

A Case Study for Comparing the Effectiveness of a Computer Simulation and a Hands-On Activity on Learning Electric Circuits

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Science education reform emphasizes innovative and constructivist views of science teaching and learning that promotes active learning environments, dynamic instructions, and authentic science experiments. Technology-based and hands-on instructional designs are among innovative science teaching and learning methods. Research shows that these two types of instructional methods designed with constructivist views of science are more beneficial for students in learning science concepts when compared to traditional science instruction. However, the comparison of effectiveness of the two approaches as well as their affordances has not been clearly addressed. This paper presents a case study comparing the effectiveness of computer-based versus hands-on instructional activity on learning electric circuits. The results show that both approaches significantly improved pre-service mathematics and science teachers' learning of electric circuits. The two types of instructional activities did not significantly differ from each other in terms of learning gains. However, hands-on activity provided ample opportunities for group interaction as well as task-related discussions. This study shows that both computer-based and hands-on activities can be effective when utilized in the right classroom environment.

Keywords: Computer-based learning, electric circuits, hands-on learning, learning environments, science education

INTRODUCTION

An effective learning environment that enhances student learning can be designed according to the principles highlighted in the National Research Council's (NRC) report entitled *How People Learn*

(Bransford, Brown, & Cocking, 2000). The *How People Learn* framework outlines four components of an effective learning environment. The first component, learner-centered environment, focuses on the knowledge, skills, attitudes, and beliefs that students bring into the classroom. The second component, knowledge-centered environment, pays attention to what is to be taught, why it is important and how well-organized structures of knowledge support critical thinking and creativity. The third component, assessment-centered environment, focuses mainly on feedback and making students' thinking visible to others to determine what students are learning or have learned. The last component, community-centered environment,

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State of the literature

- Technology integration in science instruction can be very effective if used appropriately.
- Hands-on learning can be more effective than traditional ways of learning science.
- A learning environment has to incorporate four important components: learner, knowledge, assessment, and community.

Contribution of this paper to the literature

- This paper provides a comparison between computer-based and hands-on activities in the context of electric circuits.
- Knowledge and learning gains about electric circuits for both computer-based and hands-on groups were significant and approximately the same.
- Peer interaction and collaboration was more visible in the hands-on group than it was in the computer-based group.

emphasizes the norms of the classroom, school, and other larger settings as a community.

Recent research and innovations in science teaching and learning emphasized student-centered instructional activities. Constructivism has fortunately shifted educators' perspectives on science teaching from teacher-centered to student-centered instruction (Bodner, Klobuchar, & Geelan, 2001; Eberlein et al., 2008; Moog & Spencer, 2008). In the student-centered view, teachers are perceived as facilitators rather than sources of information to be transferred to their students. New instructional techniques that are designed according to constructivist approaches can potentially encourage students to take ownership of their own learning, enhance development of critical thinking skills, and help students construct their own knowledge (Brophy, 1998; Eberlein et al., 2008; Rezaei & Katz, 2002). However, interpreting constructivism as merely engaging students through instructional practices such as hands-on or technology-integrated discovery activities and by doing so, expecting the critical aspects of learning to occur naturally would be an oversimplification of the constructivist view of how people learn. Constructivist views reverse the traditional classroom environment—where students are exposed to instructional practices as passive learners and are expected to memorize facts without understanding the meaning of those facts, to an interactive learning environment—where everyone strive to achieve learning goals. While students have critical roles in construction of their own knowledge and learning, they are not the only party in this process because learning is joint

responsibility of teachers, students, and the tools incorporated into the curriculum (Mayer, 2004). Classroom dynamics such as learning strategies, objectives, student interaction, and assessment modes, and the ways instructional tools are used should be well thought out before incorporating those tools into instructional activities (e.g., Ekmekci & Ayar, 2012; Ozel, Yetkiner, & Capraro, 2010).

There appears to be mainly three types of studies in the literature that are relevant to the topic of this paper. These studies investigate the effectiveness of technology-use, hands-on approach, and combination of both on students' learning of science concepts. In this study, we investigated the effectiveness of both types, computer-based and hands-on activities situated within a constructivist learning environment by focusing on both student learning and the learning environment itself. There is no doubt that the following questions are very important for improving science teaching and learning: How can technological tools and hands-on materials be effectively used? In what ways can these resources improve science teaching and learning? What should be the main focus when designing a science instruction with these two approaches? In this paper, we try to identify key points that should be considered when using computer-based and hands-on activities.

LITERATURE REVIEW

This section provides a brief review of the literature as it relates to computer-based and hands-on science instructions. Both computer-based and hands on activities can improve students' understanding of science concepts (Carmichael, Chini, Rebello, & Puntambekar, 2010; Ma & Nickerson, 2006; Liu, 2006). However, neither effectiveness of computer-based nor that of hands-on approaches should be taken for granted. Design principles underlie both types of instructional activities instructional activities and the role of students and teachers are among the key factors for meaningful learning experiences in science (Bransford et al., 2000), as well as the type of activity (i.e., computer-based versus hands-on).

Technology is one of the most prevalent tools complementary to innovative instructional models and it has also become one of the most important components in many aspects of our lives. Due to the prevalence of technology in our society, many educators strive to make its integration into education a reality. There are many technology-based learning environments for schools that teach science. Examples include Interactive Physics™, a computer-based Newtonian micro-world (Design Simulation Technologies, 2005-2013), PhET simulations (PhET Interactive Simulations, 2013), interactive simulation programs for physics, chemistry, biology, earth science,

and mathematics concepts (Wieman, Adams, Loeblein, & Perkins, 2010). Internet, e-mail, chat rooms, and video conferencing are other possible ways of integrating technology into science classrooms (Cook & Cook, 1998). All of these technologies can be used to effectively engage students and to promote a student-centered active learning environment that helps students take control of their own learning as promoted and supported by the current research in scientific learning (e.g., constructivist views of learning; Bransford, Brophy, & Williams, 2000; Brophy, 2011; Oros, 2007; Stone, 2012).

There are several studies showing the effectiveness of technology integration and computer use in science classrooms. Tao (2004) found that students' understanding of image formation was significantly improved through computer-based activities when used in collaborative learning environments. Computer-assisted learning programs enhance the benefits observed in such environments due to the fact that these programs target both individual learning and the joint construction of understanding (Resta & Laferrière, 2007; Tao, 2004). In a study that investigated the use of wireless laptops to enhance active learning in large classes, the focus was put on the learning environment rather than improving student learning. The results showed that the use of wireless laptops promoted active learning as well as interactions in class (Barak, Lipson, & Lerman, 2006).

One study, related to the use of technology, investigated the contribution of computer-based activities to students' learning of statistical concepts. The study showed that certain instructional modes helped students better understand correlations, while others were better at improving students' understanding of central tendency. These findings suggest that the type of activity and its quality affect student learning. The difficulty level of the topic may also impact the instructional modes. For example, some topics may be more complex and less feasible for effective computer-based activities than others (Morris, Joiner, & Scanlon, 2002). Educators can enhance students' understanding of scientific concepts by carefully selecting technological tools that are appropriate for the activity and designing idealized learning environments (National Research Council, 2011).

All these studies show that technology integration can improve students' achievement in mathematics and science, as well as their attitudes towards these subjects (e.g., Calik, 2013; Weaver, 2000). However, these improvements depend on how technology is integrated into the teaching and learning process. To best enhance student learning, technology-based or hands-on activities must be used to facilitate and align these four components of learning environments in the classroom. Computer-based activities that require "drill-practice"

types of applications, for example, do not facilitate active learning, since they hinder student creativity, which violates knowledge-centeredness (Lunts, 2001). Bransford et al. (2000) showed that the use of computer technologies is very effective at enhancing learning when they are used in the above four-component framework. This integration, though, requires very careful design. Otherwise, technological tools could become distraction rather than assisting science teaching and learning (Barak et al., 2006). In addition, there might be other challenges that teachers need to be aware of and should address when integrating technology into science instructions. These include lack of finances for the schools to purchase new technology, students' tendency to become distracted while using technology, and the amount of time it takes for them to learn the technology and pass that learning on to the students (Kumka, 2014). So, finding innovative ways of incorporating technology is necessary to allow efficient and appropriate use of technology and improve student learning.

Hands-on approach can also provide authentic learning experiences for students (Bulunuz, 2012). However, the effectiveness of hands-on approach should not be taken for granted just like technology integration (Klahr, Triona, & Williams, 2007). Learning design principles underlie hands-on instructional activities should be the main focus (Bransford et al., 2000). For example, although they provide hands-on experiences, traditional labs in which students are merely expected to follow the steps provided by a lab instructor or a textbook neglect important science teaching and learning principles. This "cookbook" type of instruction is contrary to how scientists do science and has been found to be a lot less effective than inquiry-based methods (Royuk, 2003). Hands-on approach discussed in this paper is different from cookbook type of activities performed in traditional science classrooms. Rather, it is a form of active learning in which students think and discuss the concepts related to circuits and actively perform activities.

The research also shows that combination of technology-based and hands-on approaches might be effective. Liu (2006), for example, studied the effects of a combination of hands-on and computer modeling activities, in chemistry, on student understanding of gas laws. Although the study did not pay particular attention to active learning components, it showed that computer-based activities and hands-on activities were more effective when used in combination rather than separately in terms of understanding gas laws. The combination of these activities enhanced students' understanding of the particulate and macroscopic representations of gases by giving them the opportunity to study gases not only at the macroscopic level, but

also in the virtual space of the simulation where they are able to see beyond the physical world, invisible to naked eyes, and work directly at the atomic scale in an abstract model of the system.

The effectiveness of the instructional approaches discussed herein depends on the learning theories that drive the instruction. Neither technology nor physical equipment itself should be the focus; rather, they should be used as a tool with the main focus on student learning (Barak et al., 2006; Bransford et al., 2000). Ma and Nickerson (2006) claimed that technological equipment is not enough for learning; students also learn from interactions with their peers and teachers. As Lightfoot (2005) puts it, "...technology alone does not guarantee a better learning environment. A good educational environment should be grounded in the pedagogic fundamentals and enhanced with complementary technology" (p. 209). The same applies to physical materials used under hands-on approaches. After all, computer-based and hands-on activities are the tools that should be based on learning theories and research. Technology-based and hands-on, physical tools become meaningful for teaching and learning when situated within a context in which it is used and appropriately connected to educational goals (Klahr et al., 2007; Roth, 1995).

To sum up, the literature supports the effectiveness of both technology-based and hands-on approaches. However, what is the extent of relative effectiveness of computer-based versus hands-on activities? In other words, is one approach more effective than the other in terms of students' science learning outcomes? The studies addressing these questions are scant. Carmichael et al. (2010) studied use of online simulation versus physical materials by comparing two groups of physics students studying pulley systems. One group used an online simulation that presented an experiment while the other group used a physical situation. However, the two activities not only differed in the tools that were used but they were also conceptually different. Online simulation provided an ideal state, an environment with zero friction, whereas friction played a role in the outcome of the activity in the hands-on situation.

Another important aspect is the relative affordances that each approach might provide. This paper does not only look at the relative effectiveness of each approach in terms of learning gains but it also tries to address each approach's affordances in terms of characteristics of learning environment. Therefore, the goal of this paper is to answer if there is a difference between the effectiveness of computer-based and hands-on activities in terms of improving students' understanding of circuits and what affordance each approach might provide.

METHODOLOGY

Participants

The study involved 36 college students majoring in science, technology, engineering, and mathematics (STEM) areas and pursuing secondary teaching certification in their major areas. The study took place in three sections of a major education course with a specific focus on STEM subjects in nationally-recognized secondary STEM teacher preparation program housed in a public university in central Texas, U.S.A. The number of pre-service teachers in sections A, B, and C were 16, 10, and 10, respectively. Professor A taught section A and professor B taught the remaining two sections. Students, pre-service teachers, in section A participated in a computer-based activity on electric circuits. This group of 16 students were called the computer-based group. Section B and section C students, a total of 20 students, engaged in the same activity with authentic equipment (e.g., wires, light bulbs). These students were the hands-on group. The students in all sections were almost an equal mix of science and mathematics majors, most of whom, almost 90%, were in their second year or above in the college.

Procedure

The activity took place in one class period of 75 minutes. The purpose of the activity was to help students understand how circuits in parallel and in series worked. Both instructional activities were developed according to HPL framework. The activities were learner-centered, knowledge-centered, assessment-centered, and community centered. We developed Electric Circuits Questionnaire (Appendix) and used it as pre-tests and post-tests. The questions in the instrument involved comparing the brightness of light bulbs that are parallel, series, and both parallel and series connected. The pre-test on circuit construction was given to students at the end of the previous class meeting one week before the activity took place. This reduced the possibility of familiarity with the questions when the post-test was taken after the completion of the activity.

The questionnaire had eight multiple questions. We did a pilot study and consulted with physics experts at the university level to ensure validity and reliability of the instrument. Reliability analysis revealed that the instrument had a Kuder-Richardson 20 (KR20) coefficient of .60 ($n = 36$), adequate for a small-scale study with relatively fewer number of items (Streiner, 2003).

On the activity day, students in section A launched the free software program called *Circuit Construction Kit* (Adams, Dubson, Perkins, Reid, & Wieman, 2011).

Students in the hands-on group were provided sufficient amounts of wires, light bulbs, batteries, switches, and battery and bulb sockets. In the computer-based class, students used the interactive simulation program where they could use their mouse cursors to “grab” the necessary tools to build a virtual circuit. In the activity, students were not directly asked to build parallel or series connected circuits. Instead, students were given the following four challenges that were designed so that they could understand the logic of parallel and series-connected circuits.

Challenge 1: Build a simple circuit using only one light bulb.

Challenge 2: Build a circuit using two light bulbs.

Challenge 3: Build a circuit for holiday-lights using several light bulbs but if one of lights goes out, the others should still work.

Challenge 4: Build a circuit that has two switches in a way that either of the switches would turn on or off the bulb(s). If one of the switches turns on the circuit the other should be able to turn if off.

Students in both groups were given about 45 minutes to work on the challenges in groups of 3 to 4.

Data collection and analysis

Pre-test and post-test design was used to monitor the gains of pre-service teachers’ in their understanding of circuits. Four statistical tests were conducted in total. The first two analyses compared pre-service teachers’ levels of understanding between the computer-based and hands-on groups at the beginning and at the end of the activities. Did both groups come into the instructional activity at same level? Did they leave the instructional activity with the same level of understanding? The other two statistical analyses were meant to explore the gains for each of the two groups. All statistical tests for the analysis of the pre-test/post-test results were completed using SPSS 20. All 95% confidence intervals were determined by bootstrapping (1000 samples).

Researchers took field notes while the pre-service teachers were working on the assigned activity. At least two researchers observed and took notes each class that were then analyzed qualitatively (Miles & Huberman, 1994). Researchers looked for the common terms that were used in the field notes describing characteristics of the instructional activities in all classes. Those common characteristics were then shared and confirmed with the instructors. The instructors agreed with all characteristics of their instructions that the researchers proposed.

Researchers also attended 4 classes before the class in which the research activity was completed in order to have a better understanding of the typical class

environments for the three sections. Those pre-observations revealed that instructions in all sections took place mostly in an interactive way. That is, both instructors promoted student contribution and discussions and taught the class in a constructivist way.

RESULTS

Pre- and post-tests

The total scores on the pre- and post-test provided an overall assessment of the pre-service teachers’ understanding of parallel and series-connected circuits beforehand and after the lesson, respectively. Descriptive statistics for pre- and post-test for both classes are shown in Table 1.

Table 2 shows the differences between computer-based and hands-on groups in terms of understanding of electric circuits before and after the intervention. Results showed that prior to the activities, groups did not significantly differ in understanding of circuits. The mean for the hands-on group was higher, but both the *t*-test and the bootstrapping showed that the difference was not significant at the 95% confidence level. This finding suggests that the two classes began the activities with equal knowledge of circuits. There was also no significant difference between the two groups for the post-test. The range of the 95% confidence interval is actually narrower for the post-test, suggesting the possibility that the two classes’ knowledge of circuits were closer at the end than at the beginning. The findings suggest that both computer-based and hands-on activities contributed the same amount to a student’s understanding of circuits.

Post-test means were greater than pre-test means for both groups. Repeated measures *t*-tests were calculated to determine if the difference between the tests was significant, as shown in Table 3. The results confirmed that there was a significant improvement between the pre- and post-test. Since the previous *t*-tests determined that there were no significant differences between computer-based and hands-on group, all students were grouped together to see what the overall improvement in score was. The 95% confidence interval indicated the improvement to be between 0.36 and 1.33 more questions correct. The gains in understanding of circuits had a moderate effect sizes ranging from -0.56 to -0.60 (Cohen’s *d*) implying that both computer-based and hands-on activities were effective. This improvement is likely a result of the pedagogy, learner-centered, behind the activity, rather than the delivery method, computer and hands-on. Results from *t*-tests on each individual class showed similar significant improvements.

Table 1. Descriptive Statistics of the Number of Correct Answers on Circuits Test

	n	Pre-test*				Post-test*			
		Mean	S.D.	95% CIs**		Mean	S.D.	95% CIs**	
				Lower	Upper			Lower	Upper
Computer-based	16	4.38	1.45	3.69	5.08	5.31	1.35	4.69	5.94
Hands-On	20	5.20	1.44	4.44	5.80	5.95	1.28	5.32	6.43

*Maximum possible score on pre- and post-tests: 8

** Upper and lower bounds of the 95% confidence interval were calculated by bootstrapping (1000 samples)

Table 2. Comparison of Means between Computer-Based and Hands-on Groups for Both Pre- and Post-Tests (Independent Samples t-Test)

[Computer-based] – [Hands-on]	t	df	Sig. (2-tailed)	95% CIs**	
				Lower	Upper
Pre-test	-1.70	34	0.098*	-1.67	0.19
Post-test	-1.45	34	0.156*	-1.46	0.22

* NOT Significant at 0.5 alpha level

** Upper and lower bounds of the 95% confidence interval were calculated by bootstrapping (1000 samples)

Table 3. Comparison of Means between Pre- and Post-Test Results (Repeated Measures t-Test)

[Pre-test] – [Post-test]	t	df	Sig. (2-tailed)	95% CIs ***		Effect Size****
				Lower	Upper	
All students	-3.42	35	0.002**	-1.33	-0.36	-0.57
Computer-based	-2.33	15	0.034*	-1.63	-0.19	-0.60
Hands-on	-2.45	19	0.024*	-1.35	-0.20	-0.56

* Significant at 0.5 alpha level.

** Significant at 0.1 alpha level.

*** Upper and lower bounds of the 95% confidence interval were calculated by bootstrapping (1000 samples).

**** Cohen's *d* ((0,2, 0.5): small; [0.5, 0.8): medium; >0.8: large)

Observations

Observation notes were analyzed qualitatively (Miles & Huberman, 1994). We identified the common terms that were used in the field notes describing characteristics of the instructional activities in all classes. Those common characteristics were then shared and confirmed with the instructors. The instructors agreed with all characteristics of their instructions that the researchers proposed. These characteristics were italicized henceforth.

Analysis of field notes collected during classroom observations revealed that students in the hands-on group were more *engaged in the task* than those in the computer-based group. All group members in the hands-on classes were *highly involved* in the group work. They *discussed* the activity with others and thought of possible ways to build circuits for challenges 1-4. During these *discussions* among group members, the students were able to see and *evaluate each other's thinking*. This provided many opportunities to try out different ideas.

There were more appearances of *test-revise* cycles in the hands-on group.

On the other hand, students in the computer-based group mostly worked *individually*. The main reason for this might have been that each student had a laptop in front of him or her that lead the *individual work* and caused some *distraction*. They appeared to be looking at their own screens most of the time. They were required to work in groups and to talk and discuss their results with each other, but their *interactions* within the group were limited throughout the activity. They mostly asked each other about how to use the software. Other than that, students seemed to prefer working *individually* and managing the software on their own. They were *active* in the sense that they all worked on the task and tried to complete the challenges. However, some students gave up on the task before they were done and spent their time on the internet instead of trying to solve challenges 3 and 4 which were more complex than the first two challenges and might have required *collective thinking*. From the observations it was clear that the students

needed more time and should have been informed of how essential the group work was in order to increase the *interaction* among students and improve discussions (Luangrath & Pettersson, 2012).

DISCUSSION AND CONCLUSIONS

In this study, the goal was to see if there was a difference between the effectiveness of computer-based and hands-on activities on improving students' understanding of circuits. It was determined that there were no significant differences in learning gains between students who did the activity in hands-on manner and those who did it in a computer-based environment. Therefore, the use of either hands-on and computer activities produced similar results in terms of learning gains.

The activities tested in this study did appear to improve students' understanding of circuits significantly. Both the computer-based and the hands-on conditions appeared to have approximately the same effect on student performance, according to the pre- and post-test results. This finding is supported by the prior research: there are studies in the literature showing the effectiveness of both approaches in students' science learning (Valdez, 2013).

On the other hand, student motivation and the level of interaction differed among the two groups. The hands-on students seemed more engaged in the tasks than those of the computer-based group. They were more engaged in group communication and exchanged ideas more effectively than the computer-based groups. As hands-on group interacted and communicated, students' thinking also became more visible by the instructor and researchers (Ekmekci, 2013).

Consistent with the prior research (e.g., Demir, 2011; Dominguez & Ekmekci, 2007), one could easily argue that technology and hands-on approaches both have their strengths and weaknesses. Aiming to prioritize one over the other may not be the best approach and could contribute less to the development of effective teaching methods and tools. Instead, educators should discern what aspects of each approach could be more valuable to their students and yield more effective learning depending on the topic and context. For example, if teachers want to improve students' design skills, it might make more sense for them to use hands-on activities. Similarly, if conceptual understanding is the concern then computer-based activities might work better. It should also be noted that a combination of both tools could yield better learning gains (Hmelo-Silver et al., 2008; Liu, 2006). Therefore, educators and researchers should focus on how they can synthesize new methods using the advantages of both approaches. Future studies are needed to investigate and inform about the most effective way of integrating both

approaches (i.e., computer-based and hands-on) into science classrooms.

Limitations

The course in which this study was conducted was an education course focused on STEM topics, not necessarily a physics course. The participants were college students majoring in STEM areas who were pursuing secondary teaching certification, not necessarily all physics majors. This may have affected their motivation to perform the activity. Their attitudes may have also been affected due to the fact that each student had their own computer to complete the tasks in the computer-based group. If one computer was assigned to each group, group communication and interaction might have been more visible. Students would have been encouraged to discuss the problems being presented rather than completing the task individually and moving on to other distractions (Carmichael, Chini, Rebello, & Puntambekar, 2010). What is most limiting about the study was the size of the sample and its location. With a small sample at only one location, the results of this study cannot be generalized. Further study of the activity is necessary to determine which groups of students, beyond pre-service science teachers, benefit from the activity. The evidence seems to point to the equivalency of the virtual and hands-on approaches but should be tested with other groups of students in different contexts (e.g. physics course).

Implications

Both computer-based and hands-on activities promise *learner-* and *assessment-centered* learning environments. Feedback is important in an assessment-centered learning environment, and hands-on group work creates more opportunities for students to provide feedback to their peers. Students also receive prompt feedback from the simulation. When working in a group where there is no prescribed procedure to tackle a problem, students bring their previous experiences into these activities. Student-centered learning through hands-on and computer-based activities, or the combination of both, with enough level of engagement could be very effective and sustainable because this type of learning is built on student knowledge, skills, attitudes, and beliefs (Bransford et al., 2000). The teacher can see a substantially broader range of what students know and how they learn while they are working on an inquiry-based activity. Both types of activities demonstrate the characteristics of *community-centered* learning environments. Being able to share each student's or group's work with others and seeing what other people are doing, make it possible to build a

community of practice (Bransford et al., 2000; Roth, 1995). However, technology can impede learning when it is used for non-instructional purposes during a lesson (Barak et al., 2006). Instructors should make sure that students are using the computers as a tool for learning rather than accessing material unrelated to the assignment (e.g., the students using the simulations viewed Facebook and other websites rather than completing the challenges).

Using computer simulations in place of hands-on learning does not appear to be detrimental to student learning. Indeed, in a number of studies reviewed, mentioned in the introduction section, the idealized conditions available in a virtual world appeared to equally enhance learning. Therefore, when used properly, technology can help teachers when a hands-on lab is too expensive, too long or requires too many technical skills for their students to complete the activity accurately and successfully. Alternatively, a combination of computer simulations and hands-on activities could be used to partially reduce the cost.

This study shows that both of these approaches can be effective when utilized in the right classroom environment. However, depending on the nature of activities assigned to students and how students perceive each approach, one method may be more effective than the other. For example, this study conveys that hands-on activities are more beneficial when group work is required. Future studies are needed to explore the affordances of different constructivist approaches under different learning goals.

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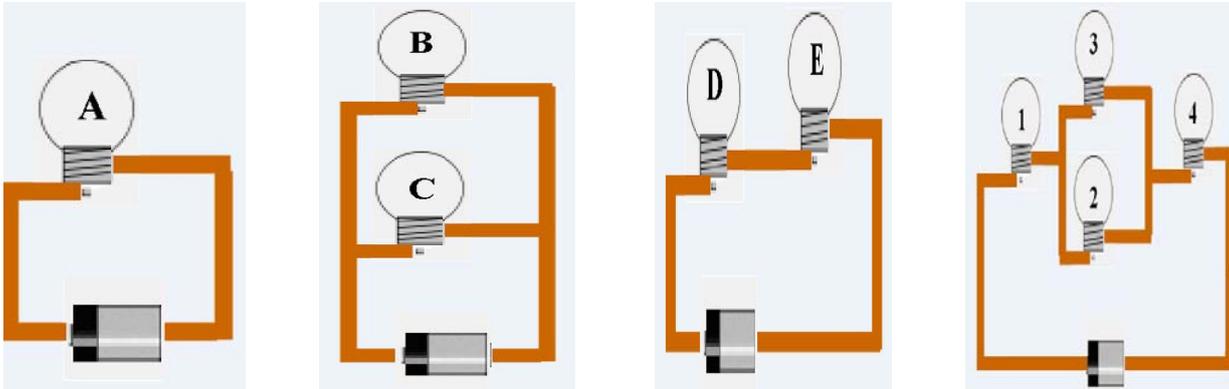
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Appendix: Electric Circuits Questionnaire

Electric Circuits Questionnaire

For these questions, consider that all batteries are identical and all bulbs are equal.



Questions 1, 2 and 3 refer to figure 1 and 2 above.

1. Compare the brightness of bulb B to the brightness of bulb C in figure 2.
 - a) B is brighter than C
 - b) B is as bright as C
 - c) B is dimmer than C
2. Compare the brightness of bulb A in figure 1 to the brightness of bulb B in figure 2.
 - a) A is brighter than B
 - b) A is as bright as B
 - c) A is dimmer than B
3. How does the brightness of bulb B change if bulb C is unscrewed opening the circuit?
 - a) B becomes brighter than before.
 - b) B becomes dimmer than before but still on.
 - c) B is turned off.
 - d) B remains as bright as before.

Questions 4, 5 and 6 refer to figure 1 and 3 above.

4. Compare the brightness of bulb D to the brightness of bulb E in figure 3.
 - a) D is brighter than E
 - b) D is as bright as E
 - c) D is dimmer than E
5. Compare the brightness of bulb A in figure 1 to the brightness of bulb D in figure 3.
 - a) A is brighter than D
 - b) A is as bright as D
 - c) A is dimmer than D
6. How does the brightness of bulb D change if bulb E is unscrewed opening the circuit?
 - a) D becomes brighter than before.
 - b) D becomes dimmer than before but still on.
 - c) D is turned off.
 - d) D remains the same as before.

Questions 7 and 8 refer to the circuit of figure 4 above.

7. Rank the brightness of the four bulbs in figure 4.
 - a) All are equally bright.
 - b) 1 is brighter than 2, 2 is brighter than 4, and 2 and 3 are equally bright.
 - c) 1 and 4 are equally bright, 2 and 3 are equally bright, and 1 is brighter than 2.
 - d) 1 and 4 are equally bright, 2 and 3 are equally bright, and 2 is brighter than 1.
 - e) 1 is brighter than 4, 4 is brighter than 2, and 2 and 3 are equally bright.

8. Rank the brightness of bulbs 1, 2, and 4 if bulb 3 is unscrewed opening the circuit.
 - a) 1, 2 and 4 will be turned off.
 - b) 2 will be brighter than 1, and 1 and 4 will be equally bright.
 - c) 2 will be dimmer than 1, and 1 and 4 will be equally bright.
 - d) 1 will be brighter than 2 and 2 will be brighter than 4.
 - e) 1, 2 and 4 will be on and equally bright.