Efficacy of Simulation-Based Learning of Electronics Using Visualization and Manipulation

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ABSTRACT

Software for simulation-based learning of electronics was implemented to help learners understand complex and abstract concepts through observing external representations and exploring concept models. The software comprises modules for visualization and simulative manipulation. Differences in learning performance of using the learning software either with or without the simulative manipulation module were investigated in 49 college sophomores. The learning performance was higher for learning software utilizing simulative manipulation and visualization yields than for that lacking simulative manipulation, which suggests that learning performance can be enhanced if visualized learning can appropriately integrate simulative manipulation activities. An analysis of the learning process revealed that the use of simulative manipulation activities to verify and clarify the existing knowledge is crucial to improving the learning performance.

Keywords

Simulations, Interactive learning environments, Applications in electronics

Introduction

Visualized simulation provides external representations of complex and abstract concepts, and helps learners to understand their nature. Gordin and Pea (1995) and Ainsworth (2006) found that visualized simulation helps learners to achieve a higher level of cognition by facilitating their interactions with multiple external representations and reflection on phenomena, as observed when learning a given abstract concept. Moreover, visualized learning also motivates learners and helps them to transfer concepts into long-term memory (Colaso et al., 2002; Naps et al., 2003).

The many studies on computer-based visualized simulation learning have covered almost all subjects of science education (Jensen et al., 2002; Khoo & Koh, 1998; Luo et al., 2005). However, studies on how computer visualization improves learning performance have produced diverse results, with some of them revealing positive influences of computer visualization on learning (Catalano & Tonso, 1996; Colaso et al., 2002; Jensen et al., 2002; Luo et al., 2005; Meyer & Krzyzkowski, 1994; Naps et al., 2003; Wallace & Mutooni, 1997), with others finding that visualization does not enhance learning performance (Reamon & Sheppard, 1997; Regan & Sheppard, 1996). Many researches have attempted to understand why visualization would not have a positive impact on learning, and our review of these research findings revealed that learning performance can be enhanced if a visualized learning environment promotes learner interactions and gives them opportunities for manipulation (Colaso et al., 2002; Jensen et al., 2002; Korhonen & Malmi, 2000; Naps et al., 2003; Tversky et al., 2002). The results of this review agree with the overall learning theory stating that interactive learning activities that gains in motivation, and enhanced motivation and learning outcomes (Prensky, 2002). The use of computer simulation by learners allows them to readily manipulate parameters and observe the resulting changes in a given phenomenon, which helps the process of higher-level reasoning (Gallagher, 1987).

A common problem faced by learners of electronics is being unable to fully understand the abstract concepts that underlie the system responses predicted by theoretical models. This often results in learners being unable to see the link between models and actual circuits (Ronen & Eliahu, 2000). Learners frequently cannot understand the abstract concepts underlying the microscopic world of electrical circuits since they cannot see the flow of electric currents authentically, and some teachers are also unable to clearly explain the details of these complex concepts. Moreover, learners may feel frustrated and discouraged if there is no real-time feedback about a learning problem when they are attempting to understand complicated abstract concepts (Oakley, 1996). Ronen and Eliahu (2000) believed that simulation has great potential as a supplementary tool, with simulation as a medium helping learners to repair missing links between theories and actual electronics processes.
Interactive simulation learning as an area worthy of study, thus, previous studies often fail to provide the information necessary to determine if interactive simulation is indeed helpful (Vogel et al., 2006). For this study we implemented electronics simulation learning software aimed at helping learners to understand the nature of the abstract electronics concepts. The software contains two modules: (1) the concept visualization module, which provides a visualized representation with corresponding narrations and descriptions of texts and symbols to help learners understand the complicated abstract concepts, and (2) the simulative manipulation module, which guides learners to observe changes resulting from manipulations of relevant parameters, thereby facilitating cognitive reflection and integration of the relevant abstract concepts. This study investigated the effectiveness of the learning activities of visualization and manipulation, and also whether the learning results of using the learning software differed depending on whether or not it contained the simulative manipulation module.

Simulation-based Learning Activities

The simulation-based learning model constructed in this study contains three phases: concept learning, simulative manipulation, and concept clarification (see Figure 1). In the concept-learning phase, the learner conducts the activities through the visualized representation with corresponding narrations and relevant texts and symbols that help learners understand complicated abstract concepts and facilitate reflection through learning-reflection learning path. After the basic concepts are understood, a learner then manipulates parameters and observes the corresponding simulated output changes in order to iteratively reflect on the concepts and understand them in more detail through manipulation-reflection learning path. If a learner finds that learned concepts conflict with each other during manipulation, he/she can reuse the concept visualization module to further clarify them through learning-manipulation-reflection learning path.

![Figure 1: Simulation-based learning model contains three phases](image)

Software for simulation-based learning of electronics was implemented to help learners understand complex and abstract concepts through the simulation-based learning model. The software comprises modules for visualization and simulative manipulation in the “half-wave rectifier”, “half-wave rectifier with filter”, “full-wave rectifier”, and “Zener diode” units. A “half-wave rectifier” is the diode circuit used to convert AC to pulsating DC is to simply allow half of the AC cycle to pass, in contrast with “half-wave rectifier”, the “full-wave rectifier” is the diode circuit used to convert AC to pulsating DC is to allow full of the AC cycle to pass. A “Zener diode” is a type of diode that permits current not only in the forward direction, but also in the reverse direction if the voltage is larger than the breakdown voltage.

Concept learning

When conducting concept-learning activities, a learner clicks on the concept visualization module that divides the learning unit into several topics, such as “half-wave rectifier circuit”, “theories of the half-wave rectifier circuit”, “the positive cycle when power is on”, “after reaching the peak value of the positive cycle, the input voltage is less than the output voltage”, and “when the voltage input is again greater than the output voltage”. For example, the learning screen shown in Figure 2 is displayed when a learner clicks on the topic of “theories of the half-wave rectifier circuit”. In the concept-learning activity, the upper-left corner and the lower-left corner of screen show the waveform of the input voltage and the output voltage, respectively. At the same time, the right side of screen allows the learner to observe how it is affected by the input voltage and the changes in electric current, thus imparting a...
gradual understanding of the principles of operation of the half-wave rectifier circuit. This process is facilitated by narrations that accompany the visual demonstration. During the process, the learner can choose to pause or repeat the material, relearn it, or go to the next topic at his/her own speed.

Simulative manipulation

Based on the learned concepts, a learner observes the changes of the outputs resulting from manipulating parameters in a simulative context in order to verify whether he/she has correctly understood the concepts. The simulative manipulation module asks a series of questions that guide the learner to manipulate the parameters and observe the results. The question shown at the top of the example shown in Figure 3 is as follows: “For a sine wave voltage amplitude of $V_p=30$ V, a frequency of $f=60$ Hz (Hz is the unit of frequency), and a load resistance of $R=10$ k$\Omega$ ($\Omega$ is the unit of resistance, $1k\Omega=1000\Omega$), please adjust the capacitance to 20 $\mu$F ($F$ is the unit of capacitance, $1\mu F=10^{-6}F$) and observe the amplitude of the ripple voltage on the oscilloscope”. The question prompts the learner to adjust the value of capacitance, set the values for the circuit components, and connect the oscilloscope to the two ends of resistance $R$ to observe whether the value of the ripple voltage is as expected. The result shows that when the capacitance was 20 $\mu$F, the ripple voltage was about 2.5 V.
The simulative manipulation module guides learners to conduct manipulations, and each set of questions guide learners to understand complicated abstract concepts. Each set typically comprises two to four questions. For example, for the “half-wave rectifier circuit” unit, the topic addressed by the question set comprising four questions was the inverted relationship between capacitance and ripple voltage. As shown in Figure 3, a learner conducts manipulations under the guidance given in question 1, and when the capacitance was 20 \( \mu \text{F} \), the ripple voltage was 2.5 V. Question 2 prompts the learner to observe the value of the ripple voltage when all conditions remain the same except for the capacitance decreasing to 10 \( \mu \text{F} \). After the manipulation, the enlarged display of the oscilloscope showed that the ripple voltage was increased to about 5 V. Question 3, which is “what is the value of capacitance that will produce the minimum ripple voltage amplitude?”, and then guides the learner to reflect on the results from questions 1 and 2. For example, based on the experimental results from questions 1 and 2, a learner may continuously adjust capacitance and observe the ripple voltage, and having a result that the ripple voltage value changes to 3.2 V when the capacitance is changed to 17 \( \mu \text{F} \) and, but increases to 4.2 V when the capacitance drops to 13 \( \mu \text{F} \). Through the continuous manipulation of capacitance parameters and observation of voltage waveforms, the learner gradually discovers how changes in the capacitance affect the ripple voltage, as indicated by question 4: “please adjust the capacitance, observe the changes in waveforms, and decide which of the following descriptions regarding the relationship between the capacitance and ripple voltage is correct”.

**Concept clarification**

Based on the guidance provided by the questions, a learner manipulates parameters in order to understand the relationships between parameters and outputs, and cross-examines them with the concepts learned during concept learning. If the manipulation outputs match the learned concepts, the learner can draw his/her own conclusions based on the simulative results. However, if the outputs conflict with the learned concepts, the learner will return to the concept learning phase and review the relevant topics in order to resolve the conflict. For example, if the learner originally assumes that capacitance is directly proportional to the ripple voltage, but the simulative results suggest otherwise, he/she can return to the concept visualization module and review the descriptions of the function of capacitance in a rectifier circuit (Figure 4). When a learner clicks on the finger icon next to the capacitance in Figure 4 the system will explain the functions of capacitance in order to help him/her reflect on how the value of the capacitance will influence the ripple voltage.

![Figure 4: Concept clarification: review the descriptions of the function of capacitance in a rectifier circuit](image-url)
Experiments

In this study, we investigated differences in the learning performance when using electronics simulation learning software that contain either only a concept visualization module (provide learning-reflection learning path only) or both concept visualization and simulative manipulation modules (provide learning-reflection, manipulation-reflection, and learning-manipulation-reflection learning paths), in order to determine the efficacy of including a manipulation mechanism in the learning software. The learners in the experimental group used software that contained both modules in order to perform the following three activities: concept learning, simulative manipulation, and concept clarification; whereas those in the control group only performed concept learning activities through the concept visualization module.

Subjects

The research subjects were 49 sophomore students in Taipei (37 males and 12 females), all of them had learned about diodes in an electronics course provided before this study. They were randomly divided into the control group (16 males and 7 females) and the experimental group (21 males and 5 females).

Experimental design

We adopted a quasi-experimental design for the study, in which the independent variables were the groups (experimental and control groups) and the test phases (pre- and posttests). The dependent variables were the posttest results of the four units on electronics topics related to diode circuits: half-wave rectifier, half-wave rectifier with filter, full-wave rectifier, and Zener diode. In order to avoid experimental errors due to the use of different instructional methods and learning materials, the same instructor and materials were used for both the experimental and control groups. The mid-term electronics examination scores of the participants were used as covariance to eliminate the influence of prior knowledge of electronics on the learning results. The mid-term examination covered the four units related to diode circuits. Pearson's correlation coefficient between the scores of mid-term examination and pretest in the experimental and control groups was 0.63 (p=.006<.01) and 0.61 (p=.008<.01). There was a strong positive correlation between the mid-term examination and pretest scores in both groups.

Tools

The tools used in the experiments were (1) electronics simulation learning software as described above and (2) pre- and posttests constructed based on the electronics material that the participants studied. The test contents were based on college-level electronics courses, and the tests were examined and amended by two experienced instructors in this subject area. Seventy-two college students participated in the pilot study, in which 36 copies of pre- and posttests were randomly given out. The Kuder-Richardson reliabilities of the pre- and posttest were .78 and .69, respectively.

Procedures

All learners underwent a 30-minute-long pretest prior to the commencement of the experiment, with the experimental treatment beginning in the following week. The simulation learning activities lasted 3 weeks. The “half-wave rectifier” and “half-wave rectifier with filter” units were given in the first week, in which both groups underwent a 20-minute system introduction before undergoing 60-minute-long learning activities. The “full-wave rectifier” unit was given in the second week, in which both groups underwent a 30-minute-long learning activity. The “Zener diode” unit was given in the third week, and both groups again underwent a 30-minute-long learning activity. After the learning activities ended, both groups received a 30-minute-long posttest and a 15-minute-long questionnaire survey.
Results

We used a two-way mixed ANCOVA to evaluate the learning performance in both groups and compare the differences between them. After eliminating the influence of prior knowledge on the learning performance of learners, we analyzed whether there were significant differences between (1) the posttest scores in the experimental and control groups and (2) the pre- and posttest scores in each of the experimental and control groups. Table 1 summarizes the pre- and posttest scores in the two groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean Pretest</th>
<th>SD</th>
<th>Mean Posttest</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>26</td>
<td>74.90</td>
<td>18.55</td>
<td>84.82</td>
<td>10.87</td>
</tr>
<tr>
<td>Control</td>
<td>23</td>
<td>71.17</td>
<td>17.37</td>
<td>71.17</td>
<td>19.94</td>
</tr>
</tbody>
</table>

Tests of the homogeneity of the regression coefficient revealed that interaction $F(2,45)$ between the independent variables and covariance was .68, and not significant ($p > .05$). This confirms the hypothesis of homogeneity of the regression coefficient.

The mid-term examination scores were used as the covariance to check the significance of differences in changes in the pre- and posttest scores in the experimental and control groups. Table 2 indicates that there were interactions between the pre-/posttests and groups ($F(1,46) = 4.90, p < .05$), and a test on simple main effects was conducted.

Table 3 lists the results of a simple main effect test on the factors of group and pre-/posttest. There was no significantly difference between the experimental and control groups at the pretest ($F(1,94)=.593, p > .05$), where the posttest scores were significantly higher in the experimental group than in the control group ($F(1,94) = 7.933, p < .05$). This indicates that the learning performance was significantly better in the experimental group than in the control group. Moreover, there were no significant differences between the pre- and posttest scores in the control group ($F(1,47)=.000, p > .05$), whereas posttest scores were significantly higher than pretest scores in the experimental group ($F(1, 47) = 10.620, p < .05$). This indicates that the experimental group improved significantly whereas the control group did not.
Discussion

It is commonly believed that visualization technologies have positive impacts on learning. However, the educational benefits of such technologies would be impaired if they do not help learners become active in the learning process (Naps et al., 2003), and many studies suggested that increasing interactions and opportunities for manipulation improves learning (Calaso et al., 2002; Jensen et al., 2002; Korhonen & Malmi, 2000; Naps et al., 2003; Tversky et al., 2002). Therefore, we incorporated interactive operations in computer-based visualized simulations and constructed simulation-based learning models aimed at helping learners to conduct concept explorations and verifications through concept learning, simulative manipulation, and concept clarification activities. Simulation-based learning activities help learners to acquire knowledge through the process of observation, exploration, experiencing, and reflection.

The posttest scores in our empirical study were significantly higher in the experimental group than in the control group. Moreover, the posttest scores were significantly higher than the pretest scores in the experimental group, but they did not differ in the control group. These results indicated that the learning performance was higher when integrating visualization and manipulation than when using visualization only, and was not improved when visualization was not included in the interactive manipulation mechanism.

A detailed analysis of the study revealed that learners whose grades improved in the experimental group often returned to previous topics to review concepts after completing the explorations in manipulation activities in order to clarify relevant concepts and revise previous concept models, and that this behavior was absent in those who showed no improvements. In contrast, there was no such difference between those who improved and those who did not improve in the control group. Although the learners in the control group also reviewed relevant concepts, they lacked a concept clarification process and did not gain a better understanding of the concepts or construct a comprehensive knowledge structure. This resulted in most of them not improving, and also performing worse than the subjects in the experimental group. The limitation of study is that it had focused on the qualitative exploration of learning activities; detail research is needed to analyze the learning behavioral patterns in such learning environment from a quantitative perspective.

Doulai (2001) stated that the use of computer simulation software improves the motivation of learners, with the resulting exploration activities improving their learning performance. Matching this idea with the questionnaire findings, we found that 66% of the learners in the experimental group stated that the manipulations helped to increase their interest in electronics, with 77% of them stating that manipulation benefited their learning. In contrast, only 30% in the control group stated that concept visualization motivate them, with only 48% of them stating that it benefitted their learning.

Conclusions

Based on the electronics topic of diode circuits, learning models that included concept learning, simulative manipulation, and concept clarification phases were formulated in this study in order to realize learning software that contained concept visualization and simulative manipulation modules. Applying this learning software to 49 college sophomores showed that the learning performance was higher for those who utilized manipulative tools, which indicates that integrating visualization with an appropriate manipulation context benefits the learning achievements of learners. Our analysis of the learning process revealed that the important factors for an enhanced learning performance are whether learners can follow the simulation-based learning model, construct knowledge through concept learning, simulative manipulation, and concept clarification activities, make use of simulative practice to identify the nature of concepts, and integrate this with their existing knowledge.

Even though some previous studies reporting negative results about educational technology enhance learning, but other studies revealed that learning performance can be enhanced when pedagogy is sound (Kadiyala & Crynes, 2000). The meaningful learning will take place when these technologies allow learner to be engaged in the knowledge construction, conversation, articulation, collaboration, authenticity, and reflection activities (Jonassen et al., 2000). An important aspect of the pedagogical model presented in this paper is the idea that authentic manipulation in simulation-based learning environment will stimulate deeper reflection about the electronics concept while learners construct knowledge through the learning-manipulation-reflection learning path base on the
simulation-based learning model. In the learning model, another finding is that problem solving strategy used in the manipulative environment will facilitate critical reflection through the manipulation-reflection learning path. Interactive simulation helps learners engaged in the authenticity, reflection and knowledge construction activities to achieve a higher level of cognition. Moreover, interactive learning also motivates learners and useful to improve learning in complex domains (Spector, 2000).

To increase and refine our knowledge of this subject, it would be interesting to extend the study to other learning domains, and to conduct quantitative studies involving large numbers of students using these environments in real learning context. It would also be worth investigating the learning behavioral patterns, either in qualitative or quantitative studies, in the simulation-based learning environment. On the other hand, Learners exhibit diverse types of misconceptions when learning about electronics (Ronen & Eliahu, 2000). We have demonstrated the efficacy of applying simulative manipulation to learning performance, and future studies should attempt to elucidate whether simulative manipulation can clarify learner misconceptions.

References


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