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Using Hands-On and Virtual Laboratories Alone or Together—Which Works Better for Acquiring Knowledge and Skills?

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Abstract

Although hands-on laboratory experiments are traditionally used in schools, virtual laboratories have entered today's classrooms, due to their specific affordances. In this study, we compared the effect of using hands-on and virtual laboratories in isolation to two different combinations on middle school (7th grade) students' acquisition of conceptual knowledge and inquiry skills. Our findings indicate that using hands-on and virtual laboratories sequentially instead of in isolation gives better results for students' acquisition of knowledge and inquiry skills. This result, together with similar findings from other studies, suggests that virtual and hands-on laboratories may have complementary affordances. In the current study, no advantage was seen for either of the two different combinations used.

Keywords Virtual laboratory · Hands-on laboratory · Conceptual knowledge · Inquiry skills · Science teaching

Introduction

Laboratories have a central role in science education, and it is obvious that science cannot be taught meaningfully to students without practical experiences in school laboratories (Hofstein and Lunetta 2004; Hofstein and Mamlok-Naaman 2007). Although hands-on laboratory experiments have traditionally been used in schools, nowadays, virtual laboratories have also entered the classroom. Because each type of laboratory environment (hands-on or virtual) has its own affordances, researchers have begun to investigate the sequencing (doing the same experiment in a hands-on lab and then in a virtual lab or vice versa) and combination (doing different experiments in a hands-on lab followed by a virtual lab or vice versa) of the two laboratory environments (e.g., Sullivan et al. 2017; Toth et al. 2009; Wang and Tseng 2018).[1]

In the current study, we focused on the effects of using hands-on and virtual labs in isolation or in combination to enhance students' knowledge gains (measured as conceptual knowledge) and development of skills. In particular, we investigated the effects of these different laboratory environments on middle school (seventh grade) students' learning about the topic of electricity and development of specific inquiry skills (i.e., inferring, classification, determining variables, and designing experiments). A quasi-experimental research design that involved four conditions was used. The first and second conditions used purely hands-on and purely virtual laboratories, respectively. The third and fourth conditions used both hands-on and virtual laboratories in different combinations. All conditions followed a guided inquiry-based approach. In the hands-on laboratories, students used structured worksheets; the virtual laboratories were embedded in an online learning environment that included online tools to support students. The online learning environments were created within the Go-Lab ecosystem (see de Jong et al. 2014). The off-line and online supports were conceptually equivalent.

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[1] There is no universal terminology here. In some publications, the terms sequencing and combination are used as we do it here; in other publications, the usage is reversed, with "combination" denoting presenting the same experiment in the two types of laboratories and "sequencing" meaning that different experiments are done in each type of laboratory.

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Theoretical Framework

Laboratories in Science Teaching and Supporting the Inquiry Process

Learning by inquiry, which can be achieved through the use of laboratories, is one of the effective ways to learn in science (see, e.g., Minner et al. 2010). Activities in a science laboratory provide students with opportunities to construct their own knowledge by experimenting (Tobin 1990). Nevertheless, gaining scientific knowledge from scientific investigations in school laboratories is not an easy task (Gunstone 1991) and students should be provided with sufficient time and adequate facilities to interact with the main steps (i.e., defining problems, designing experiments, discussing findings) of the inquiry learning process (Gunstone and Champagne 1990). In inquiry-based learning environments, many students have trouble generating a hypothesis, designing and implementing a proper experiment, interpreting data, and drawing conclusions based on the results (de Jong and van Joolingen 1998). Therefore, teachers' interventions are vital in inquiry-based learning, and teachers should support their students in the various stages of inquiry learning (Polman 1999). Guidance for inquiry learning can vary from fully structured to open-ended (Hofstein and Mamlok-Naaman 2007) and can be implemented in different forms, such as paper-based worksheets or online scaffolding tools (de Jong et al. 2013; Lazonder and Harmsen 2016). The importance of guidance in inquiry-based learning environments is based on the idea that appropriate support may help students to cope with the limitations of working memory and may help them to perform processes they are not fully capable of doing by themselves (de Jong and Lazonder 2014).

Types of Laboratory Environments

Hands-on laboratory environments are traditionally and commonly used in science classes. Yet, teachers often face difficulties presenting hands-on laboratories due to restrictions related to the laboratory environment (Nivalainen et al. 2010), such as the potential dangers of chemicals, high cost of laboratory equipment and materials, liabilities of using tools or other laboratory materials, and the use of classroom hours to (repeatedly) set up traditional experiments (Scalise et al. 2011 p. 1051). To address these problems with hands-on laboratory environments, virtual laboratory environments provided by computer technology (de Jong et al. 2013) can be offered as an alternative that provides a safe and cost-efficient solution (Hsu and Thomas 2002). Another important advantage of virtual laboratories is that phenomena that cannot be seen in the real world can be made visible in virtual laboratories, such as electrical current (Kollöfel and de Jong 2013) or light beams (Olympiou et al. 2013). Besides augmenting reality in virtual laboratories, reality can also be simplified so that students can focus on key concepts and do not need to pay attention to detailed and irrelevant information (Trundle and Bell 2010). Furthermore, it is also possible to integrate scaffolding tools to support students in their inquiry learning process (de Jong et al. 2014). All of these affordances make virtual laboratories useful as a basis for learning. However, hands-on laboratory environments also have their affordances. For example, in a hands-on laboratory, touch sensory input is provided by directly touching the physical materials and apparatus (Zacharia 2015), which helps students to develop their practical laboratory skills (de Jong et al. 2013). This is important not only to enhance learning in science laboratories, but also to develop students' psychomotor abilities (Kontra et al. 2015).

Combining Hands-On and Virtual Laboratories

Recently, studies have focused on using hands-on and virtual laboratories in a combination or in sequence, because well-designed combinations or sequences of the two laboratory environments result in greater understanding when compared to using one type of environment alone (Jaakkola and Nurmi 2008; Olympiou and Zacharia 2012; Wang and Tseng 2018; Zacharia and Michael 2016). Nevertheless, how to combine the two types of laboratories in teaching contexts is still under discussion. Toth et al. (2014) stated that the combination of hands-on and virtual laboratories should be first the virtual and then the hands-on laboratory. They claimed that virtual laboratory environments offer opportunities for students such as simplification and augmentation that make them more appropriate for teaching basic concepts about the topic. Learning fundamentals of the topic via a virtual laboratory and then taking advantage of a hands-on laboratory later might enable students to gain deeper and more complex understandings. Similarly, Zacharia and de Jong (2014) concluded that a virtual laboratory should precede the hands-on laboratory environment. They investigated different combinations of laboratory environments for teaching concepts related with electricity for undergraduate students, and stated that not all hands-on and virtual laboratory environment combinations have the same impact on students' conceptual knowledge. They claimed that a virtual laboratory is more appropriate for acquiring key concepts since it provides instant feedback, which facilitates learning. They also claimed that progressing through virtual laboratories first may help students to acquire process-related skills they need for working with hands-on laboratories later on. In another study, Sullivan et al. (2017) designed two different laboratory combinations, hands-on followed by virtual laboratory or virtual laboratory followed by hands-on laboratory, and compared middle school students' resulting understandings about physics concepts related to pulleys. These authors concluded that they could not find unequivocal evidence that one combination was better than the other. Similarly, based on their study, Chini et al. (2012) claimed that there are no differences between different combinations of laboratory environments for teaching pulleys in the university physics class. However, in another study done by Smith and Puntambekar (2010), it was concluded that middle school students who used a hands-on laboratory environment followed by a virtual laboratory environment showed better achievement regarding the topic of pulleys than the students who followed the reverse order.

These studies show that although it is not easy to determine the most effective combination of different types of laboratory environments, there are some indications that student learning benefits from offering virtual laboratories first.

Research Questions

In this study, we compared the use of hands-on and virtual laboratory environments in isolation and in different combinations with respect to middle school students' knowledge and skills acquisition. Studies about usage of different laboratory environments in a combination have generally been done with university students. It is difficult to find studies done with middle school students and such studies so far have had conflicting results. Furthermore, these studies just compared the order of different laboratory environments. They did not involve laboratory environments alone to compare with combination forms of laboratory environments. The following research question was investigated in the current study: Do seventh grade middle school students who learn about the domain of electricity in a pure hands-on laboratory, in a pure virtual laboratory, or in an alternating combination of these laboratory environments, differ in their acquisition of conceptual knowledge and inquiry skills?

Method

Participants

Participants in the study were seventh grade students from a public school in Turkey. The school was equipped with a good internet connection and housed a science laboratory, which enabled convenient implementation of both types of laboratories. The science teacher involved, who taught the students in all four conditions, had more than 20 years of experience in science teaching. There were a total of 143 participants, who came from four different classes; their ages were between 12 and 14. A quasi-experimental research design was used in the study, with students assigned to condition by classes; the classes were coded as HHH, VVV, VHV, and HVH, in which H stands for "hands-on" and V for "virtual" and the sequence of the letters indicates the sequence in which the labs were offered. Students' distribution over conditions is as follows: 33 students in HHH, 34 students in VVV, 39 students in VHV, and 37 students in HVH. All of the students had prior experience with computers or tablets.

Instruments

Multiple-Choice Conceptual Knowledge Test

The multiple-choice conceptual knowledge test was developed by Sencar Tokgöz (2007). This test involves 28 questions; 22 are multiple-choice questions (each question has four choices), three are true/false questions, and the last three are matching questions. The questions on the test are about electrical circuits, serial and parallel circuits and measuring potential difference, current, and resistance (for some examples of questions, see Appendix 1) and asked for students' conceptual knowledge of the domain. Each correct answer was given one point. Possible scores therefore varied between 0 and 28. Cronbach's alpha coefficient was 0.80 for the conceptual knowledge posttest.

Open-Ended Conceptual Knowledge Test

The open-ended conceptual knowledge test (for some examples of questions, see Appendix 2) was developed for this study in order to diagnose middle school students' misconceptions about the domain of electricity. The difference between the multiple-choice conceptual knowledge test and open-ended conceptual knowledge test is that the latter was intended to measure students' deeper understandings by having them make drawings themselves. Objectives from the unit on electricity in the seventh-grade science curriculum were considered when developing the test in order to ensure content validity. A researcher with a bachelor's and a master's degree in physics education and a science teacher examined and reviewed the test in terms of content validity. The adapted form of the test was piloted with 24 seventh grade students. Terms that could cause misunderstandings were revised according to students' feedback. Table 1 shows a number of questions from the final version of the test and the corresponding topics and their objectives. The test involves six open-ended questions, which require drawing circuits, analyzing graphs, and writing explanations.

Table 1 Classification of questions in open-ended conceptual knowledge test

Objective	Topic	Questions
Students are able to explore and to draw how to design serial and parallel circuits.	Differences in bulbs' brightness in serial and parallel circuits. Batteries provide electrical energy to the circuits.	Q1a, Q1b, Q4
Students are able to connect an ammeter to a circuit and can read its measurements and know its units.	Function of ammeter in a circuit.	Q2, Q5
Students are able to connect an ohmmeter to a circuit and can read its measurements and know its units.	Function of ohmmeter in a circuit.	Q2, Q5
Students are able to explore the relation between voltage and current by designing experiments.	Adding batteries to serial and parallel circuits.	Q6
Students are able to correlate the different brightness of bulbs in serial and parallel circuits with the resistance.	Adding or extracting bulbs to (or from) serial and parallel circuits.	Q3

Students' answers were coded as fully correct, showing partial understanding, or showing misunderstanding (no answer was coded as misunderstanding). In order to determine inter-rater reliability, two independent coders coded 20% of the open-ended conceptual knowledge test individually. The percentage of agreement based on the two raters' coding was 81.3%. The remaining tests were coded by only one rater.

For further analysis of the data from the open-ended conceptual knowledge test, these qualitative data were transformed into quantitative data. Fully correct answers, which involved meaningful explanations and/or correct drawings, were given 2 points. Partial understanding responses, which showed a correct result with wrong explanation or partial (deficient) drawings, were given 1 point. Misunderstandings (no answers or wrong responses) were given 0 points.

Inquiry Skills Test

The inquiry skills test was developed by Aydoğdu (2009). The test includes 28 questions (for examples of questions, see Appendix 3) and is intended to measure students' basic inquiry skills (e.g., observation, classification, prediction) and higher-order inquiry skills (e.g., forming hypothesis, determining/checking/changing variables, designing experiment) through multiple choice questions related to topic of electricity. Cronbach's alpha coefficient was 0.96 for the inquiry skills posttest.

Research Design and Implementation

Because we wanted to perform our study in a real school context, we followed the organization used in the unit on electricity in the students' curriculum and divided the instructional material into three sections. The first section addressed a basic closed circuit and serial and parallel circuits. The next section involved how to add an ammeter and voltmeter to the serial and parallel circuits. The last section of the unit treated Ohm's law. The lesson plans for the students that included the topic of electricity, how to use virtual laboratories in a classroom environment, some basic technical issues about the virtual laboratory platform, and the laboratory worksheets that were used in the hands-on laboratory environment were all discussed with the science teacher.

The four classes were assigned randomly to one of the conditions from the study. The class coded as HHH was fully taught in the science laboratory and did all experiments within the hands-on laboratory. The class coded as VVV was totally taught in a computer laboratory and students from this class performed all experiments with a virtual laboratory. For the other two classes, we created the two possible different combinations of alternating hands-on and virtual laboratories. The class coded as VHV was taught in the virtual laboratory environment for the first and the last sections of the unit and was instructed in a hands-on laboratory for the middle section of the unit. The class coded as HVH was taught in a hands-on laboratory environment for the first and the last sections of the unit and used a virtual laboratory environment for the middle section of the unit.

After the classes had each been assigned to a condition, the three different tests were taken as pretests. Exercises with virtual laboratory activities were also done for the classes coded as VVV, VHV, and HVH. The aim was to introduce virtual laboratories for the students in these classes. The students worked with similar labs and learning environments as in the real laboratory. Their questions about the virtual laboratory environments were answered and some basic technical information was provided. The virtual laboratory platform was not introduced to the students in the HHH condition. The students in all four classes were divided into groups of three, using the alphabetic ordering of the students. After this, students worked in their groups with the combination of labs designated for their class's assigned condition. The first and second sections of the unit each took 1 week and the third section of the unit lasted for 2 weeks. Science classes were 4 h per week. At the end of the study, the same tests were taken as the posttests. The pretests and posttests were taken on an individual basis, and did not count for the students' official results. They were administered in the first and last weeks of the study; we assumed that the duration of the study (6 weeks) and the total number of questions on the tests prevented students from memorizing the questions.

The same science teacher instructed each class. The researcher observed all the classes and only interfered when technological problems occurred. Paper-based laboratory worksheets were used for the classes that were taught in the hands-on learning environment; online scaffolding tools were used for the classes that were instructed in the virtual laboratory environment.

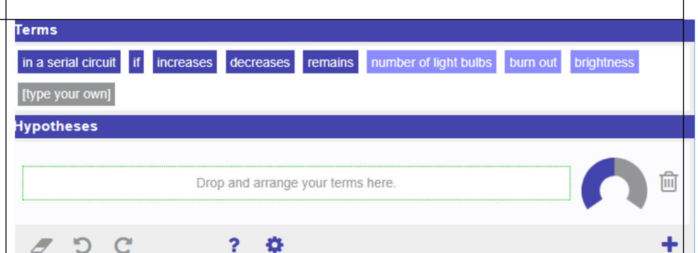
Guided inquiry-based learning was used in the study. All classes were taught with the same teaching approach. The inquiry cycle used involved the phases of orientation, hypothesis generation, experimentation, conclusion, and evaluation (de Jong 2006). In the hands-on laboratory environment, the science teacher acted as the main source of guidance supporting the students; a laboratory worksheet also provided scaffolding for them. In the virtual laboratory environment, three online scaffolding tools were used in the inquiry cycle (see the Go-Lab Sharing and Authoring Platform 2015; Pedaste et al. 2015). Students in all classes received scaffolds for the hypothesis generation process, according to their assigned condition. If they were assigned to be in the virtual laboratory environment, an online hypothesis scratchpad was provided for them. For the students in the hands-on laboratory environment, a paper worksheet was provided for generating hypotheses. For the experimentation phase, a brief demonstration video that showed how to design an experiment was provided to the students in the virtual laboratory environment. In the hands-on laboratory environment, the science teacher guided students in how to create circuits. And lastly, a conclusion tool that enables learners to see the group's hypotheses and the result of their experiment(s) and gives a space to write their conclusion was provided for students in the virtual laboratory environment. For the students in the hands-on laboratory environment, the laboratory worksheet contained a separate space for the students to write what they concluded about their hypotheses in relation to the findings from their experimentation. Figure 1 shows, as an example, the hypothesis scratchpad as used in the virtual laboratory and its equivalent as used in the hands-on laboratory.

Laboratory worksheets were distributed at the beginning of the study for the students in the HHH, VHV, and HVH classes. Similarly, each group in the VVV, VHV, and HVH classes had an account in the virtual laboratory environment platform. The students in the groups in the VHV and HVH classes used both the worksheet and the online tools, according to the type of laboratory they were currently using.

Data Analysis

The same approach was used for the analysis of the scores from the multiple-choice conceptual knowledge test and the inquiry skills test. First, a one-way ANOVA was used for comparing the pretest scores of the four classes. After

Fig. 1 Hypothesis scratchpad used in the virtual laboratory and its equivalent in the laboratory worksheet (the concepts in the figure translated from Turkish)

Laboratory Environment	Scaffolding Tool
Hypothesis Tool as a Laboratory Worksheet (Hands-on Laboratory)	**Terms** - in a serial circuit - number of light bulbs - if - burn out - decreases - remains - brightness - increases (You are also free to develop hypothesis with your own words.) Write your hypothesis into the given box.
Online Hypothesis Scratchpad (Virtual Laboratory)	

that, paired samples t tests were used for comparing the pretest and posttest scores of the four classes. This procedure was followed to determine whether a class improved their conceptual knowledge (measured by the multiple-choice test) and/or inquiry skills significantly. And last, an ANCOVA was used for comparing the posttest scores of all classes, taking the relevant pretest scores as covariate. Because of the fact that the data gathered from open-ended conceptual knowledge test were not normally distributed, non-parametric tests were used for comparing those scores. First, a Kruskal-Wallis test was used for comparing the pretest scores of the four classes. Then, Wilcoxon tests were implemented for comparing the pretest and posttest scores of the four classes. Finally, an ANCOVA was used for comparing the posttest scores of all classes.

Results

The results for the multiple-choice conceptual knowledge test are presented first. Then, the results for the open-ended conceptual knowledge test are given. Finally, the results for the inquiry skills test are presented.

The Multiple-Choice Conceptual Knowledge Test

The multiple-choice conceptual knowledge test was administered as both pretest and posttest. Table 2 and Fig. 2 display descriptive results of this test.

All classes' pretest scores were compared in an ANOVA. Two main assumptions (normal distribution and homogeneity of variances) were checked before conducting the ANOVA.

ANOVA results showed that there were no differences among the classes on the pretest ($F(3, 138) = 2.108$; $p = 0.102$). Separate paired samples t tests showed that each class increased its score on the multiple-choice conceptual knowledge test significantly (HHH, $t(32) = 7.17$, $p = 0.000$; VVV, $t(33) = 5.94$, $p = 0.000$; VHV, $t(38) = 6.58$, $p = 0.000$; HVH, $t(36) = 11.70$, $p = 0.000$). An ANCOVA using the pretest score as covariate indicated that the classes differed on their posttest scores ($F(3, 138) = 6.024$; $p = 0.001$, partial $\eta^2 = 0.12$). In order to understand which class's posttest scores were reliably different from the other(s), post hoc tests were performed. Post hoc analysis revealed that posttest scores of the classes in which hands-on and virtual laboratories were alternated (VHV and HVH) were higher than for the class that followed only virtual laboratories (VVV); for the comparison between VHV and VVV, $p = 0.000$, $d = 0.94$, and for the comparison between HVH and VVV, $p = 0.015$, $d = 0.87$.

To sum up, all classes improved their conceptual knowledge (measured with multiple-choice questions) about the topic of electricity significantly. Furthermore, the overall picture suggested by these comparisons is that using hands-on and virtual laboratories in a combination provides a better learning opportunity than using virtual laboratories alone for teaching about electricity and that replacing some of the traditional hands-on laboratories with ones using virtual components resulted in similar results as using hands-on laboratories alone.

The Open-Ended Conceptual Knowledge Test

The open-ended conceptual knowledge test was also implemented as a pretest and posttest. The correlation between the open-ended and multiple-choice conceptual knowledge posttests was 0.128. This non-significant correlation means that the two tests generally measured something different. The open-ended conceptual knowledge test involved six questions. Table 3 and Fig. 3 show descriptive results for the open-ended conceptual knowledge test for all classes.

Due to non-normal distribution of the data, we used non-parametric tests for analysis in which the pretest scores were involved and, since in this case necessary conditions were not violated, parametric tests for the posttest.

Kruskal-Wallis test results showed that there were no differences between the classes at the pretest ($H = 6.075$; $p = 0.108$). At the following stage, Wilcoxon tests showed that each class increased its score on the open-ended conceptual knowledge test significantly (HHH, $Z = -4.552$, $p = 0.000$; VVV, $Z = -4.403$, $p = 0.000$; VHV, $Z = -5.200$, $p = 0.000$; HVH, $Z = -5.112$, $p = 0.000$). For the posttest scores, an ANCOVA was performed using the pretest score as a covariate. ANCOVA results demonstrated that the classes differed on the posttest scores ($F(3, 138) = 3.291$; $p = 0.023$, partial $\eta^2 = 0.06$). In order to understand

Table 2 Average scores for the multiple-choice conceptual knowledge test, by class (max = 28)

	HHH class ($n = 33$) mean (SD)	VVV class ($n = 34$) mean (SD)	VHV class ($n = 39$) mean (SD)	HVH class ($n = 37$) mean (SD)
Pretest	9.60 (2.70)	9.32 (2.22)	10.53 (2.95)	9.21 (2.21)
Posttest	14.42 (3.37)	12.76 (2.89)	16.10 (4.08)	15.18 (2.67)
Difference	4.82 (3.86)	3.44 (3.37)	5.56 (5.27)	5.97 (3.10)

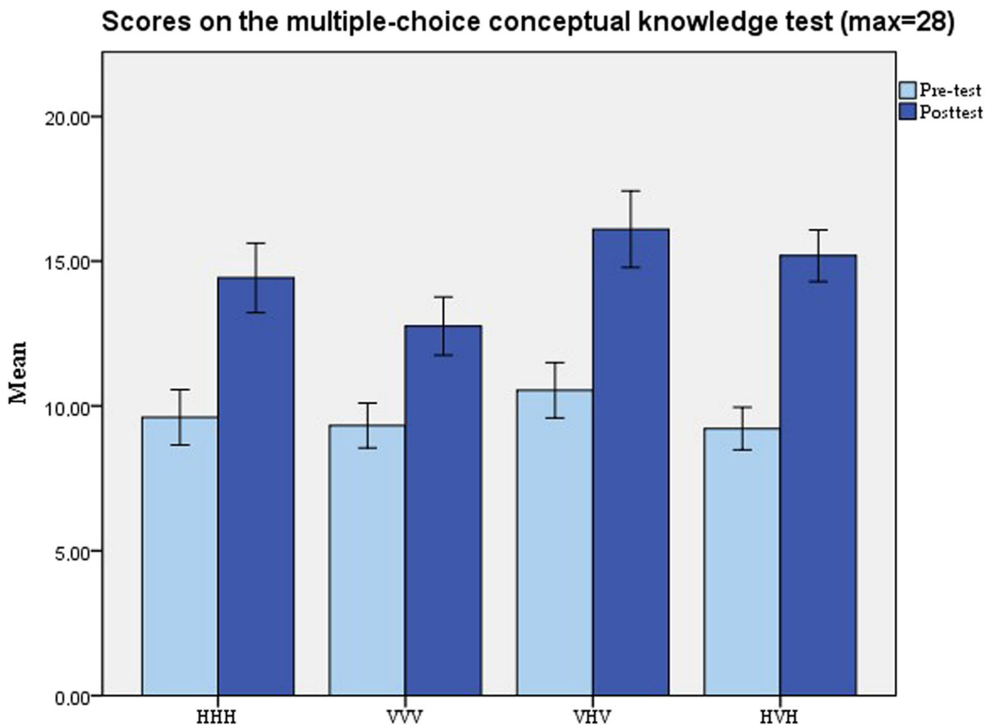


Fig. 2 Multiple-choice conceptual knowledge test scores at pretest and posttest, by condition (error bar 95% CI). *For the comparison between VHV and VVV, $p = 0.000$, $d = 0.94$, and for the comparison between HVH and VVV, $p = 0.015$, $d = 0.87$

which class's posttest scores were reliably different from the other(s), post hoc tests were performed. Post hoc analyses revealed a significant difference between the posttest scores for the VHV class and the VVV class ($p = 0.000$, $d = 0.60$, the VHV class had the higher score for open questions conceptual knowledge). This finding supports the view that using virtual laboratories alone does not yield successful outcomes as well as using different laboratory formats in a combination. Furthermore, students' pretest and posttest scores were further compared using Wilcoxon tests, with respect to three major topic categories (serial and parallel circuits, ammeter and voltmeter, and Ohm's law). For the first topic, serial and parallel circuits, the findings were as follows: for HHH, $Z = -3.904$, $p = 0.000$; for VVV, $Z = -4.522$, $p = 0.000$; for VHV, $Z = -4.920$, $p = 0.000$; for HVH, $Z = -4.740$, $p = 0.000$. For the second topic, adding ammeters and voltmeters to circuits, the results were as follows: for HHH, $Z = -4.448$, $p = 0.000$; for VVV, $Z = -3.888$, $p = 0.000$; for VHV, $Z = -5.358$, $p = 0.000$; for HVH, $Z = -4.651$, $p = 0.000$. Lastly, for the third topic, Ohm's law, the results were as follows: for HHH, $Z = -2.460$, $p = 0.014$; for VVV, $Z = -2.055$, $p = 0.040$; for VHV, $Z = -3.883$, $p = 0.000$; for HVH, $Z = -3.206$, $p = 0.001$. Results based on the analysis by topic category revealed that students in all conditions developed their conceptual knowledge for all three topics.

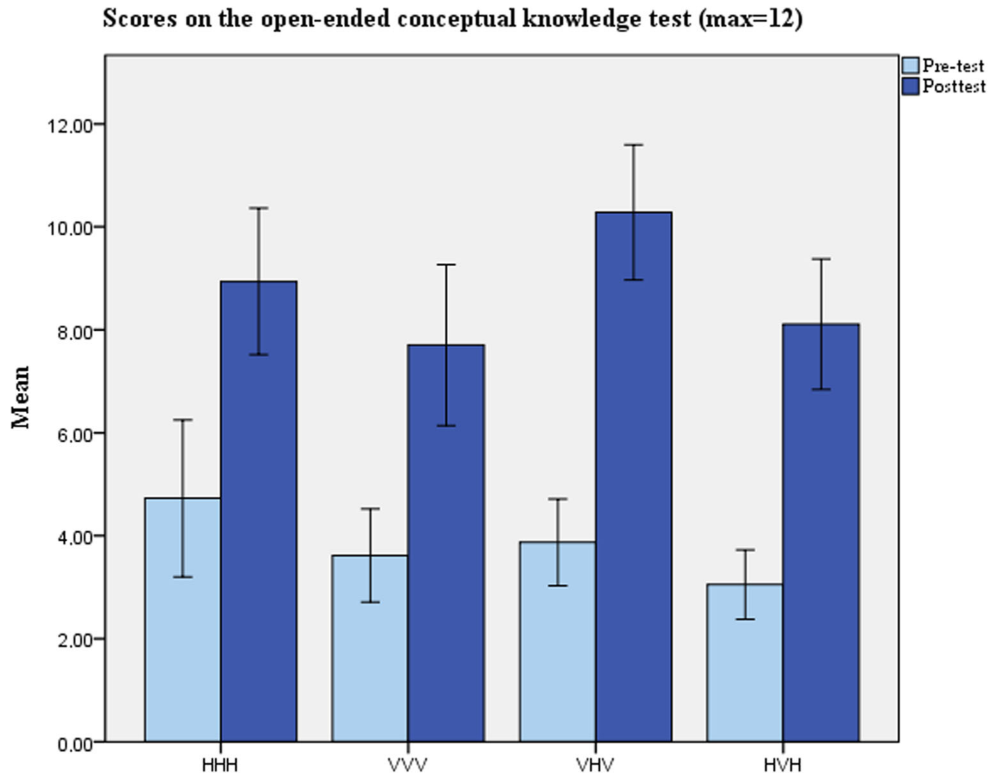
Students' misconceptions about electricity were also investigated. Table 4 shows students' misconceptions about electricity from pretest to posttest. The number in the table shows the number of students with the corresponding misconception in that class. The percentage between brackets shows the percentage of the students in that class.

Table 4 shows that students' misconceptions about closed electrical circuits and connecting batteries to each other were removed over the course of the study. In addition, students' misconceptions about drawings of parallel circuits and adding ammeters and voltmeters to circuits diminished. Nevertheless, Ohm's law still seemed to be one of the difficult topics for students. The number of students who answered the questions about Ohm's law

Table 3 Average scores for the open-ended conceptual knowledge test, by class (max = 12)

	HHH class ($n = 33$) mean (SD)	VVV class ($n = 34$) mean (SD)	VHV class ($n = 39$) mean (SD)	HVH class ($n = 37$) mean (SD)
Pretest	4.73 (4.30)	3.62 (2.59)	3.87 (2.60)	3.05 (2.03)
Posttest	8.94 (4.00)	7.71 (4.48)	10.28 (4.04)	8.11 (3.81)
Difference	4.21 (3.28)	4.09 (3.92)	6.41 (3.85)	5.06 (3.26)

Fig. 3 Open-ended conceptual knowledge test scores at pretest and posttest, by condition (error bars 95% CI). *For the comparison between VHW and VVV, $p = 0.000$, $d = 0.060$



correctly was not as high as for other questions. This might be because questions about Ohm's law required higher-order thinking skills such as analyzing the correlations among variables or interpreting a graph.

For the misconception about adding light bulbs incorrectly to create parallel circuits, students in the HVH and VHV conditions improved their misconceptions more than those in the other two classes. Similarly, for the other misconception about adding a voltmeter in serial or adding an ammeter in parallel in an electrical circuit, students in the HVH condition showed greater improvement than those in the other classes. The number of students who held a

Table 4 Students' misconceptions about electricity from pretest to posttest, by class

Misconceptions	Pretest				Posttest			
	HHH ($n = 33$)	VVV ($n = 34$)	VHV ($n = 37$)	HVH ($n = 39$)	HHH ($n = 33$)	VVV ($n = 34$)	VHV ($n = 37$)	HVH ($n = 39$)
Adding light bulbs incorrectly to create parallel circuit (Q1b, Q4)	12 (36%)	11 (32%)	13 (33%)	23 (62%)	6 (18%)	5 (15%)	3 (7%)	3 (9%)
Incomplete electrical circuit (Q1b, Q4)	1 (3%)	1 (3%)	2 (5%)	4 (%11)	–	–	–	–
Adding batteries in the wrong direction to electrical circuit (Q4)	1 (3%)	–	1 (3%)	2 (5%)	–	–	–	–
Adding voltmeter in serial or adding ammeter in parallel in electrical circuit (Q2, Q5)	6 (18%)	7 (21%)	5 (15%)	11 (30%)	2 (6%)	4 (12%)	2 (5%)	1 (3%)
Voltage, resistance and electrical current are directly proportional with each other (Q3)	1 (3%)	4 (12%)	3 (9%)	1 (3%)	1 (3%)	2 (6%)	1 (3%)	1 (3%)
Ohm's law is R = I × V or I = V × R. (Q3, Q6)	2 (6%)	–	–	2 (6%)	1 (3%)	–	–	–
Electrical current is intensity in an electrical circuit. (Q3)	5 (15%)	–	–	–	–	–	–	–
Increased resistance in a circuit causes burning out of the bulbs in the circuit. (Q3)	–	1 (3%)	–	–	–	–	–	–
If resistance in a circuit is high, then the potential energy of that circuit is high. (Q3)	–	1 (3%)	–	–	–	–	–	–

misconception about relations among voltage, resistance, and electric current decreased more in the VVV and VHV conditions than in the other two classes. Furthermore, two students in the VVV condition had other misconceptions about electricity at the beginning of the study, which were both corrected during the study.

The Inquiry Skills Test

For the inquiry skills test, a similar procedure was followed as for the multiple-choice conceptual knowledge test. The test was implemented as both pretest and posttest. Table 5 and Fig. 4 show descriptive results of this test.

The classes' pretest scores were compared with each other through an ANOVA after checking the assumptions. Results showed that there were no differences among the classes at the pretest ($F(3, 138) = 2.118$; $p = 0.101$). Separate paired samples t tests showed that students in the VVV, VHV, and HVH classes increased their scores on the inquiry skills test significantly but those in the HHH condition did not (HHH, $t(32) = 1.89$, $p = 0.068$; VVV, $t(33) = 2.46$, $p = 0.019$; VHV, $t(38) = 4.07$, $p = 0.000$; HVH, $t(36) = 4.40$, $p = 0.000$). An ANCOVA was done for students' inquiry skills posttest scores, using the pretest score as a covariate. The finding indicated that the classes did not differ on the posttest scores ($F(3, 138) = 2.390$; $p = 0.071$, partial $\eta^2 = 0.05$). This finding showed that the use of either the hands-on or virtual laboratory was equally effective in developing students' inquiry skills, across all conditions.

Discussion

In the current study, we investigated the effectiveness of the use of different laboratory environments for middle school students' development of conceptual knowledge and skills. The results for the multiple-choice conceptual knowledge test showed that the students who followed alternating combinations of different laboratory environments (VHV and HVH conditions) gained more conceptual knowledge than those in the VVV condition. Similarly, findings based on the open-ended conceptual knowledge test demonstrated that students in the VHV condition gained more conceptual knowledge than those in the VVV condition. These results indicate that using hands-on and virtual laboratory environments in alternation should be preferred over using the virtual laboratory alone. As students in the VHV condition spent 12 h in the virtual lab and 4 in the hands-on lab, and for HVH, this was the other way around, it seems that it is not the number of hours that mainly counts, but the combination per se. These results are in line with other studies, for example, Olympiou and Zacharia (2012) and Zacharia and Michael (2016), but also differ from results from other studies, such as Zacharia and Olympiou (2011), who found that combinations of different laboratory environments were equally effective as single laboratory environment. These differing results are puzzling and an explanation may be found in differences in the domain and/or students involved. For example, in terms of domain and participants, in the study performed by Olympiou and Zacharia (2012), undergraduate students were involved and the topic was light and color. These authors found that combinations of virtual and hands-on laboratories enhanced students' conceptual knowledge more than the use of a single representation. On the other hand, Zacharia and Olympiou (2011) implemented another study with undergraduate students, based on the topic of heat and temperature, and they did not find a significant difference in effects among hands-on, virtual, hands-on then virtual, and virtual then hands-on conditions in their study. How different combinations of students and domain characteristics may influence the results should be the subject of further research. An additional explanation may possibly be found in the level of experience that students have with virtual laboratories, which may have an impact on their ability to learn from virtual learning environments (Chini et al. 2012). In our case, for example, students had no prior experience with learning from virtual laboratories.

Another important topic regarding combinations of different laboratory environments concerns the sequencing of hands-on and virtual laboratories. In the current study, in order to investigate whether different combinations of the laboratory environments work better, two different combinations of the laboratory environments were presented. Our findings showed no difference between the different combinations in terms of middle school students' learning about the topic of electricity. Although there are studies that have found that a hands-on then virtual

Table 5 Average scores for the inquiry skills test, by class (max = 28)

	HHH class ($n = 33$) mean (SD)	VVV class ($n = 34$) mean (SD)	VHV class ($n = 39$) mean (SD)	HVH class ($n = 37$) mean (SD)
Pretest	8.96 (2.68)	6.82 (2.85)	7.35 (3.10)	7.72 (2.51)
Posttest	10.33 (3.53)	8.55 (3.53)	10.58 (3.71)	10.64 (2.96)
Difference	1.36 (4.14)	1.73 (4.09)	3.23 (4.94)	2.91 (4.03)

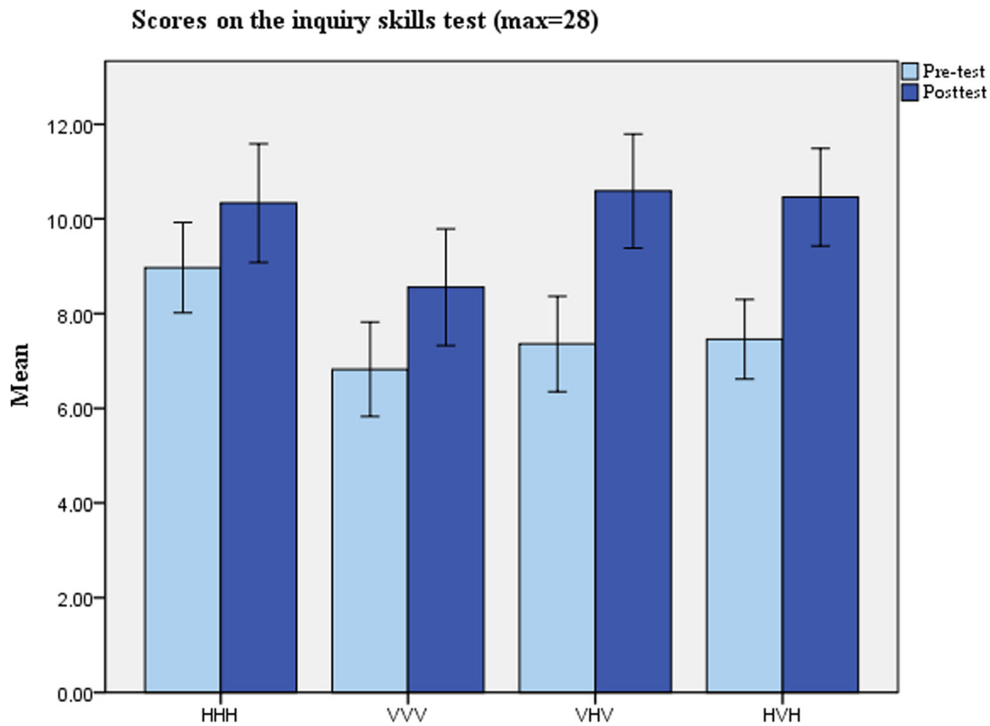


Fig. 4 Inquiry skills test across at pretest and posttest, by condition (error bars 95% CI). *The condition did not differ on the posttest scores, $p = 0.071$, partial $\eta^2 = 0.05$

sequence led to better results than a virtual then hands-on sequence (e.g., Smith and Puntambekar 2010), most studies, as in our case, have not found differences in effects between different combinations of hands-on and virtual laboratories (e.g., Chini et al. 2012). The two types of laboratories differ insofar as there is the possibility of making better observations and using less time to set up experiments in virtual labs versus the physicality that is present in hands-on laboratories. One could argue that using virtual labs before hands-on laboratories would help learners to act more effectively in the hands-on laboratory, but the other combination also obviously works; in our case, students in the HVH condition could have benefited in the third part from using the virtual lab in the middle phase. As in the comparison between combinations versus single laboratory environment, more studies are also needed to identify the best combination, so that any underlying mechanisms can be identified.

Although the results for the two types of knowledge test were mainly coherent with each other, there was no significant correlation between these two tests. This non-significant value means that the two tests measured different aspects of the domain. Still, results from both tests generally pointed in the same direction. Students in the two conditions that combined types of laboratories (especially in the VHV condition) showed better performance than the students who used the virtual laboratory exclusively (VVV). Concerning students' misconceptions, we can, very prudently and based on descriptive data, conclude that when students were exposed to both hands-on and virtual laboratory environments in combination, their scientific knowledge increased and misconceptions faded more than when exposed to virtual labs or hands-on labs alone. Some studies have emphasized the opportunities provided by virtual laboratory environments, such as the ease of changing variables, as being beneficial for handling misconceptions (Crawford et al. 2005; Perry et al. 2008), whereas other studies (e.g., Lazonder and Ehrenhard 2014; Zacharia et al. 2012) have advocated that physical experiments are a prerequisite for conceptual change. The main difference between this study and the studies that claimed physicality as a prerequisite for conceptual change is the participants' age. Students in the current study are older than the students in the studies done by Lazonder and Ehrenhard (2014) and Zacharia et al. (2012). The participants' age is important in terms of Piaget's theory of cognitive development (Piaget 1936). Students in this study are, most probably, in their formal operational stage, which mean that they have abstract reasoning skills that might help them to achieve conceptual change without physicality. Students in the studies by Zacharia et al. (2012) and by Lazonder and Ehrenhard (2014) were at an age level related to the pre-operational stage or concrete operational stage, which meant that they might not be able to deal very well with abstract concepts, so they might need to see and touch the materials for conceptual understanding. In this respect, it is important to note that in the current study, students in the VVV condition had also corrected their misconceptions by the end of the study (going on average from 25 to 11 misconceptions).

The learning environments were designed to support students with their inquiry processes in the current study. Scaffolding supports (in online form for students in the virtual laboratory environments, and as paper worksheets for the hands-on laboratories) were provided to overcome a lack of inquiry skills. Overall, we found no significant differences between conditions in terms of effects of laboratory environments on middle school students' inquiry skills. Similarly, Mustafa and Trudel (2013) found that hands-on and virtual laboratories were equally effective for acquiring inquiry skills when a guided inquiry approach was used. However, interestingly enough, students in conditions in which virtual labs and these online tools were used (VVV, HVH, and VHV) all significantly increased on inquiry skills, whereas this was not the case for the HHH condition. This may be a cautious indication that the paper worksheets used in the hands-on environments may have been less effective than the online interactive tools used in the virtual learning environment. In other words, the online scaffolding tools could be easier for students to use. For example, Hovardas et al. (2017) used a hypothesis formulating tool similar to the one used in the current study, and they concluded that using the tool helped students to develop their inquiry skills better than the condition with no tool. As a general conclusion though, we have to say that students' inquiry skills were and remained fairly low. This could mean that the scaffolding tools helped the students to perform in the learning environment, but that these tools (or the duration and frequency of their use) were insufficient to elicit a large change in students' inquiry skills.

Because of the fact that there were no sub-scales in the inquiry skills test used in the current study, no conclusions can be drawn about differences between types of inquiry skills. Yet, when the results of the open-ended conceptual knowledge test and the inquiry skills test are further analyzed, we may tentatively conclude that using higher-order skills was difficult for students. For example, the questions that required analyzing graphs or correlating concepts with each other were answered correctly by fewer students than the other questions. Furthermore, students' scores on the inquiry skills were relatively low even on the posttest. The reason behind this result may be that Turkish students' science inquiry skills are generally at a low level. For example, PISA 2015 results showed that Turkish students ranked 55th out of 73 countries for scientific literacy level (Taş et al. 2016). Similarly, TIMMS 2015 results also showed that Turkish fourth grade students ranked 35th out of 47 countries and Turkish eighth grade students ranked 21st out of 39 countries (Yıldırım et al. 2016). Students' limited inquiry skills might be difficult to develop through just one intervention, such as the one we applied in this study.

Conclusion and Implications

In conclusion, the findings of this study revealed that using hands-on and virtual laboratory environments together in a combination such as VHV or HVH gives significantly better outcomes for students' achievement than using virtual laboratories alone. Although students in the VVV condition only experienced the virtual laboratory environment, there was no significant difference between this condition and the HHH condition in terms of gains in knowledge and inquiry skills. This result shows that virtual laboratory environments are as effective as hands-on laboratory environments for increasing students' domain knowledge and developing their inquiry skills.

xOverall, the findings of this study offer several practical implications for science teachers as far as deciding which type of laboratory environment is more beneficial to use for learning science through experimentation. First, this study shows that when virtual laboratories are considered as an alternative for hands-on laboratories (for example, for reasons of easier experimental setup), they can be regarded as being as effective as hands-on laboratories. Second, if the opportunity is there, providing students with alternating hands-on and virtual laboratories should be preferred over single laboratory formats, especially single virtual labs.

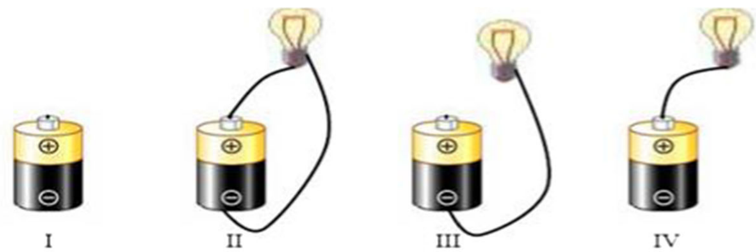
Finally, the results of this study should be interpreted taking the study's limitations into account. As mentioned above, using the same test as pretest and posttest could have been a possible threat to internal validity in the form of a testing effect. However, we assumed that the time that elapsed between the pretest and posttest and the total number of questions the test contained minimized the students' opportunity to memorize the questions. Another limitation is that students had no prior experience with virtual laboratory environments, and this could have been a disadvantage for them. Finally, due to practical circumstances we used a quasi-experimental setup. Different conditions (and thus classes) did not differ on scores on the pretests, but random assignment of students to conditions would have ruled out possible class-related effects.

Compliance with Ethical Standards

All procedures performed in the current study involving human participants were in accordance with the ethical standards of the institutional and ministry of national education research committee.

Conflict of Interest The authors declare that they have no conflict of interest.

Appendix 1: Example Questions From Multiple-Choice Conceptual Knowledge Test



1. In which of the circuit(s) do(es) the light bulb(s) work?

a) Only III b) Only II c) Only IV d) II, III, and IV

2. Select the correct option from the following statements.

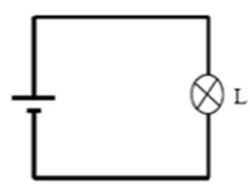
a) A battery produces the same electrical current whatever the circuit is.

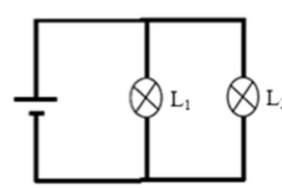
b) When a new resistor is connected in parallel to the single resistor in the circuit, the equivalent resistance increases.

c) A battery causes the same potential difference in all circuits.

d) A battery is a source of electrons that make up the current in the circuit.

3. The batteries and lightbulbs are identical in the following circuits. Accordingly, select the correct option given below.





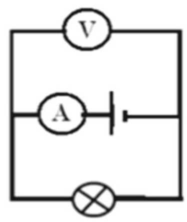
a) The potential difference between the ends of light bulbs L_1 and L_2 is less than the potential difference that L light bulb has.

b) The potential difference between the ends of light bulbs L_1 and L_2 is equal to each other.

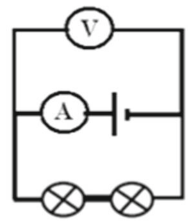
c) Light bulbs L_1 and L_2 are less bright than light bulb L.

d) Since the equivalent resistance in the second circuit is larger, the total amount of current flowing in the circuit is less.

4. Select the correct option for the following circuits. (Batteries and light bulbs are identical.)



I. Circuit



II. Circuit

a) The voltmeter in the second circuit shows a lower potential difference than the voltmeter in the first circuit.

b) Light bulb L_2 is brighter than light bulb L_1 because it is closer to the battery.

c) Light bulbs L_1 and L_2 are less bright than light bulb L.

d) The total current measured by the ammeter in the first circuit is less than the total current measured by the ammeter in the second circuit.

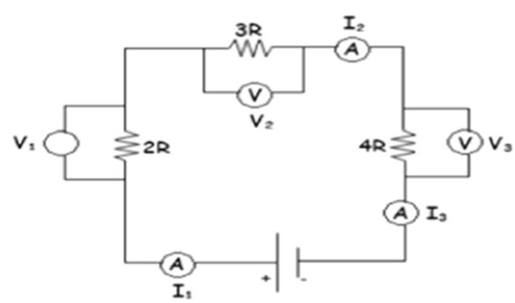
5. The values shown by the ammeter in the circuit are I_1, I_2, and I_3, and the values shown by the voltmeter in the circuit are V_1, V_2 and V_3. What is the relationship between these values?

a) $V_3 > V_2 > V_1$ $I_1 = I_2 = I_3$

b) $V_1 = V_3 < V_2$ $I_1 = I_2 > I_3$

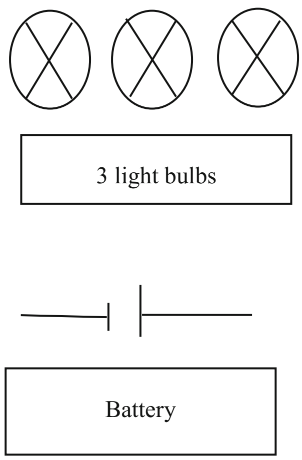
c) $V_2 > V_1 = V_3$ $I_1 = I_2 = I_3$

d) $V_2 > V_1 > V_3$ $I_3 > I_1 > I_3$



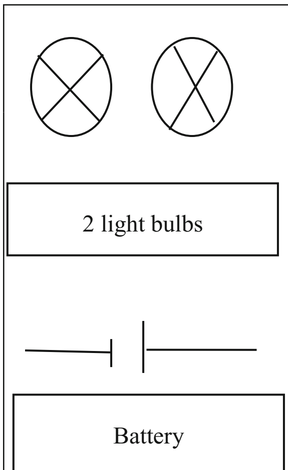
Appendix 2: Open-Ended Conceptual Understanding Test

1. a)



Draw **a serial electrical circuit** using 3 light bulbs and 1 battery.

b)

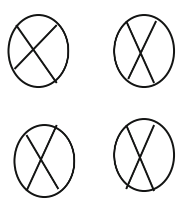
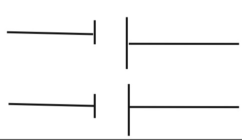


Draw **a parallel electrical circuit** using 2 light bulbs and 1 battery.

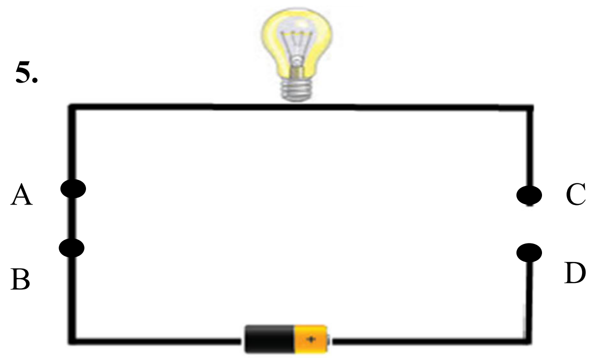
2. A teacher wonders whether his/her students have learned about how ammeters and voltmeters are connected to circuits. The teacher asks his/her students to design an electrical circuit by using light bulb(s), battery, cable, ammeter and voltmeter. Accordingly, how could the student have designed a circuit?

3. Please explain the relations among electrical current, potential difference and resistance in an electrical circuit.

4.

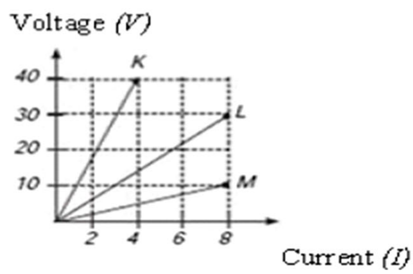
 4 light bulbs  2 batteries	You have 4 light bulbs and 2 batteries. Draw a circuit which has light bulbs connected both in series and in parallel. Show which light bulbs are connected in series and which in parallel.

5.



An electrical circuit is shown. This circuit isn't working right now. We would like to activate the circuit by adding an ammeter and a voltmeter. At what points should we connect the ammeter and voltmeter?

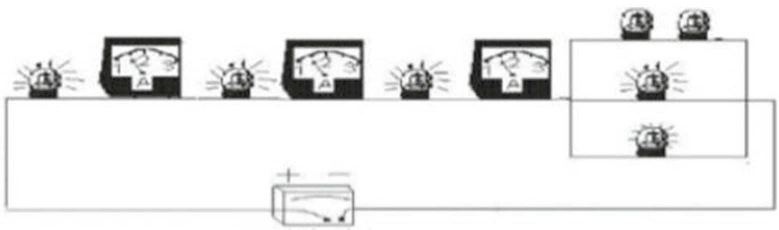
6.



Please put in increasing order the resistance of K, L and M based on their magnitude with respect to the V-I graph. Explain the reason(s) for your sorting.

Appendix 3: Example questions from Inquiry Skills Test

1. An electrical circuit is shown below.



There are some explanations below. Which one of them is **an observation**?

a) Some light bulbs do not work; these light bulbs could be broken due to high potential difference.

b) Light bulbs in the circuit are not bright enough. This may be because of low potential difference.

c) Light bulbs in the circuit are made of poor-quality materials.

d) The same amount of current passes through serially connected circuit components.

2. A circuit in which there are light bulbs with different shapes and colors is shown below. According to which characteristics can we **classify** the bulbs as belonging to only two groups?

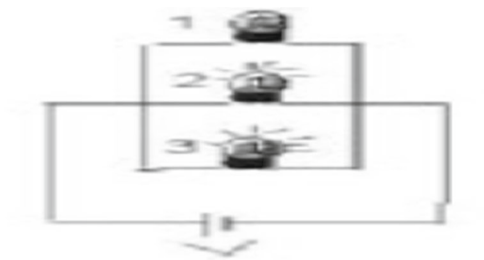
a) Yellow and green light bulbs

b) Serial and parallel light bulbs

c) Triangular and square light bulbs

d) Round and square light bulbs

3. A circuit that involves three bulbs connected in parallel is given below. Whereas Light bulb 1 doesn't work, Light bulb 2 and Light bulb 3 are bright. What **inference** can you make based on this result?



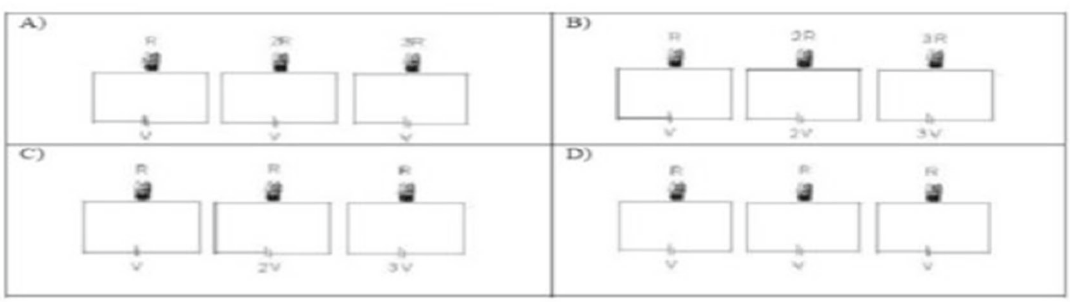
a) Light bulb 1 and Light bulb 2 are identical because the burning out of Light bulb 1 is not important.

b) Light bulb 1 and Light bulb 3 aren't identical, because Light bulb 1 doesn't work with same amount of potential difference.

c) Light bulb 2 and Light bulb 3 are identical because they are still bright.

d) All of the light bulbs in the circuit are identical.

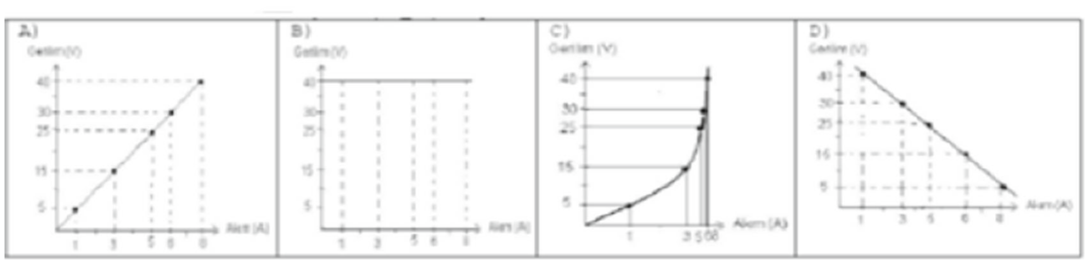
4. In order to test the hypothesis: "The luminosity of a bulb decreases as the bulb's resistance increases in a circuit," which **experimental design** can we set up?



5.

Voltage	Current	Resistance
5 V	1 I	5 R
15 V	3 I	5 R
25 V	5 I	5 R
30 V	6 I	5 R
40 V	8 I	5 R

How are the voltage and current values **plotted in a graph**?



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