

An Inquiry-Based Learning Approach for Effective Concept Teaching

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Cover Page Footnote

This study presented as oral presentation at 7th International Instructional Technologies & Teacher Education Symposium has been greatly expanded.

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Abstract

The purpose of this research was to investigate the effect of simulation-supported inquiry-based learning on pre-service teachers' conceptual understanding of capacitors. The participants consisted of 50 pre-service teachers studying at a state university in Turkey. The participants were divided into two groups of 25 each on the basis of their physics grades in the previous semester. The research was patterned according to a non-equivalent control group design with pretest and posttest. The experimental group used simulation-supported inquiry-based learning, and the control group used lecture-based learning supported by simulations. The research data were collected with the Capacitor Concept Test prepared by the researchers. The findings showed that pre-service teachers had various misconceptions about parallel plate capacitors before the implementation. The research revealed that inquiry-based learning was more effective than lecture-based learning in eliminating these misconceptions.

Keywords: Inquiry-based learning, simulation, capacitors, concept

Introduction

According to constructivist understandings, learners participate in learning settings with the knowledge they have acquired via past experience (Srisawasdi & Panjaburee, 2015). Unfortunately, this prior knowledge, whether from formal or informal learning settings, is often incompatible with scientific information. Misconceptions emerge due to learners' prior knowledge of various events and phenomena that contradict scientific conceptions (Windschitl & Andre, 1998). For learning to be in line with correct conceptual constructs, it

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is important to eliminate students' misconceptions resulting from past experience in existing schemes of knowledge. However, this requires more than simply pointing out the inaccuracies in existing concepts and replacing them with true scientific concepts. To correctly construct the concepts in their schemes of knowledge, learners must make associations between their existing concepts and the scientifically correct explanations of these (Srisawasdi & Panjaburee, 2015). This requires a learning environment that allows for asking questions, making inquiries, forming hypotheses, and collecting data. Inquiry-based learning (IBL) is an exceptionally useful approach in terms of providing learners with this type of learning environment. IBL allows students to relate their prior knowledge with scientific definitions of concepts (Panasan & Nuangchalem, 2010). It provides a classroom climate in which learners can express aspects of their own thought processes, creativity, and views, thus transforming theoretical knowledge into practical outcomes (Colburn, 2000). An inquiry process using scientific methods and implementations teaches students about not only scientific methods but also science content (Edelson et al., 1999). In this context, the literature shows that IBL is an effective approach to concept teaching (Dagnew & Mekonnen, 2020; Maknun, 2020; Marchionda, 2006; Mensah-Wonkyi & Adu, 2016; Önder et al., 2018; Solikin et al., 2020; Şenyiğit, 2020).

The literature shows that one of the subjects about which students develop misconceptions in science courses is parallel plate capacitors (Başer & Geban, 2007; Taşkın, 2021). Capacitors have an important place in technology due to their use in electronic circuits. All electronic devices we use in daily life contain capacitors, and because of their widespread use, capacitors are also included in many science curricula. Although there are different types of capacitors, the parallel plate capacitor is taught in fundamental science courses because of its simple structure. Teaching about capacitors starts with their structural properties and continues to more advanced levels, with the use of capacitors in DC and AC circuits. Learning the concepts of capacitors helps students understand the relationship between science and technology. Therefore, it is important for educators to clearly explain the basic concepts of capacitors and eliminate misconceptions. However, in the literature, most studies aimed at eliminating the misconceptions in this field focus on static electricity (Akpınar, 2014; Başer & Geban, 2007; Dilber, 2010; Suma et al., 2019) rather than directly addressing parallel plate capacitors. Therefore, this study aimed to explore the effectiveness of simulation-supported IBL in eliminating misconceptions about parallel plate capacitors.

The researchers aimed to answer the following research questions:

1. What are pre-service teachers' existing misconceptions about parallel plate capacitors?
2. Is simulation-supported inquiry-based learning effective in eliminating pre-service teachers' misconceptions about parallel plate capacitors?
3. Is simulation-supported inquiry-based learning more effective than lecture-based instruction at reducing pre-service teachers' misconceptions?

Inquiry-Based Learning

The roots of inquiry thought reach far back into the history of science teaching due to the influence of educational theorists such as Dewey, Bruner, Postman, and Weingartner (Justice et al., 2009). There are many different definitions of IBL in the literature, including "applied science," "doing science," and "real world science" (Crawford, 2000). IBL is described as the process of asking questions, conducting research, learning by analyzing data, and

transforming the obtained data into useful information (Perry & Richardson, 2001). According to The National Science Education Standard (NRC, 2000), in the IBL process, students should seek evidence-based answers to scientifically-oriented questions, use the evidence to formulate their own explanations, and associate these explanations with scientific knowledge. In this respect, well-established IBL environments enable students to adopt the thinking processes of scientists. The IBL process is structured as an inquiry cycle. Llewellyn (2002) describes this cycle as having six phases. The cycle starts with a problem under consideration. Then, students work in small groups to find solutions; at this stage, students present possible solutions using their prior knowledge (Llewellyn, 2002). Next is the hypothesizing phase. The students construct a hypothesis regarding their solutions from the previous stage (Llewellyn, 2002). Subsequently, students design and implement a plan to solve the problem (Llewellyn, 2002). This phase is followed by the data collection and recording phase, in which students comment on the data and draw conclusions. In the final stage, students share the information they have obtained regarding the problem verbally, visually, or in writing (Llewellyn, 2002).

When examining the inquiry cycle, one can understand that not every well-structured activity is an inquiry-based activity; for an activity to qualify, a well-structured research question should be answered through data analysis (Bell et al., 2005). IBL is classified under four headings: “confirmation inquiry,” “structured inquiry,” “guided inquiry,” and “open inquiry,” based on the structure of the activities (Banchi & Bell, 2008). In confirmation inquiry, students are given a question and a solution procedure to verify a previously learned concept or principle (Whitworth et al., 2013), and in most cases, they experience the verification and validation of existing scientific principles by following certain procedures (Windschitl, 2002). Thus, confirmation inquiry has the advantages of allowing learners to experience process skills like data collection and recording, to recognize the experience of conducting research, and to reinforce a concept (Banchi & Bell, 2008). Laboratory activities performed to validate a previously taught concept exemplify confirmation inquiry (Bell et al., 2005). Confirmation inquiry is followed by structured inquiry. In structured inquiry, while the teacher presents the question and procedure, the results to be achieved are left to the students (Windschitl, 2002); learners reach the results by following a process in which the teacher presents not only the problem situation but also a set of pre-determined instructions (Zion & Mendelovici, 2012). Therefore, although structured inquiry hinders autonomous thinking skills, it provides an excellent opportunity to develop inquiry skills (Zion & Mendelovici, 2012). In guided inquiry, the teacher gives the question, but students are left to determine both the procedure and the results to be achieved (Bell et al., 2005; Sadeh & Zion, 2009). Guided inquiry eliminates step-by-step instructions (Bell et al., 2005); the learners direct the methods to discover principles and concepts (Tafuya et al., 1980). Therefore, guided inquiry functions as a transition to open inquiry (Martin-Hansen, 2002; Zion & Mendelovici, 2012). In open inquiry, the highest level of inquiry, the entire process, including reaching the question, is the student’s responsibility, as it would be for a scientist. Therefore, open inquiry that requires high-level thinking skills such as critical thinking and reflection is a simulation of experimental studies performed by scientists (Zion & Mendelovici, 2012). Throughout the inquiry learning process, students use their current concepts to answer questions. In this process, students formulate explanations about events and phenomena by using their scientific knowledge that activates scientific process skills (Van Joolingen et al., 2007). The refutation of the hypotheses during the inquiry cycle decreases students’ confidence in their own (mis)conceptualizations, which prepares them for conceptual change.

Simulations and Inquiry-Based Learning

Considering the nature of science content and scientific developments, science education emphasizes the selection of appropriate teaching strategies supported by technology (Srisawasdi & Panjaburee, 2015). Computer and internet technologies offer a range of new opportunities to acquire knowledge and promote meaningful learning (Owens et al., 2002). Also, the use of technology gives students the opportunity to research realistic problem situations in the learning process (Van Joolingen et al., 2007). Simulations are thus an effective contemporary technology tool in the inquiry process. Simulations occupy an increasingly important place for educators, learners, and teaching settings in today's globalizing world (Srisawasdi & Panjaburee, 2015). Simulations are regarded as highly effective and productive, reducing the time needed for teaching and learning in complex and dynamic systems and for converting theoretical knowledge into practical implementation (Parush et al., 2002). Simulations provide content that brings learners closer to reality and offers a systematic view of both realistic and hypothetical situations (Van Berkum & de Jong, 1991). This approach supports realistic questioning practices, ranging from formulating questions about the subject and creating an experimental setup to developing hypotheses and collecting and testing data (Rutten et al., 2012). Simulations allow the observation of changes in variables in the related experimental setup and of the effects of these changes on the results (Srisawasdi & Panjaburee, 2015).

Using simulations within a well-designed constructivist approach gives learners the chance to freely formulate and evaluate hypotheses about phenomena in an enriched and contextualized setting (Windschitl & Andre, 1998). Computer simulations also provide an opportunity for conceptual change, as they allow students to reflect on and articulate their ideas and thus reconcile any conceptual conflict between these and observations in the micro world (Tao & Gunstone, 1999). In this process, simulations impact conceptual development by enabling learners to interact with explanations of phenomena in supportive cognitive environments (Windschitl, 1997). These opportunities and benefits can help increase the effectiveness of students' actual experiences in learning environments (Kubicek, 2005). In this sense, simulations are useful tools for IBL environments. Using simulations, educators can design realistic experiments for students to test their hypotheses. Using these experiments, students can collect data and reach results—that is, perform many steps of the inquiry cycle. Computer technologies and simulations, with their potential to support inquiry, are popular components of science education (Edelson et al., 1999; Sabah, 2011), and previous studies have emphasized the positive effect of simulation-supported IBL on concept teaching (Kırılmazkaya, 2014; Önder & Bilal Önder, 2018; Zacharia & Anderson, 2003).

Method

Research Design

This research was conducted using a non-equivalent control group design with pretest and posttest, a quasi-experimental design (Creswell, 2009). In this design, the participants were not assigned randomly to the experimental and control groups (McBurney & White, 2009). Over the course of the study, the experimental group used simulation-supported IBL, and the control group used lecture-based learning. Before the implementation, the researchers conducted a pretest to ascertain the participants' conceptual understanding of capacitors. At the end of the process, the participants took the same test as a posttest to determine the change in their conceptual understanding scores.

Data Analysis

The *Capacitor Concept Test* served as the pretest and posttest in both the experimental and control groups. The independent samples t-test, a hypothesis test used to detect any statistically significant difference between the means of two independent data sets (Russo, 2003), was used to compare the mean scores of the groups in the concept test before and after the implementation. The paired samples t-test, which examines the differences between two means obtained from the dependent samples (Cronk, 2020), was conducted to determine whether the conceptual understanding of the groups improved significantly compared with the pre-implementation levels. Quantitative analysis of the concept test provides knowledge about the level of participants' misconceptions. The researchers examined participants' answers to open-ended questions to determine which misconceptions existed among them. After grouping the explanations containing similar misconceptions, the researchers determined the number of participants who had these misconceptions. To support the findings, we include direct quotations from the answers that contained misconceptions.

Participants

The participants in the research consist of 50 pre-service teachers enrolled in the Physics II course at a state university in Turkey. Sixty-eight percent of the participants were female, and the average age was 18.7. The participants were divided into two groups of 25 each based on their physics course grades in the previous semester. To ensure homogeneity between groups, the participants were ranked by their first semester physics course grades, and the lower and upper 25% slices were determined. Then, these participants were divided into two homogeneous groups in a way that ensured the groups matched in terms of student achievement. Participants in the remaining 50% slice with moderate success were randomly assigned to one of these two groups in equal numbers. One group was designated as the experimental group and the other, as a control group. The single blinding method (Çaparlar & Dönmez, 2016; Ma et al., 2019) was used to reduce participants' bias in the experimental and control groups regarding the purpose of the study. To reduce bias, the participants were not informed of which intervention they would receive. Since the researchers were also responsible for conducting the course, they had information about the groups to which the participants were assigned.

Implementation Process

The implementations in both the experimental and control groups were carried out by the same researcher to eliminate any effects caused by different educators.

Experimental Group

In this study, IBL was organized according to guided inquiry. Both groups used Capacitor Lab and Capacitor Lab: Basics simulations (PhET Interactive Simulations, 2011, 2019), provided free of charge by the University of Colorado PhET Interactive Simulations Project. During the experimental process, participants performed four activities, each lasting two class hours (a total of 90 minutes). Before the activities, the participants in the experimental group answered questions about the basic concepts of the subject to draw their attention to these concepts. Then, the participants were divided into four groups, and each received activity sheets containing questions that would lead them into the research questions. After reading these questions in their groups, the participants were asked to define the problem and form a

hypothesis to facilitate solving the problem. After discussing their hypotheses, they started introducing ideas about the experiment needed to test the hypothesis. Each group discussed their ideas and decided on the experiment they would perform. After the data collection stage using the simulation program, groups reviewed their hypotheses. If a group considered it necessary, they then formed another hypothesis and repeated the process. At the end of the procedure, the groups performed a short scan of the literature and related their results to the sources. Each group then briefly presented their findings and results to the class. Below is one of the activities used in the implementation.

Sample Activity

Learning Objectives:

- To learn the concept of capacitance
- To learn the variables that affect the capacitance of a parallel plate capacitor
- To establish a relationship between capacitance and charges on the plates of the capacitor
- To be able to distinguish absolute charge and net charge concepts.

At the beginning of the course, the researchers drew participants' attention to the concepts to be taught using discussion questions such as the following: What is electric charge? What are the properties of electric charge? What is a capacitor? What is capacitance? Then, the first activity sheet was distributed to the groups. The first activity sheet contained the following question:

It is necessary to increase the charges on the plates of a parallel plate capacitor connected to a voltage source of 1.5 volts. Since the potential difference between the ends of the voltage source cannot exceed 1.5V, what can you do to increase the charge on the plates of the capacitor? Can you increase the charge on the plates without increasing the potential difference between the ends of the capacitor?

In the first stage, the participants were asked to provide an explanation for this activity sheet question, and in the second stage, to establish a hypothesis based on their explanation. After setting up a hypothesis, they tested it by designing an experiment using Capacitor Lab: Basics or Capacitor Lab: Simulations. Before the experiment, the participants were asked to define their variables (dependent, independent, control) and explain what results they expected to confirm their hypothesis. After conducting the experiment and collecting the data, the participants drew graphs to show the relationships between the dependent and independent variables. At the end of this phase, the participants should have met the following expectations:

- to understand that in a parallel plate capacitor, capacitance changes directly proportionally ($C \propto A$) to the surface area of the plates and inversely proportionally ($C \propto 1/d$) to the distance between the plates
- to reach approximately the $C = \text{constant} \times A/d$ equation
- to understand that the charge on each plate of the capacitor varies in direct proportion to the capacitance

The last part of the course consisted of gathering information from sources and then compiling and presenting this information in support of the results.

Control Group

In the control group, the courses started with questions focusing attention on the subject. In the first course, a capacitor was charged, and its legs were connected to a lamp. Then, the instructor asked the following questions for consideration: Why did the lamp light up? Why did the lamp light up for a short time? How can I make the lamp light up for a longer time? And what will happen if I connect the same capacitor back to the lamp?

After the discussion, the researcher made a presentation in accordance with the curriculum of the Physics II course with special emphasis on misconceptions cited in the literature. After the presentation, the instructor carried out demonstration experiments with simulations. To increase the participants' involvement, the researcher asked questions about the effects of the variables manipulated, and the class discussed their predictions. In the last period of the course, participants solved sample problems related to the subject, and the researcher presented a course summary and answered participants' questions.

Data Collection Instruments

Capacitor Concept Test

The *Capacitor Concept Test* consists of seven open-ended questions prepared by the researchers in consultation with two field experts. Quantitative data comprised scores from the test, with wrong answers scored as 0, correct answers without explanation as 1, and answers with correct explanations scored as 2. Before the implementation, the researchers conducted the statistical analysis of the concept test with the data from 75 pre-service teachers using multifaceted Rasch analysis. These pre-service teachers were selected from among those who were successful in the Physics II course.

Results of the Multifaceted Rasch Analysis

Figure 1 presents the variable map emerging from the multifaceted Rasch analysis. The raters are ranked in the column, with the most generous at the bottom. A rater with a positive measurement value was stricter in scoring than a rater with a negative measurement value. Accordingly, the first rater can be said to have used more stringent scoring than the second, the second more stringent than the third, and so on.

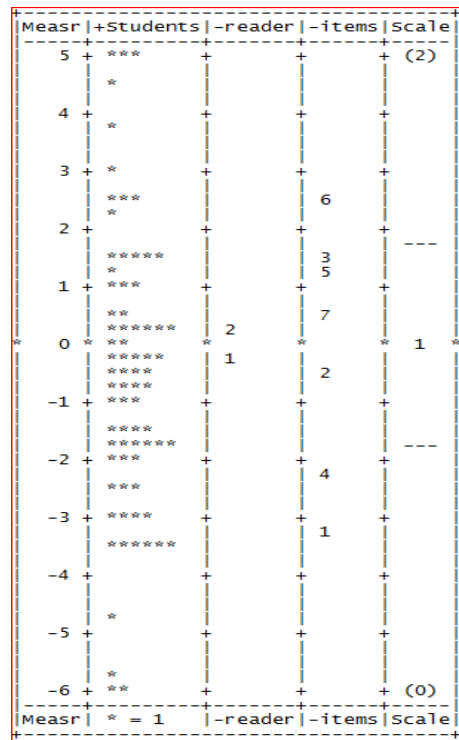


Figure 1. The variable map for measurements of the capacitor concept test.

The numbers in the *item* column represent the sequence numbers of the questions in the test. In this column, the difficulty level of the items decreases from top to bottom. Figure 1 shows that the sixth item is the most difficult question in the test.

Measurements Related to the Student Facet

In multifaceted Rasch analysis, variables are scored on a scale called logit. Table 1 shows that the mean of the participants on the Capacitor Concept Test was $-.53$ logit with a standard deviation of 2.64. To understand how well the model and data fit each other, we analyzed the Infit MnSq and Outfit MnSq values. According to Wright and Linacre (1994), values of between 0.6 and 1.4 show a reasonable fit. Table 1 shows that the measurements related to the student facet displayed mean Infit and Outfit statistics of .98 and .96, respectively, meaning there was an adequate fit between the data and the model.

Table 1

Student facet analysis results

	<i>Logit Measurement</i>	<i>Model Standard Error</i>	<i>Infit MnSq</i>	<i>Outfit MnSq</i>
Mean	$-.53$.69	.98	.96
Standard Deviation (population)	2.62	.33	.55	.74
Standard Deviation (sample)	2.64	.33	.55	.75
Model, Population; RMSE=.76	sd=2.51	Separation=3.29	Reliability=.92	
Model, Population; RMSE=.76	sd=2.53	Separation=3.32	Reliability=.92	
Model, Fixed (all same) chi-square: 663.5	df=74	p=.00		
Model, Random (normal) chi-square: 62.2	df=73	p=.81		

To ascertain whether the test made a significant discrimination between participants at high and low levels of achievement, the researchers reviewed the separation rate and chi-square test results. This review revealed that the separation rate was 3.32 at a reliability of .92, showing that the participants could be discriminated at a high reliability according to achievement. This finding was also supported by the chi-square test results ($\chi^2=663.5$, $sd=74$, $p<.05$).

Measurements Related to Item Facet

Table 2 displays the results of the analysis of the item facet of the Capacitor Concept Test, showing that the question with the lowest Infit MnSq value was item 6, and the highest was item 7. The Outfit MnSq values revealed that the question with the lowest value was item 1, and the question with the highest value was item 7. The Infit MnSq and Outfit MnSq averages of the seven items in the test were .98 and .88, respectively. These determined values were between 0.6 and 1.4, meaning that there was harmony between the data and the model.

Table 2

Item facet analysis results

<i>Item</i>	<i>Logit</i>	<i>Standard Error</i>	<i>Infit MnSq</i>	<i>Outfit MnSq</i>
I1	-3.15	.22	.88	.69
I2	-.62	.18	.85	.99
I3	1.59	.20	1.00	.90
I4	-2.22	.19	.97	.86
I5	1.28	.19	.98	1.12
I6	2.58	.23	.80	.96
I7	.54	.19	1.31	1.21
Mean	.00	.20	.98	.88
sd Population	2.37	.02	.24	.22
sd Sample	2.56	.02	.25	.24
Model, Population, RMSE=.20 Separation=11.79			Reliability= .99	
Model, Sample, RMSE=.20 Separation=12.74			Reliability= .99	
Model, Fixed (all same) chi-square=891.3			df=6	p=.00
Model, Random (normal) chi-square=6.0			df=5	p=.31

Table 2 indicates that the most difficult question was Item 6, and the easiest, Item 1. The chi-square test was employed to ascertain whether there was a statistically significant difference between the difficulty levels of the test questions and shows that the difference was significant ($\chi^2=891.3$, $sd=6$, $p<.05$).

Measurements Related to Rater Facet

Rater eligibility statistics show how well the scores provided by a given rater match the expected scores generated by the model (Eckes, 2015). The analysis showed that the Infit MnSq values for the raters were 1.03 and .93, and the Outfit MnSq values were .98 and .94 (Table 3). The obtained values were between .60 and 1.40, confirming that the scores provided by the raters were sufficiently compatible with the scores generated by the model.

Table 3

Rater facet analysis results

<i>Reader</i>	<i>Logit</i>	<i>Standard Error</i>	<i>Infit MnSq</i>	<i>Outfit MnSq</i>
R1	-.18	.10	1.03	.98
R2	.18	.10	.93	.94
Main	.00	.10	.98	.96
sd Population	.18	.00	.05	.02
sd Sample	.25	.00	.07	.03
Model, Population, RMSE=.10	sd=.14		Separation =1.46	Reliability=.68
Model, Sample, RMSE=.10	sd=.23		Separation =2.29	Reliability=.84
Model, Fixed (all same)	chi-square=6.3 1		p=.01	

Results**Assessment of Total Test Scores**

The pretest mean scores of the experimental and control groups were 3.80 and 3.72, respectively (Table 4). To test the significance of this difference, we used the independent groups t-test to compare the two groups' pretest mean scores, finding no statistically significant difference ($t_{(48)}=.09$; $p>.05$). The inclusion of parallel plate capacitors in high school physics education programs means that students acquire some basic concepts about capacitors before their university education. According to constructivist theory, since new concepts build on more basic concepts, any existing differences between participants' misconceptions before the implementation may affect the conceptual change process. However, the results of the analysis showed no statistically significant difference between the experimental and control groups in terms of misconceptions held before the implementation. In other words, the posttest scores of the experimental and control groups were not affected by any differences in pre-knowledge.

Table 4

Independent groups t-test analysis results

<i>Group</i>	<i>Pretest</i>						<i>Posttest</i>					
	<i>n</i>	\bar{X}	<i>sd</i>	<i>df</i>	<i>t</i>	<i>p</i>	<i>n</i>	\bar{X}	<i>sd</i>	<i>df</i>	<i>t</i>	<i>p</i>
Experimental	25	3.80	3.12	48	.09	.93	25	11.84	3.69	48	2.86	.006*
Control	25	3.72	3.47				25	8.76	3.92			

* $p<.05$

At the end of the implementation, the experimental group's posttest score increased to 11.84, and the control group's, to 8.76. To determine the significance of the difference between the posttest mean scores of the groups, we used the independent groups t-test (Table 4). The analysis results show that the posttest mean scores of the experimental group were significantly higher than those of the control group ($t_{(48)}=2.86$; $p<.05$).

Table 5

Paired sample t test results

Group	Test	\bar{X}	Difference	sd	t	p
Experimental (n=25)	Pretest	3.80	8.04	3.12	10.17	.000*
	Posttest	11.84		3.69		
Control (n=25)	Pretest	3.72	5.04	3.47	5.47	.000*
	Posttest	8.76		3.92		

*p<.05

To determine whether there was a significant improvement in the experimental and control groups’ posttest scores over their pretest scores, we analyzed the differences between the post- and pretest scores with the paired sample t-test. Table 5 shows the differences between the posttest and pretest scores of the groups as well as the results of the analysis of these differences. The results of the analyses indicate significant improvement over the pretest for both the experimental ($t_{(24)}=10.17$; $p<.05$) and the control group ($t_{(24)}=5.47$; $p<.05$).

Assessment of the Open-Ended Responses to the Concept Test

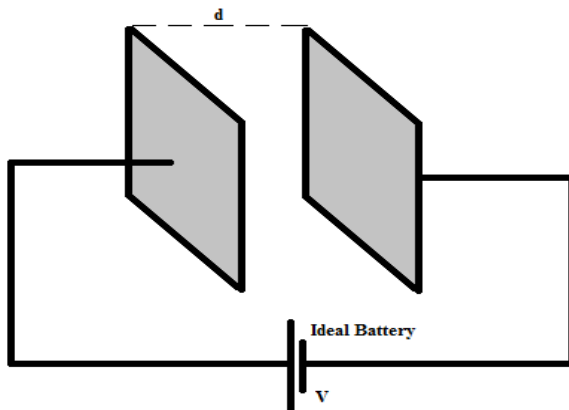


Figure 2. Parallel plate capacitor.

In the first three items of the test, the researchers asked the participants to explain changes in the capacitance, the potential difference between the parallel plates, and the net charge of the capacitor when the distance between the plates was reduced, as shown in Figure 2. Most correctly answered the first question about capacitance change, but two gave the wrong answer. However, because the source of the error was an incorrect expression of the capacitance equation ($C=\epsilon_0d/A$), these responses were not considered misconceptions. Five participants (three from the control and two from the experimental group) used the equation $Q=C.V$ to state that the capacitance of the capacitor would not change. One participant provided the following explanation:

Because the capacitor is connected to a battery, the voltage and charge are fixed. Thus, according to the equation $Q=C.V$, capacitance is fixed. As long as the voltage of the battery does not change, the capacitance of the capacitor does not change.

By the end of the implementation, the participants no longer held the notion that capacitance would change depending on potential difference. All in both groups responded correctly to

the question. All but three in the experimental group stated that capacitance was a structural property of a capacitor. Most of the control group, however, chose to give simply the capacitance equation rather than an explanation.

In the second question, the participants' misconceptions fell into two categories. In the first category, 20 participants tried to explain the potential difference between parallel plates in terms of the equation $Q=C.V$. In the second category, seven tried to explain the potential difference between the plates of the capacitors in terms of the electric potential generated by a point charge. One example of a participant's explanation is as follows:

As the distance between the plates decreases, the voltage stored by the capacitor will increase because voltage and distance are inversely proportional according to the equation $V=kq/d$.

This explanation shows an inability to differentiate between the concepts of electric potential and potential difference. Furthermore, as in the explanation above, these participants used the concept of the "voltage stored by a capacitor"; that is, they thought that capacitors were devices that stored voltage.

At the end of the implementation, a review of the second question showed correct responses from 24 in the experimental group and 19 in the control group. A large proportion of the participants had understood that a change in the capacitance of a capacitor would affect the charge contained in the plates; however, three in the experimental group and nine in the control offered scientifically inaccurate answers. At the same time, no one in the control group was able to correct their notion about a capacitor's storing up voltage, while no one in the experimental group held on to this misconception.

In the third question, about the net charge of a capacitor, many in both groups responded incorrectly. The analysis of the explanations showed that none of those providing the wrong response (42) believed that the net charge contained in the capacitor plates was zero. Another misconception that emerged as a result of this explanation is the belief that the plates of a capacitor transfer electrical charges to each other. As one participant stated,

When the distance between the plates decreases, this will make it easy for electrons to jump from one plate to another, and therefore, the net electric charge in the capacitor increases.

After the implementation, 20 in the experimental group provided the correct answer to the third question and made scientifically accurate explanations, pointing out the equal amounts of charges in the capacitor's plates. This indicates that the participants in the experimental group understood that the net electric charge of a capacitor was zero. In the control group, only 11 participants gave the correct answer, while three displayed the misconception that "a capacitor does not carry a charge," a notion that had not existed in the pretest but had arisen by the end of the implementation. Also, the control group's misconception regarding the transfer of charge between the capacitor plates continued after the implementation.

The fourth, fifth, and sixth questions are related to the effect on capacitance, potential difference, and net charge when changing the distance between the plates of a capacitor when the capacitor's connection with a battery is cut. Most responses to the fourth question, about

capacitance, were correct, and the incorrect responses were due to misremembering the capacitance equation. A review of the responses to the fifth question showed that 29 participants based their explanations on the misconceptions expressed in the previous questions—that is, that capacitors store voltage and that the potential difference between the parallel plates can be determined by the electrical potential of point charge. Another misconception was that if the capacitor is disconnected from the battery, the potential difference between the capacitor plates will be zero. One explanation was as follows:

The source of the voltage in the circuit is the battery. If the battery were disconnected, there would be nothing to provide the capacitor with voltage, so the voltage of the capacitor would be zero.

After the implementation, 20 in the experimental group responded correctly to fifth question, and 17 were able to explain it accurately, compared with 14 in the control group, with 9 making an accurate explanation. The responses of the control group show that the misconception “the capacitor stores the voltage” continued to exist after the implementation.

In their answers to the sixth question, the participants displayed all of the misconceptions that had been seen in Question 3. At the same time, some thought that the charge in the capacitor would decrease when the battery was disconnected. At the end of the implementation, 20 participants in the experimental group stated that the net charge would be zero, and 17, that the absolute charge would remain the same. In the control group, 12 stated that the net charge would be zero, and only two touched on the concept of absolute charge in their explanations.

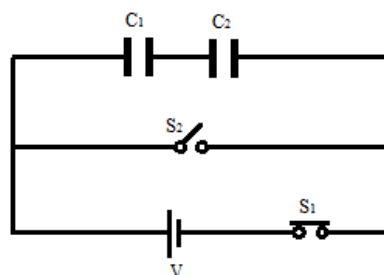


Figure 3. Serial capacitors.

In the seventh question (Figure 3), two capacitors of different capacitances and a battery were connected in a series. After the capacitors were charged, S₁ was switched off, and S₂ was switched on. When asked to explain the change in the capacitors’ charges, 28 participants considered that there would be a charge transfer between the capacitors until their charges were equal. After the implementation, 22 in the experimental group and 19 in the control group showed an understanding that the total charge of the capacitors was directly proportional to their capacitances.

Discussion and Conclusion

The results indicate that the experimental group, which experienced simulation-supported IBL, displayed higher scores on the concept test than the control group, which was exposed to a lecture-based instruction. This reveals that IBL is more effective than the lecture method in teaching capacitor concepts. Other studies support the finding of our study. Fan et al. (2018) concluded that interactive simulation-assisted inquiry-based teaching is more effective than conventional teaching in improving conceptual understanding. Hwang et al. (2013)

found that inquiry-based mobile learning has more positive effects than a traditional approach on student achievement. IBL gives learners the opportunity to consider a problem, to form a hypothesis about the solution, and to test this hypothesis. The hypothesis-forming and testing process allows learners to become aware of and replace their misconceptions with science-based concepts. Testing hypotheses in science requires experimentation and data collection. However, school laboratories may lack experimental sets for the teaching of many concepts, and there may not be sufficient experiment sets for all students. In this case, simulations are a good alternative to real experiments for performing inquiry-based activities. Başer and Durmuş (2010) determined that IBL using simulations is as effective as IBL using real laboratory experiments. Husnaini and Chen (2019) determined that IBL-supported virtual laboratory implementations are as effective as real laboratory implementations in teaching simple concepts and more effective in teaching difficult concepts.

In the control group, lecture-based instruction was supported by demonstration experiments with simulations to limit the effect of using only simulation on the dependent variable. After the implementation, however, although the control group improved their scores on the concept test, they improved less than the experimental group. The findings revealed that a large majority of the participants had various misconceptions about parallel plate capacitors, particularly that capacitors could store a net charge. Başer and Geban (2007) report that the likely cause of this misconception is the textbook definition that states, “Capacitance is the ability of a capacitor to store charge.” In line with this definition, participants found it difficult to understand that the total charge in both plates of a capacitor is not zero. Before the implementation, no participants from either group mentioned the concept of absolute charge; afterward, however, those in the experimental group showed evidence of understanding concepts such as absolute charge and charging by induction. The simulation shows the charge, along with its symbol, that is accumulated in the plates of the capacitor. Testing their hypotheses, the participants were able to note the charges of the plates. Thus, conflicts emerged between their beliefs and their observations, leading to the questioning of their previous misconceptions. Experimental findings were reinforced with information gathered from the literature and class discussions, triggering a turning point—the differentiation between a capacitor’s net charge and absolute charge. In the control group, the zero net charge in the plates of the capacitor was emphasized, which was illustrated with diagrams drawn on the board, and the simulation program was used in a demonstration. However, the results show not only that this lecture-based instruction was ineffective in eliminating this misconception but also that it led to the formation of another: namely, that there was no charge in the plates of the capacitor. This was likely because of the lack of opportunity to inquire into the subject, leading to participants’ uncritical acceptance of what they heard.

Another finding revealed by the research is that one of the preexisting misconceptions was not sufficiently changed in the experimental group, reflecting the situation in the control group, after the implementation. Prior to the implementation, the participants had difficulty explaining a particular point: that the potential difference between the plates of a capacitor connected to a battery was independent of its capacitance. The review of the participants’ responses showed related misconceptions. Participants thought a battery was a fixed source of current and a provider of a fixed charge, that a battery provided the capacitor with a fixed magnitude of charge, and, therefore, that bringing the plates closer to each other would have no effect. The capacitance of the capacitor would increase as a result. According to the equation $Q=C.V$, the potential difference between the plates of the capacitor must decrease for the charge to remain the same. This situation illustrates the negative effects of misconceptions about electric current on learning about capacitors. McDermott and Shaffer

(1992) report that students believe not that the potential difference between an ideal battery's poles is fixed but, rather, that a battery is a constant source of electric current. Other studies on the subject of electric current also indicate that students think that a battery is a source of constant current (Cohen et al., 1983; Küçüközer & Kocakulah, 2007; Tarciso Borges & Gilbert, 1999). At the end of the implementation, this particular misconception continued unchecked in the control group. The participants in the experimental group made less reference to the battery as a source of fixed current, but the misconception did not entirely disappear. This was likely because the inquiry-based activities were set up without considering the misconceptions that existed about the topic of electric currents. The participants were not involved in investigations of the topics of batteries and electric currents, and thus, they did not find the opportunity to test their conceptions in these fields. To achieve a complete conceptual understanding of capacitors, we recommend activities to counter the idea that a battery provides a fixed magnitude of charge.

Simulation-supported IBL caused a significant change in all other concepts as determined by concept testing. Our findings reveal that simulation-supported IBL is extremely effective in overcoming misconceptions, a major issue in science education. A literature search reveals other studies showing the effectiveness of IBL in concept teaching (Marchionda, 2006; Prince et al., 2016; Trundle et al., 2010). Posner et al. (1982) maintain that for conceptual change to take place, learners must be dissatisfied with their existing conceptions and that new concepts must be intelligible, plausible, and fruitful. The lecture-based instruction method does not fully provide these conditions. IBL, however, led students to question their existing conceptions, explore the possibility that prior knowledge was mistaken, and test new hypotheses with experiments of their own. Students were able to support their newly learned concepts with their experiments and, later, a review of the literature. Understanding that the new knowledge was in concordance with the concept and that it could be used to solve other problems made the newly learned concept more intelligible, plausible, and fruitful in the students' minds. This, in turn, provided the students with the opportunity to experience a more meaningful process of conceptual change.

Developments in technology have resulted in educational computer simulations developing both quantitatively and qualitatively. Teachers today have free access to high-quality simulations in many fields of science. However, these simulations are more effective at bringing conceptual change when integrated into the IBL process, compared with lecture-based instruction.

The simulations used in the study enabled the participants to observe the charges on the capacitor plates. By manipulating some variables in the simulation, they were able to directly observe how the charge was affected in a way that is not possible in real laboratory experiments. Another possible subject of research is a comparison of the effectiveness of real laboratory materials and simulations in inquiry-based activities regarding the change in concepts related to charge.

This research reveals the positive effect of IBL on conceptual change. In addition, previous studies in the literature show that IBL has a positive effect on many variables, such as success (Abdi, 2014; Khan et al., 2011; Maxwell et al., 2015; Wilson et al., 2010), scientific process skills (Af'idayani et al., 2018; Gunawan et al., 2019; Khan & Iqbal, 2011; Şimşek & Kabapınar, 2010), critical thinking (Kitot et al., 2010; Nisa et al., 2018; Qing et al., 2010), and science literacy (Gormally et al., 2009). Science education will benefit from the full

integration of IBL into the curriculum at all educational levels, from primary education to university.

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