create an optimal design that best supported the learners. We evaluated different designs in order to resolve our design dilemma. Specifically, we compared (a) sequencing (transition) from feedback after every attempted problem step (per-problem step feedback) to feedback after attempting a complete multi-step practice problem (per-problem feedback); (b) sequencing from feedback after a complete problem to feedback after every problem step, and as control conditions; (c) feedback after each problem step throughout an instructional session, and feedback after each complete problem throughout an instructional session.

Findings on the design of feedback sequencing indicated that feedback provided after each problem step attempt and feedback that transitioned from per-step to per-problem produced higher problem solving near-transfer performance than feedback provided throughout after each problem and feedback sequencing from per-problem to per-problem step (Johnson, Reisslein, & Reisslein, 2015). Additionally, sequencing from per-problem step to per-problem feedback resulted in higher ratings of program liking and feedback helpfulness than sequencing from per-problem to per-problem step feedback. Overall, the findings from this feedback design indicated the benefits of maintaining high feedback frequency (per-problem step) and reducing feedback frequency (sequencing from per-problem step to per-problem feedback) compared to low feedback frequency (per-problem) or increasing feedback frequency (sequencing from per-problem to per-problem step) as novice learners acquire engineering problem solving skills.

CONCLUSION

The design team engaged in stimulating iterative design processes where experts and collaborators from a variety of fields, including but not limited to instructional design, educational psychology, learning, multimedia design, and engineering, created over a period of several years a rich computer-mediated learning platform for teaching basic engineering concepts. Our engineering outreach allowed approximately 3,600 K-12 students to gain introductory engineering knowledge by learning with the computer-mediated learning platform and to interact with hands-on engineering kits. We hope that there will be more engineering and STEM outreach projects that focus on designing instruction for students in these fields. We also feel optimistic that we generated solid guidelines on how to deliver the content and instructional designs that support the learning of K-12 students and their motivation for the engineering field. These guidelines will inform the future implementations of our design team. We are also hopeful that the students who participated in our outreach have gained positive experiences related to learning and knowing more about engineering. Perhaps these experiences will inspire them to pursue STEM careers in the future.

Below are a few takeaways that our team learned from this design case. First, it is important to tightly integrate theoretical research-oriented design issues with practical outreach implementation strategies for effective engineering outreach to K-12 students in their classrooms. This design case integrated a research strand consisting of a theoretical framework and evaluation studies on instructional design aspects of K-12 engineering education with a practical outreach implementation strand that centered on a mobile computer lab. Because instructional designs for engineering education at the K-12 level had received very little attention from the research community at the starting time of this design project (in the year 2007), we could extract only a baseline module design from the theoretical framework and prior empirical studies. Therefore, an extensive research strand was needed to ensure sound and effective instructional design decisions in the newly emerging area of engineering education in K-12 classrooms.

As the project progressed, the lessons that our team learned from the evaluation studies for the instructional design aspects were cumulatively incorporated into the module designs. Thus, the module designs became more and more refined and effective as more and more of the evaluation studies were completed.

Second, instructional designs that intent to engage the individual K-12 students in a personalized manner need to address the issue of computer-based module delivery to K-12 schools. Our goal has been to engage each individual student to maximize learning and provide every student with the opportunity to interact with the instructional modules. Also, the instructional modules on the engineering topic benefitted from the rich visual representation capabilities of computer screens. Other instructional designs that similarly seek to personally engage K-12 students in their classrooms with rich computer displays will need to address the practical aspect of bringing the computer infrastructure to the K-12 schools. Our mobile computer lab approach proved useful in presenting computer-based instructional modules in K-12 schools.

Finally, a K-12 outreach project of this scope and duration requires a professionally working team, and very clear communication strategies between all the team members. We also think that pilot testing and continuous teacher inputs during the design and development processes are crucial to ensure the success of similar projects. As you read in this design case, we continuously needed to change, adapt, and iterate our designs based on the feedback and findings.

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