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Correcting Misconceptions on Electronics: Effects of a simulation-based learning environment backed by a conceptual change model

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ABSTRACT

Computer simulation has significant potential as a supplementary tool for effective conceptual-change learning based on the integration of technology and appropriate instructional strategies. This study elucidates misconceptions in learning on diodes and constructs a conceptual-change learning system that incorporates prediction-observation-explanation (POE) and simulation-based learning strategies to explore the effects on correcting misconceptions and improving learning performance. Thirty-four sophomore students majoring in engineering participated in the experiments. The empirical results indicate that the system significantly corrects participants' misconceptions on diodes and improves learning performance. This study shows that conceptual-change instructions could correct misconceptions effectively by constructing scenarios that conflict with existing knowledge structures. The results also show that misconceptions on diode models and semiconductor characteristics could be corrected in more than 80% of cases. Conversely, difficulty in correcting misconceptions correlates with the fundamental definition of voltage, circuit analysis, or the interaction between different diode concepts.

Keywords

Computer simulation, Visualization, Misconception, Conceptual change strategies, Applications in electronics

Introduction

Learning electricity-related concepts is often confusing for various levels of learners (Belcher & Olbert, 2003; Reiner, Slotta, Chi, & Resnick, 2000). The difficulty in learning electricity, electronics, and electromagnetism concepts is attributed to their abstract nature, complexity, and microscopic features (Pfundt & Duit, 1991). Some studies show that most difficulties experienced by learners of electricity-related concepts originate from certain abstract concepts that cannot be comprehended or associated with actual circuits (Ronen & Eliahu, 2000). The inability to see currents flowing through circuits in daily life and to comprehend abstract concepts leads to various misconceptions (Sengupta & Wilensky, 2009) related specifically to the understanding of current, voltage, and power consumption (Lee & Law, 2001; Engelhardt & Beichner, 2004; Sencar & Eryilmaz, 2004; Periago & Bohigas, 2005). Moreover, it is difficult to avoid these misconceptions through general instruction (Ronen & Eliahu, 2000; Tytler, 2002; Kikas, 2003; Mutimucuio, 1998).

Conventional instructions do not focus on detecting and correcting learner misconceptions on electricity (Jaakkola, Nurmi, & Lehtinen, 2005; Jaakkola & Nurmi, 2004; Liégeois & Mullet, 2002). The process of correcting learner misconceptions depends on not only the delivery of new knowledge but also the gradual integration of new concepts related to learners' existing conceptual structures (Vosniadou, 2002). New instructional strategies must be developed to assist learners in actively constructing and adapting their knowledge (de Jong & Van Joolingen, 1998). Posner, Strike, Hewson, and Gertzog (1982) stated that conceptual change develops through cognitive conflict and comprises four conditions: (1) dissatisfaction with existing concepts, (2) intelligibility of new concepts, (3) plausibility of new concepts, and (4) the ability of new concepts to solve existing problems and provide methods for future investigations. The conceptual-change learning environment may incorporate these four conditions by, at first, creating scenarios of conceptual conflict that guide learners to discover their dissatisfaction with existing concepts. Moreover, learning environment needs to manifest plausible and fruitful concept features and implement an effective instructional strategy for learners to comprehend new concepts. This study identifies three key elements for constructing a conceptual-change learning environment according to the four conceptual-change conditions: (1) an appropriate learning environment to manifest plausible and fruitful concept features, (2) an effective instructional

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strategy that assists learners to comprehend conceptual implications, and (3) construction of conceptual conflict scenarios for the adaptation and reconstruction of existing knowledge structures.

Simulation-based learning environments are appropriate for manifesting plausible and fruitful concept features. Previous studies have shown that a computer simulation conceptual learning environment that supports activities of observation and reflection helps facilitate the learning of abstract concepts (Chen, Hong, Sung, & Chang, 2011; Mzoughi, Foley, Herring, Morris, & Wyser, 2005; Dori, Barak, & Adir, 2003; Papaevripidou, Hadjiagapiou, & Constantinou, 2005). Computer simulations provide learners with real-time data related to a dynamic phenomenon and information on how certain parameters change synchronously to facilitate higher-level thinking (de Jong & van Joolingen, 1998; Ronen & Eliahu, 2000). Ronen and Eliahu (2000) suggested that simulation could assist in explaining an actual phenomenon by linking it with the implications of a conceptual model. This has led to the frequent use of computer simulations in virtual experimental environments for electricity-related curricula and experimental computer simulation learning (Bradbeer, 1999; Zacharia, 2007; Jimenez-Leube, Almendra, Gonzalez, & Sanz-Maudes, 2001; Donzellini & Ponta, 2004), as well as assisting elementary and high school students to understand electricity-related concepts (Jaakkola & Nurmi, 2008; Kukkonen, Martikainen, & Keinonen, 2009). Additionally, computer simulations can help learners understand complex abstract scientific concepts and modify learners' understanding of electric circuit concepts (Forinash & Wisman, 2005). Colella (2000) argues that computer simulation environments allow learners to observe and investigate specific models of new concepts, and to modify existing incorrect concepts.

Computer-simulated visualizations can allow learners to observe and comprehend abstract and complex concepts (Chang, Chen, Lin, & Sung, 2008; de Jong & Van Joolingen, 1998; Colaso, Kamal, Saraiya, North, McCrickard, & Shaffer, 2002). Ainsworth (2006) also argues that visualization can improve learning performance and assist learners to attain a higher cognitive level. Gordin and Pea (1995) described the prospects for visualization in education to facilitate the learning of difficult, abstract, and complicated concepts based on the usage of discrimination modes and observation processes of the human visual system. Kelly and Jones (2007) also revealed that visualization has excellent potential for learning abstract and obscure scientific concepts because of its ability to activate learner imagination for microscopic scientific phenomena and the development of corresponding concepts. Accordingly, visualization could be an effective instructional strategy for assisting learners to comprehend conceptual electronic implications. However, visualization will probably have educational value only if learners are highly motivated to perform conceptual investigations during a learning activity (Naps et al., 2003). Therefore, effective conceptual-change visualized learning environments must integrate the application of technology and an appropriate instructional strategy to motivate conceptual investigation.

Previous pedagogic studies on conceptual change investigated several instructional strategies that emphasize conflict situations between new concepts and existing knowledge structures, such as anomaly, Socratic dialogue, and prediction-observation-explanation (POE) strategies. The anomaly strategy uses unexpected events for students to produce conceptual conflict (Chinn & Brewer, 1993), whereas Socratic dialogue employs conversation that encourages learners to recall existing concepts and then guides the learner to recognize inconsistencies in their deduction process (Chang, Lin, & Chen, 1998; Chang, Wang, Dai, & Sung, 1999; Chang, Sung, Wang, & Dai, 2003; Vosniadou & Brewer, 1987). Both methods emphasize the learner-perceived conceptual conflict under an instructor's intentional direction, although passive learning activities do not necessarily empower active learner investigations (Eryilmaz, 2002; Liégeois, Chasseigne, Papin, & Mullet, 2003). Conversely, the POE strategy facilitates the reorganization of knowledge structures by exposing learners to cognitive conflict through inconsistencies between existing knowledge structures and the new concepts (White & Gunstone, 1992). The experience is a sequence of prediction, observation, and explanation activities that scaffold self-explanation in conceptual learning. The scaffolding mechanisms that prompt for self-explanation might present the greatest benefits in producing deep learning by removing misconceptions (Chi, 1996; Chi, Bassok, Lewis, Reimann, & Glaser, 1989). The POE strategy constructs a scenario of conceptual conflict for adaptation and reorganization of knowledge structures by engaging a learner to observe, comprehend, and then self-explain a new concept within an interactive learning environment.

This study incorporates the POE strategy into a computer simulation learning environment to develop a conceptual-change learning system based on the difficulties of learning electricity-related concepts and the key elements of conceptual-change learning. A computer simulation environment based on the POE strategy for developing scenarios of conceptual conflict allows learners to observe and investigate electricity-related concepts, and helps them develop new concepts to facilitate conceptual change. System development and the efficacies of correcting misconceptions and learning performance on diodes are also investigated.

Misconceptions in learning about diodes

The concepts of the diode investigated in this study comprised some conceptual contents such as "semiconductor concept of a diode", "feature of diode bias", "simplified model of a diode", and "basic circuit of a diode." The high probability of misconceptions about diodes being experienced by students who learn basic semiconductor and circuit concepts makes it important to understand these misconceptions.

In this study we have investigated the misconceptions about diodes and related concepts by reviewing the literature (Lee & Law, 2001; Engelhardt & Beichner, 2004; Sencar & Eryilmaz, 2004; Periago & Bohigas, 2005; Küçüközer & Kocakülah, 2007) and conducting a diagnostic test. The 40 questions in the diagnostic test provided by researchers and two subject-matter experts were used to collect information on misconceptions about diodes. First of all, 64 sophomores (who had previously studied diodes) were asked to answer these questions. Their answers were then analyzed to summarize all possible misconceptions held by these students. Table 1 summarizes these results, indicating that there were 7 misconceptions about "semiconductor concept of a diode," 4 misconceptions about "feature of diode bias," 7 misconceptions about "simplified model of a diode," and 10 misconceptions about "basic circuit of a diode."

Table 1. Probable misconceptions of a student who learns about diodes

Conceptual Content	Misconception Designation	Misconception
Semiconductor Concept of a Diode	M1	Confusion about the diode symbol.
	M2	Holes are the majority carriers of an N-type semiconductor.
	M3	The depletion region narrows when reverse bias is applied to a diode.
	M4	A diode's depletion region is caused by minority carriers in the P- and N-type semiconductors.
	M5	Confusion about the drift and diffusion of carriers.
	M6	No current flows through a non-conducting diode when forward or reverse bias is applied.
	M7	Reverse saturation current is affected only by temperature.
Feature of Diode Bias	M8	A diode conducts with no resistance when forward bias is applied.
	M9	Confusion about the status of a diode when forward or reverse bias is applied.
	M10	Confusion about the status of a zener diode when forward or reverse bias is applied.
	M11	A zener diode will irreversible breakdown whenever a reverse bias is applied.
Simplified Model of a Diode	M12	Disregarding internal resistance in the linear model.
	M13	No current in the parallel resistance when a diode is conducting.
	M14	Disregarding barrier voltage in the linear model.
	M15	Disregarding barrier voltage in the constant-voltage-drop model.
	M16	The barrier voltage and internal resistance are included in the constant-voltage-drop model of a diode.
	M17	The internal resistance is included in the ideal diode model.
	M18	The barrier voltage is included in the ideal diode model.
Basic Circuit of a Diode	M19	Incorrect definition of the average output voltage of a rectifier.
	M20	Incorrect definition of the RMS (root mean square) output voltage of a rectifier.
	M21	Only the positive half-cycle input passes through a bridge rectifier.
	M22	The output waveform of a full-wave rectifier is identical to the input waveform.
	M23	Only the positive half-cycle input passes through a full-wave rectifier.
	M24	Both the positive and negative half-cycle inputs pass through a half-wave rectifier (both as positive output waveforms).

	M25	The output current passing through an element in a circuit is less than the input current.
	M26	Confusion about concepts of basic series-parallel circuits.
	M27	The current passing through a zener diode is equal to the current passing through a load resistance.
	M28	No current passes through a load resistance when the breakdown voltage is applied to a zener diode.

Twenty-one of the 28 misconceptions about the concepts of a diode listed in Table 1 are related to semiconductor characteristics, bias types, elementary models, and applicable circuits. Four of the remaining seven misconceptions are attributable to incorrect analyses of basic electric current, voltage, and circuit behavior (i.e., “The output current passing through an element in a circuit is less than the input current”, “Incorrect definition of the average output voltage of a rectifier”, “Incorrect definition of the RMS (root mean square) output voltage of a rectifier”, and “Confusion about concepts of basic series-parallel circuits”), while the last three are ascribed to the interaction between fundamental concepts of current (or voltage) and diode (i.e., “No current in parallel resistances when a diode is conducting”, “The current passing through a zener diode is equal to the current passing through a load resistance”, and “No current passes a through a load resistance when the breakdown voltage is applied to a zener diode”). It can be seen that past misconceptions directly affect not only the learning of relevant concepts but also result in further misconceptions as well as learning issues due to interactions.

Conceptual-change learning activity

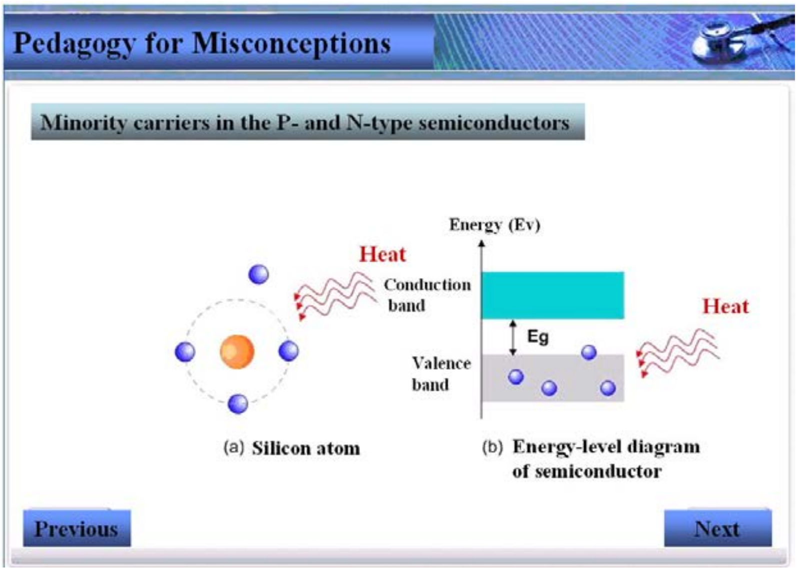
The conceptual-change activities in this system are designed to create conceptual conflict scenarios and support conceptual change through the three POE strategy stages. The activities in these three stages are described in subsections below.

Prediction

All misconceptions are listed by the system in which a learner is able to click on the corresponding buttons to enter a page for the prediction phase of the conceptual-change scenario. The system provides a learner with one question that focuses on the given misconception, and that is the first stage to guide learners to discover their dissatisfaction with existing concepts. During a prediction activity, the question and the corresponding possible answers are provided by the system. For example, the question for M4 was “How is a diode’s depletion region produced?”, and the two possible answers are “Majority carriers in the P- and N-type semiconductors produce a diode’s depletion region” and “Minority carriers in the P- and N-type semiconductors produce a diode’s depletion region.” In the prediction phase of the POE conceptual-change strategy, a learner needs to answer the question and is encouraged to deliberate any critical point affecting misconceptions about the observation activities.

Observation

The objective in the observation phase is to allow a learner to visualize abstract concepts by means of visualization of a computer simulation. As shown in Fig. 1, how minority carriers or majority carriers are generated in P- and N-type semiconductors is illustrated in the system’s demonstration along with narration. In general, the generation of majority carriers rather than minority carriers is emphasized by most instruction despite both carriers simultaneously existing in P- and N-type semiconductors. To ensure that the minority electron-hole pair is substantially understood by a learner, how both majority and minority carriers are generated is displayed visually by our system. A learner can click on “Next” on the screen to go to a follow-up learning activity after comprehending how minority and majority carriers are generated by repeated observation and deliberation.



Pedagogy for Misconceptions

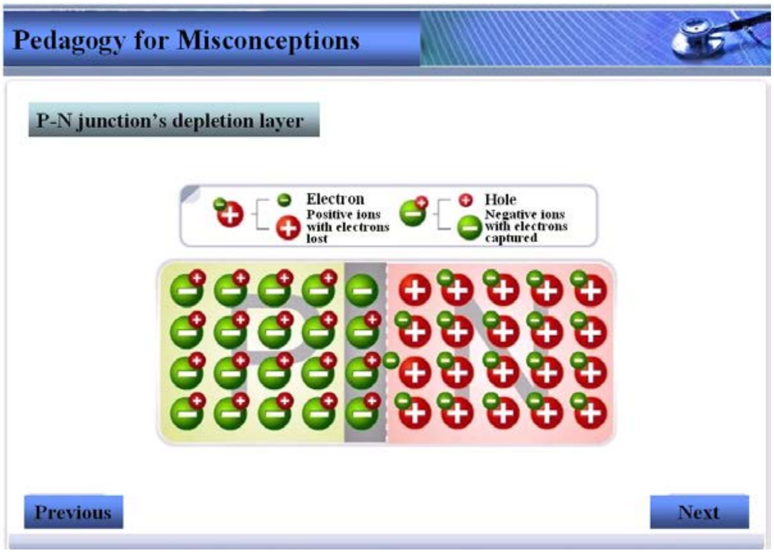
Minority carriers in the P- and N-type semiconductors

Figure 1. Visualization of how minority carriers are generated

While a learner is becoming familiar with the concept of minority and majority carriers, the process of how the depletion region is produced is illustrated in the system's demonstration. A P-N junction instantaneously produces a depletion region as follows:

1. Electrons (majority carriers) around the P-N junction diffuse to the P-type semiconductor and combine with holes around the junction (Fig. 2).
2. Atoms with five and three valence electrons around the junction form positive ions (due to one electron being lost) and negative ions (due to one electron being captured or one hole being lost), respectively.
3. An ionic layer or a so-called depletion region containing a large number of positive and negative ions develops around the P-N junction.
4. The electric field around the junction developed by positive and negative ions inside the depletion region acts against the diffusion of carriers (electrons and holes) so that an equilibrium is reached.

A learner who has a result consistent with his/her previous concept during the observation phase will draw a verified conclusion, while a learner who has a result that conflicts with his/her previous concept should click on "Back" or "Next" in order to comprehend the conflict concept through repeated observation and deliberation.



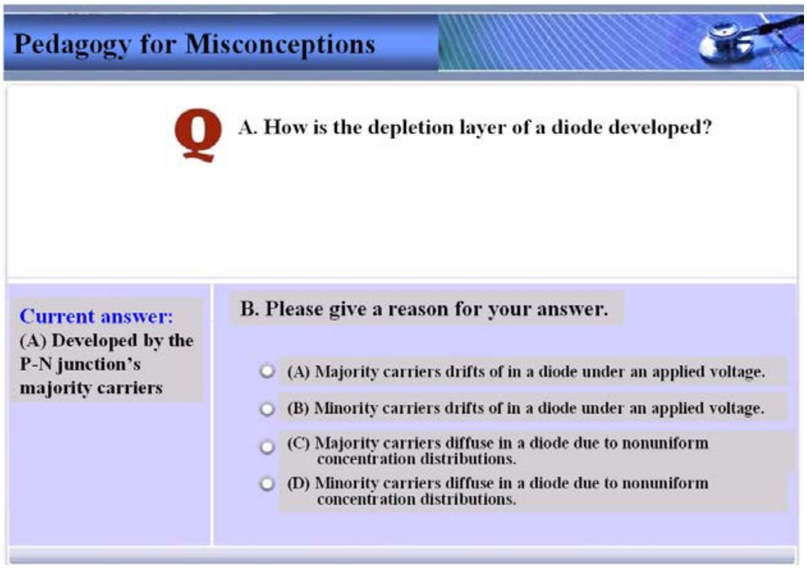
Pedagogy for Misconceptions

P-N junction's depletion layer

Figure 2. Schematic of how electrons and holes combine around a P-N junction

Explanation

After the observation activities, the explanation phase provides the opportunity for the learner to review and deliberate the rationality of the previous inference for the question “How is the depletion region of a diode developed?” The question and the learner’s previous answer are displayed on the screen again. If the learner’s misconception has been corrected in the observation phase, the correct answer would be generated. In addition, the learner needs to select the corresponding reason for the answer he/she has chosen in order to verify that the concept has been learned rather than guessed (Fig. 3). If the learner can draw correct conclusions based on the results of observation, he/she is allowed to conduct other misconception-correcting activities as needed; otherwise the learner will return to the observation phase and again review how the depletion region is produced. This procedure corrects his/her incorrect concepts in a step-by-step manner in order to resolve conceptual conflicts.



A. How is the depletion layer of a diode developed?

Current answer:
(A) Developed by the P-N junction’s majority carriers

B. Please give a reason for your answer.

○ (A) Majority carriers drifts of in a diode under an applied voltage.
○ (B) Minority carriers drifts of in a diode under an applied voltage.
○ (C) Majority carriers diffuse in a diode due to nonuniform concentration distributions.
○ (D) Minority carriers diffuse in a diode due to nonuniform concentration distributions.

Figure 3. Reasons for an answer given in the explanation phase

Experiments

This study seeks to verify the system efficacy in correcting misconceptions and improving the learning performance. The learners in the experimental group used the proposed system to perform POE conceptual-change activities, whereas those in the control group performed general Web-based learning activities by reading didactic text and graphical materials. The primary purpose of the adopted quantitative experimental design is to compare the posttest differences between the two groups. Descriptive statistical analysis also measures the effectiveness and efficiency of learning processes beyond the test score to further elucidate any distinction between groups.

Subjects

Thirty-four sophomore students from two classes majoring in engineering (mean age of 19 years) were randomly distributed into the experimental group (17 students) and the control group (17 students). All participants had been learning electronics during their freshman year and possessed conceptual knowledge on diodes.

Experimental design

This study adopts a randomized pretest/posttest experimental design. The independent variable is the group (experimental and control group), whereas the dependent variables are the posttest scores and quantity of misconceptions on diodes. Except the POE visualization and simulation system that was used only in the experimental group all the other learning materials and the instructor were the same for both groups to avoid experimental errors caused by the use of different instructional methods and learning materials. Analysis of covariance (ANCOVA) was performed using participant's pretest scores as a covariance in case random assignment did not equalize the pre-experimental knowledge between the two groups (Begg, 1990; Mohr, 1995; Sung, Chang, Hou, & Chen, 2010). The pretest scores were used to eliminate the influence of prior knowledge of diodes on the learning results (Fraenkel & Wallen, 2003; Shadish, Cook, & Campbell, 2002).

The treatment of experimental and control groups is summarized in Table 2. Thirty-four students were randomly assigned into the experimental group or the control group during the experiment. In both the experimental and control groups, participants received their own misconception list after the pretest. As expected from the treatment model, participants in the experimental group clicked on the corresponding button of one of the misconceptions in the list to enter a POE learning object; meanwhile, participants in the control group entered didactic learning material by clicking on the corresponding button of one of the misconceptions in the list. After entering a POE learning object, participants in the experimental group answered the question focusing on the given misconception, and visualized abstract concepts by a computer simulation. Following the observation activities, participants reviewed and deliberated on the rationality of the previous inference of the question and selected the corresponding reason for the chosen answer. Meanwhile, participants in the control group read the didactic learning material focusing on the given misconception. Students used the mouse to click or drag the scroll bar to read graphics and the corresponding description on the related concept of the given misconception.

Table 2. Treatment of experimental and control groups

Procedure	Period (minute)	Experimental group	Control group
Pretest	50	Conducting a pretest and receiving his/her own misconception list.	Conducting a pretest and receiving his/her own misconception list.
Instruction about using the learning tools	20	Receiving instruction about using the conceptual change learning system.	Receiving instruction about using the web-based didactic learning environment.
Learning activity	60	Conducting prediction (answer the question on the given misconception), observation (visualize abstract concepts by means of a computer simulation), and explanation (review the rationality of the previous inference and select the corresponding reason for the answer) activities for given misconceptions.	Conducting learning activities with the didactic learning material focusing on the given misconceptions. Participants can use the mouse to click or drag scroll bar to read graphics and the corresponding description about related concept of given misconceptions.
Posttest	50	Conducting a posttest.	Conducting a posttest.

The objective of such an experimental design is to compare the active learning and passive learning environment in correcting misconceptions on electronic concepts. The conceptual change strategy was used in the learning environment as a type of scaffold to help learners grasp electronic concepts. This study proposed the conceptual change scenario to move passive learning to active learning and to find better approaches of engaging students in the learning process for correcting misconceptions. To maintain equal conditions in the two groups, the learning time of participants in the experimental and control groups was equal. We also maintained different presentation forms for the content of each didactic learning material and each POE learning object of given misconceptions, but retained the same content on all related concepts.

Tools

The experimental tools used in the study (the misconception diagnosis test and the conceptual-change learning system) are described below.

Misconception diagnosis test

The diagnosis test which was used in both the pre- and posttests, is based on the procedure of the two-tier diagnosis test provided by Treagust (1988). The test comprises 28 questions in the diagnosis, with each question having two tiers: Tier 1 involves evaluating a learner's learning achievement for any concept, and Tier 2 understands the reason for a learner's answer in Tier 1. To establish expert validity, the questions were submitted to two senior electronics teachers for review and correction. The subjects in the pilot test were 30 juniors who had taken electronics at some stage and were engineering majors, for whom we obtained reliability (KR20) of .732, indicating good internal consistency of this test.

Conceptual-change learning system

The POE system development consists of three primary steps: (1) collecting information on misconceptions on diodes by the two-tier diagnostic test (misconceptions on diodes are described in Section 2); (2) designing the questions, corresponding reasons for answers, and a script of each simulation object according to each misconception with corresponding prediction, observation, and explanation learning scenarios (conceptual change learning activities are described in Section 3); and (3) developing simulation objects with corresponding scenarios and misconceptions using ASP.net and Flash development tools.

There are 28 learning objects corresponding to the 28 misconceptions on diodes in the POE system (Fig. 4). Each learning object consists of a question relating to the corresponding misconception, answers, and the reasons for each answer (each question has two or three alternative answers, each answer has two or three alternative explanations), and visual learning material that facilitates the learning of abstract concepts. Survey data of possible misconceptions held by students discussed in Section 2 form the basis of questions as well as their possible answers and explanations. The visual learning materials were categorized into four groups: (1) semiconductor concept of a diode, (2) features of diode bias, (3) simplified model of a diode, and (4) basic circuit of a diode. The visual learning materials for "semiconductor concept of a diode" and "features of diode bias" groups assist learners in comprehending abstract and complex concepts by demonstrating characteristics of P- and N-type semiconductors and P-N junctions. The remaining groups assist learners in observing the changing waveform of voltage and electric currents in the diode circuits. Narrations accompany visual demonstrations to support all visual learning materials. Learners can choose to pause or repeat the material at their own discretion throughout the process.

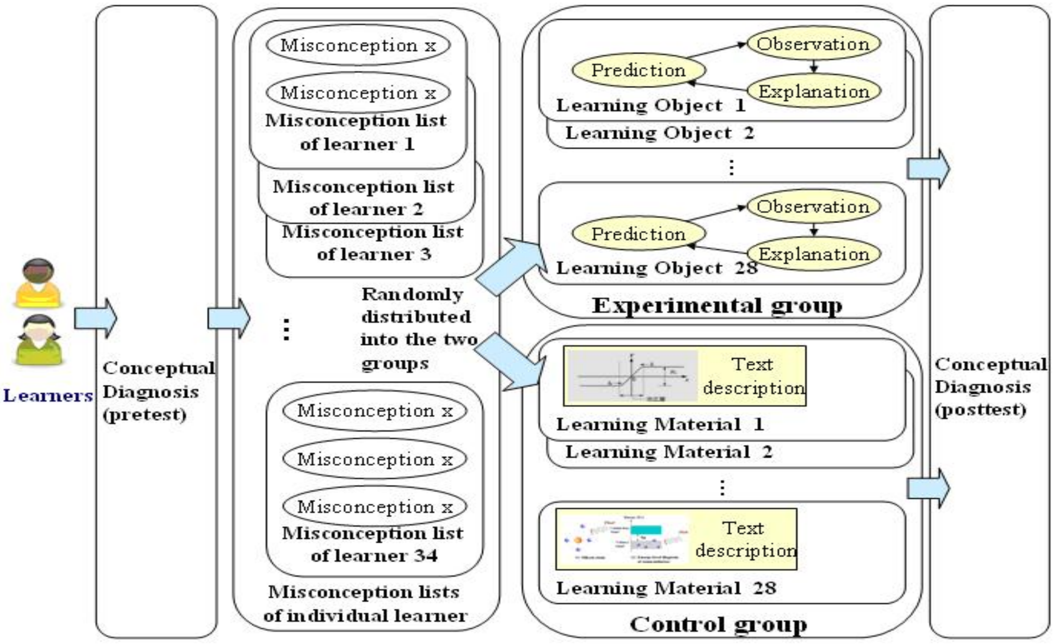


Figure 4. Experiment procedures

Procedures

All subjects in both groups (1) took the 50-minute pretest, (2) received 20 minutes of instruction about using the experimental tools, (3) performed the 1-hour learning activity, and (4) then took the 50-minute posttest. Learners underwent a pretest prior to commencement of the experiment, and misconception lists of each learner were reported at the end of the pretest. The learners were randomly distributed into the experimental group or the control group after the pretest, and received an adaptive POE learning object (experimental group) or hypertext learning material (control group) based on individual learner misconceptions (Fig. 4). Learners in the experimental groups worked with the conceptual-change learning system individually. Participants were encouraged to explore the given misconceptions on diode circuits by conducting the prediction, observation, and explanation activities in a conceptual-change learning context with simulation-based learning material. When conducting the learning activities, participants used the mouse to click or drag components to observe changes, or revised the original prediction based on the concepts discovered in the learning system to construct a final explanation. Contrasted to experimental groups, learners in the control group worked with hypertext learning material individually. Participants were also encouraged to explore the given misconceptions on diode circuits by reading the hypertext learning material. A posttest was applied after the experiments were completed.

Results

Learning performance

This study used ANCOVA in the pretest/posttest experimental design to evaluate and compare the learning performances between the two groups (Kirk, 1995). Significant posttest differences were analyzed after eliminating the influence of prior knowledge on learning performances. The pre- and posttest scores in the two groups are summarized in Table 3.

Table 3. Pre- and posttest scores [mean and standard deviation (SD) values] in the two groups

Group	N	Pretest		Posttest		Adjusted mean
		Mean	SD	Mean	SD	
Experimental	17	8.71	3.58	14.12	5.94	14.00
Control	17	8.53	3.28	11.24	5.72	11.35

Tests of the homogeneity of the regression coefficient revealed that interaction *F* between the independent variables and the covariate was .952 (*p* =.337), which confirms the hypothesis of homogeneity of the regression coefficient.

The pretest scores were used as the covariate to check the significance of differences in changes in the pre- and posttest scores in the experimental and control groups. Table 4 indicates that there were significant differences between the groups (*F* = 4.577, *p* = .040), with the learning performance in the experimental group (adjusted mean = 14.00) being superior to that in the control group (adjusted mean = 11.35).

Table 4. Summary of learning-performance data from ANCOVA

Source of Variation	SS	df	MS	*F*	*p*
Covariate (Pretest Score)	684.400	1	684.400	52.722	<.001
Between Groups	59.417	1	59.417	4.577*	.040
Error	402.423	31	12.981		

Note. *$p < .05$.

Efficacy of misconception correction

We used ANCOVA to evaluate and compare the efficacies of misconception correction in the two groups. After eliminating the influence of prior knowledge on the misconceptions of learners, the significance of differences in the posttest of the number of misconceptions about diodes was analyzed. The numbers of misconceptions in the pre- and posttests in the two groups are summarized in Table 5.

Table 5. Numbers of misconceptions in the pre- and posttests in the two groups

Group	*N*	Pretest		Posttest		Adjusted mean
		Mean	SD	Mean	SD	
Experimental	17	14.71	2.82	6.47	3.94	6.32
Control	17	14.41	3.97	8.59	4.73	8.74

Tests of the homogeneity of the regression coefficient revealed that interaction *F* between the independent variables and the covariate was .097 ($p = .758$), which confirms the hypothesis of homogeneity of the regression coefficient.

The pretest scores were used as the covariate to check the significance of differences in changes in the numbers of misconceptions in the pre- and posttest scores in the experimental and control groups. Table 6 indicates that there were significant differences between the groups ($F = 6.447$, $p = .016$), with the number of corrected misconceptions being higher in the experimental group than in the control group.

The data in Table 5 indicate that the mean number of misconceptions reduced by 8.24 in the experimental group and by 5.82 in the control group, which demonstrates that the efficacy of misconception correction was significantly higher for the conceptual-change learning system than for the general web-based learning environment.

Table 6. Summary of misconception-correction data from ANCOVA

Variance Source	SS	df	MS	*F*	*p*
Covariate (Pretest Score) Score)	406.830	1	406.830	53.097	.000
Between Groups	49.399	1	49.399	6.447*	.016
Error	237.523	31	7.662		

Note. *$p < .05$.

Analysis of misconception correction

To further characterize the efficacy of the system in correcting any misconceptions and investigate the detailed reasons for the findings, we analyzed pre- and posttest misconceptions of the experimental group. The misconceptions could be categorized into two groups: (1) those that were difficult to correct—M20, M27, and M13, with success rates of 7%, 14%, and 29%, respectively; and (2) those that were effectively corrected—M1, M6, M12, M10, M4, M2, and M14, with success rates of 100%, 100%, 100%, 90%, 89%, 83%, and 83%, respectively.

The three misconceptions that were difficult to correct were attributable to misinterpretation of the basic definition of voltage (M20) and fundamental electricity concepts affect follow-up learning of new conceptions about diodes (M13 and M27). On the other hand, the seven misconceptions that could be effectively corrected were categorized as being associated with (1) the diode symbol, elementary model of a diode, and functioning of applicable circuits of a diode (M1, M10, M12, and M14); and (2) abstract semiconductor characteristics (M2, M4, and M6). The reasons for the success rate differing with the type of misconception correction are discussed in detail in Section 6.

Learning process

The learning performance and process recorded in the learning system were analyzed to further elucidate any distinctions between the learning processes of individual learners. Three aspects of the learning performance and process were analyzed:

1. Correction rate of misconceptions: The mean ratio of misconceptions corrected by each subject (the number of corrected misconceptions after learning divided by the number of misconceptions before learning) was 58% in the experimental group and 43% in the control group.

2. Learning effectiveness: A strong positive correlation existed between the mean learning time and the mean ratio of misconceptions corrected in the experimental group (Pearson's correlation coefficient $r=.641$, $p=.006$), but there was no significant correlation in the control group ($r = –.060$, $p = .819$). This indicates that the ratio of

misconceptions corrected by a learner who spent more time in learning was proportionally high in the experimental group, whereas the learning time spent in the control group had no effect on the efficacy of misconception correction.

3. Learning sequence: The learning sequence of the four subjects in the experimental and control group are listed in Table 7. For misconception correction, learners E1 (experimental group) and C1 (control group) had high success rates, whereas learners E2 (experimental group) and C2 (control group) had low success rates. Based on the learning sequence findings, regardless of the success rates in misconception correction, the control group read the same learning material twice or even three times more (on average, the control group is 1.94 times per learning material, experimental group is 1.1 times per learning object). This required more time for the control group participants to correct the same misconception. The mean learning time spent on a single misconception was 119 s in the experimental group and 218 s in the control group.

Table 7. List of the learning sequence of four learners

subject ID	success rate of correction	learning sequence	mean learning time (second)
E1 (experimental group)	83%	Start> learning object A(226 s)> learning object B(232 s)> learning object C(122 s)> review learning object C(96 s)> learning object D(173 s)> learning object E(368 s)> learning object F(161 s)	230
C1 (control group)	67%	Start> learning material A(200 s)> review learning material A (86 s)> learning material B(241 s)> review learning material B (142 s)> learning material C(260 s)> learning material D (240 s)> review learning material D (186 s)> learning material E (185 s)> review learning material E (161 s)> review learning material E (31 s)> learning material F (269 s)> review learning material F (59 s)	343
E2 (experimental group)	20%	Start> learning object A(57 s)> learning object B(81 s)> learning object C(111 s)> learning object D(196 s)> learning object E(116 s)	112
C2 (control group)	20%	Start> learning material A(212 s)> review learning material A (17 s)> learning material B(356 s)> learning material C(165 s)> review learning material C (102 s)> learning material D (217 s)> review learning material D (74 s)> learning material E (280 s)	285

Discussion

Different approaches addressing the pedagogical challenges of simulation-based learning have recently been implemented and examined. The results indicate that the effectiveness of simulation-based learning is reduced, if learning context becomes a stepwise procedure rather than an autonomous activity (Chang, Chen, Lin, & Sung, 2008; Njoo & de Jong, 1993; Quinn & Alessi, 1994). Studies also show that learning performance is higher when learning environments enhance the manipulation mechanism in learning activities (Chen, Hong, Sung, & Chang, 2011; Naps et al., 2003). However, the question remains as to whether simulation environments that emphasize mental manipulation would enhance learning performance without hands-on manipulation. This study attempts to implement a suitable strategy that scaffolds self-explanation to increase the opportunities for learners' mental manipulation through a sequence of POE activities in a simulation-based learning environment. Moreover, different from the previous studies, this research adopted the deeper consideration in the correcting misconceptions on diodes.

The results show that the efficacy of participants' learning on diodes with the POE conceptual-change strategy was significantly greater than participants using general Web-based learning. Previous research has shown the learning efficacy and positive learning effects that visualization and computer simulation provide (Colaso, Kamal, Saraiya, North, McCrickard, & Shaffer, 2002; Jensen, Self, Rhymer, Wood, & Bowe, 2002; Luo, Stravers, & Duffin, 2005; Naps et al., 2003). Visualization through computer simulation allows learners to observe and learn abstract scientific concepts (de Jong & Van Joolingen, 1998; Colaso, Kamal, Saraiya, North, McCrickard, & Shaffer, 2002), and the interaction with multiple external representations facilitates learning at a higher cognitive level (Ainsworth, 2006). The abstract, complex, and microscopic nature of fundamental electricity and follow-up electronics concepts can be incomprehensible to learners and might present barriers to learning (Pfundt & Duit, 1991; Ronen & Eliahu, 2000). Accordingly, a simulation-based visualized learning environment that resolves these difficulties will improve learning performance. This study investigated the differences in learning performances between a conceptual-change learning system and general Web-based learning environment and also examined differences in learning effectiveness. The results indicate that the conceptual-change learning system can improve learning performance, learning effectiveness, and correct misconceptions.

Our results for the efficacy of correcting misconceptions about diodes revealed that the system with the integrated POE strategy was significantly better than the general web-based learning. In previous studies related to applications of conceptual-change instructions, changing a learner's concept driven by constructing the scenario of a new concept conflicting with the existing knowledge structure could correct the misconceptions (Chinn & Brewer, 1993; Vosniadou & Brewer, 1987; White & Gunstone, 1992). In our study, a learner who confronted any inconsistency between a predicted result and observed phenomenon was easily able to resolve a conflict that could not be explained by his/her own concept, and he/she was inclined to change his/her existing concept for any new concept learned (Liew & Treagust, 1998; Gunstone & Champagne, 1990).

To strengthen the efficacy of correction, we further analyzed those misconceptions that were difficult to correct (with success rates less than 30%). It is notable that such misconceptions (i.e., M20, M27, and M13) were correlated with the fundamental definition of voltage, circuit analysis, or the interaction between different concepts of a diode. Accordingly, the interaction between a misconception about fundamentals of electricity and a new concept about a diode can generate the new misconception. The learner's misconception about a mathematical model (or definition) or fundamental circuit analysis is still not clarified in a visualization environment. On the other hand, those misconceptions that were effectively corrected (with success rates greater than 80%) could be categorized as being related to the diode symbol or confusion about simplified model of a diode (i.e., M1, M10, M12, and M14) or to abstract semiconductor characteristics (i.e., M2, M4, and M6). In this regard, the use of visualization and demonstration produced a highly effective correction of misconceptions about the diode model, and semiconductor characteristics since they were categorized (Kelly & Jones, 2007).

From our analyses and findings, the effect of this conceptual-change learning system with the integrated POE strategy on the correction of misconceptions was better for abstract element models, and semiconductor characteristics than for some mathematical models (or definitions) and circuit analysis. For the purpose of instruction, we now consider four conditions necessary for conceptual change as argued by Posner et al. (Kelly & Jones, 2007) in the simulation-based conceptual-change learning system:

1. Dissatisfaction: A learner's dissatisfaction with existing concepts is substantially triggered by cognitive conflict constructed in the POE conceptual-change learning strategy.
2. Intelligible: A new concept displayed by a visualized computer simulation is intelligible to a learner.
3. Plausible: The rationality of a concept defined by some mathematical models is difficult to represent in a visualized observation process owing to the process of deducing and exhibiting a mathematical model not being similar to changes in a scientific phenomenon.
4. Fruitful: Fundamental misconceptions about circuit analysis that have been present for a long time might not be correctable by repeated observation and reflection alone. Therefore, it is necessary to provide a more fruitful learning environment that incorporates visualization, manipulation, and exploration contexts into the learning mechanism.

Having summarized the literature on the application of visualization to education, Sanger, Brecheisen, and Hynek (2001) stated that students' misconceptions could be substantially alleviated by representing the microscopic world using the visualization of a computer simulation; however, the visualization did not appear to satisfy the learning requirements for all kinds of learning content. This indicates that the improvement in learning performance varies with the learning content, which is consistent with the experimental results obtained in the present study. Therefore, correcting misconceptions about mathematical models and fundamental circuit analysis requires manipulative models and scientific exploration functions in the learning environment. Among all possible factors affecting the efficacy of learning performance revealed by previous studies, the common recommendation is to employ an appropriate learning strategy and promote interaction with learners for more active manipulation in addition to observation and reflection (Colaso, Kamal, Saraiya, North, McCrickard, & Shaffer, 2002; Korhonen & Malmi, 2000; Naps et al., 2003; Tversky, Morrison, & Betrancourt, 2002). Furthermore, some previous studies found that using a scientific exploration environment constructed by computer simulation allows learners to manipulate parameters and observe the resulting changes in a given concept, which not only helps learners to comprehend abstract and complexity concepts, but also helps them to construct a concrete model of new concepts, and finally to correct existing misconceptions about fundamental circuit analysis (Colella, 2000; Forinash & Wisman, 2005).

Conclusions

This study analyzed and classified misconceptions that learners can have about diodes. The results revealed both existing fundamental electricity concepts and follow-up electronics concepts, and further explored the possible difficulties confronted by a learner. The results could provide important reference data for improving the instruction of electronics and the learning performance of diodes and relevant topics.

The POE conceptual-change strategy was incorporated into the visualized learning environment of computer simulation, and empirical research revealed that by interacting with this system, learners can correct their misconceptions about diodes and substantially reinforces the learning effectiveness of online learning.

The results of this study also indicate that misconception corrections in definitions of mathematical models and fundamental circuit analysis need to be improved. Therefore, the functions of this conceptual-change learning system should be expanded, such as by providing more parameter manipulation of abstract models and a scientific exploration context, and employing mechanisms that promote interaction between a learner and the system. Besides that, we will enhance the system by providing more than three possible answers and more than three possible explanations in each question to avoid guessing by the learners.

Future studies should focus on the following issues: (1) verify the ability of the system to correct misconceptions about fundamental circuit analysis and relevant mathematical models; and (2) conduct empirical studies comparing various functions of learning environment for conceptual change.

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