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Effectiveness of Guided Inquiry Based Laboratory Instruction on Prospective Science Teachers' Procedural and Conceptual Understandings

Rehberli Sorgulamaya Dayalı Öğretimin Fen Bilgisi Öğretmen Adaylarının İşlemsel ve Kavramsal Anlamalarına Etkisi

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ABSTRACT

The purpose of this study was to interrogate the effectiveness of open guided inquiry laboratory approach on prospective science teachers' procedural and conceptual understanding of direct current circuits. The study was realized during the first year of teacher training program with participation of eight prospective science teachers (PST). Laboratory reports and observations notes were used as data collection instruments. The analysis, based on two fold effectiveness model considers what students do and achieve compared to what their teacher intended them to do and achieve. Inquiry based lab instruction was seen to be effective for nearly all PSTs in contributing to procedural understanding and conceptual understanding of a single loop circuit but not especially of a two-loop circuit containing resistors in parallel. It seems that activities in the domains of procedural and conceptual were improved depending on each other. Unavoidable scaffolding such as supplying experimental hardware and giving some hints by the lecturer during lab work contributed with varying amounts to the flow of activities and to learning outcomes from PSTs.

Keywords: Effectiveness, guided inquiry, direct current, circuit, prospective science teacher (PST)

ÖZ

Bu çalışmanın amacı, doğru akım devreleri konusunda yürütülen açık rehberli sorgulama laboratuvar yaklaşımının fen bilgisi öğretmen adaylarının işlemsel ve kavramsal anlamaları üzerindeki etkilerini incelemektir. Çalışma, öğretmen yetiştirme programının 1.sınıfında öğrenim gören sekiz fen bilgisi öğretmen adayının katılımıyla gerçekleştirilmiştir. Veri toplama aracı olarak laboratuvar raporları ve gözlem notları kullanılmıştır. Toplanan veriler çift yönlü etkililik modeli kullanılarak adayların konuyla ilgili ulaştığı kazanımlar ile öğretim elemanının hedeflediği kazanımlar karşılaştırmalı olarak analiz edilmiştir. Sorgulamaya dayalı laboratuvar yaklaşımının öğretmen adaylarının hedeflenen kazanımlara ulaşmalarında seri bağlı devrelerde paralel bağlı devrelere göre daha etkili olduğunu göstermiştir. İşlemsel ve kavramsal alanlarındaki etkinliklerin birbirine bağlı olarak geliştiği görülmüştür. Laboratuvar çalışmaları sırasında sağlanan destek ve rehberliğin etkinliklerin yürütülmesine ve öğretmen adaylarının öğrenme süreçlerine değişen derecelerde katkıda bulunduğu gözlenmiştir.

Anahtar Kelimeler: Etkililik, rehberli sorgulama, doğru akım, devre, öğretmen adayı

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Introduction

When schools began to teach science formally laboratory work became a characteristic feature of science education (Hofstein & Kind, 2012) and, at the beginning of twenty century, laboratory activities were used almost exclusively for illustrating information presented by the teacher and the textbook (Jenkins, 2002; Lunetta et al., 2007). With the reform in science education in the 1960s, the laboratory became the core of science learning and teaching processes (Hofstein & Lunetta, 1982) and the new curriculums planned to engage students in investigation, inquiry and hands-on activities (Lunetta et al., 2007). The aim of this approach was to have students understand science by performing activities in a school laboratory, such as designing experiments, collecting and processing data and reaching certain scientific relations. Studies during 1970–1980 showed that learning outcomes from school graduates did not quite match the proposed goals of science education (Lunetta et al., 2007), because teachers preferred a cook-book approach and teaching practice in the laboratory did not change much towards an open-ended style suggested by the reform (Tamir & Lunetta, 1981). In 1980-1990, there was little evidence about students being provided with opportunities to engage in the process of constructing knowledge by doing science in lab experience (Hodson, 1993; Tobin, 1990) and students failed to achieve the expected conceptual and procedural understandings. Hodson (2001) wrote that although essential outcomes for lab work were articulated in the past, the nature of student's performance in lab and related assessment practices remained relatively unchanged. After 1990s, rapid technological development calling for educational systems with high-quality science education required reforms in this area and provided support for inquiry learning (Bybee, 2000; Duit & Tesch, 2010; Hofstein & Kind, 2012). To offer students important opportunities such as investigative experience with which the students can construct scientific concepts, it was suggested that the school science laboratory should focus on inquiry (Hofstein & Lunetta, 2004). Because inquiry-focused teaching rests on the constructivist notion claiming that learning is a process in which the student actively constructs personal ideas and links them with other ideas in a complex network (Duschl & Grandy, 2008; Harlen, 2013). With scientific inquiry, it is expected that students are at least able to understand the rationale of an investigation and critically analyse the collected data (Lederman & Lederman, 2012).

In spite of changes occurred in science curriculums and teaching sources, many of the activities in the science laboratory continued ritualistically according to 'cook-book' type lists of tasks (Hofstein & Lunetta, 2004; Kind et al., 2011; Lunetta et al., 2007; Royuk & Brooks, 2003). Although this type of laboratory instruction is the most popular, and yet the most heavily criticized (Wieman, 2015), teachers' implementation of practical work did not seem to have changed over the last century (Hofstein & Kind, 2012; Mamlok-Naaman et al., 2018). One of the reasons for this situation, according to Tibergien et al. (2001), and Sere (2002), is that the objectives articulated for the laboratory (i.e. understanding theories, concepts, and laws; conducting experiments) were too numerous and comprehensive for teachers to address successfully in individual laboratory sessions. The other is that change or manipulation in the past and at present occurs in equipment but not in ideas is a problem related to teachers' fear of losing control in the classroom and assessment (Mamlok-Naaman et al., 2018; Millar & Abraham, 2009). Therefore, inquiry-type activities in science laboratory should be conducted in the context of and integration with concepts to be taught (Mamlok-Naaman et al., 2018) and limited by specific learning objectives (Abraham & Millar, 2008; Buning et al., 2018; Jenkins 1999; Sere, 2002).

'Inquiry' is one of the teaching and learning strategies that must be mastered to design courses and laboratories (Andersson, 2017; Forcino, 2013; Hofstein & Lunetta, 2004; Molohidis & Hatzikraniotis, 2018) and it is necessary to introduce prospective teachers to inquiry-based learning and affect epistemologies of PSTs (Crawford, 2000; Wilcox & Lewandowsky, 2016). Because inquiry as a learning strategy is interwoven with explicit instruction and well-scaffolding opportunities (Darling-Hammond et al., 2020), lab activities based on inquiry teaching approach can take multiple forms from teacher-lead to student-led processes as sometimes expressed by the degree of 'openness' (Hegarty-Hazel, 1986; Molohidis & Hatzikraniotis, 2018). The more responsibility students have for conducting an activity, the more "open" the inquiry; the more responsibility the teacher takes, the more "guided" the inquiry. For the students' gradual transition from verification to more open inquiry, the teacher should vary the amount of guidance (Eick et al., 2005; Molohidis & Hatzikraniotis, 2018): Verification inquiry indicates the closed lab approach to verify the theory and open inquiry corresponds to the open-ended lab procedure (Fitzgerald et al., 2019; Tiberghien et al., 2001). Due to its nature, an open-ended laboratory approach requires creativity, imaginative intelligence and experience and thus is challenging (Piaget, 1964; Toothacker, 1983) and open-ended experimental activities may only be learned in long-lasting step-by-step attempts

(Andersson, 2017; Duit & Tesh, 2010). In addition, minimal guidance in open inquiry may cause failure at acquisition of science content knowledge (Kirschner et al., 2006; Mayer, 2004).

Guided inquiry indicates the guided inquiry in which students are provided with the question and procedure but are requested to generate an explanation supported by the evidence they collected (Molohidis & Hatzikraniotis, 2018). In open guided inquiry students are provided with the research question, and sometimes with experimental setup, and are supposed to design the remaining steps. In this study lab activities on direct current circuits were conducted with open guided inquiry and their effectiveness on prospective science teachers' procedural and conceptual understanding of the subject was interrogated.

Theoretical Framework

In order for an assessment to be effective it is necessary to consider conceptual understanding, procedural understanding and related skills (Reiss et al., 2012). Conceptual understanding means a knowledge base of substantive concepts such as the laws of physics which are underpinned by scientific facts (Duggan & Gott, 2002). Conceptual knowledge refers to patterns and interrelationships among the basic elements within a larger structure that enable them to function together. Conceptual knowledge and 'factual' knowledge together is named as 'declarative' knowledge about facts (Jiamu, 2001). Procedural understanding means 'the thinking behind the doing' of science and is complementary to conceptual understanding (Gott & Duggan, 1995). It includes decisions on measurements, ranges, patterns of data and the completion of the task (Duggan & Gott, 2002).

Many studies have been conducted to investigate the educational effectiveness of lab works in science education (Hofstein et al., 2008) and preferred to assess student's knowledge of conventional science facts and indicated that students enjoy laboratory works (Lunetta et al., 2007). But, it was emphasized that little attention was paid to searching the characteristics, such as cognitive development, of the student sample, the nature of laboratory teaching by teachers and their expectations and assessment practices (Hofstein & Lunetta, 1982; 2004) and the interrelationships between various instructional approaches and their impact on learning outcomes in different contexts (Hmelo-Silver et al., 2007). Although the potential of laboratory learning is valued, its effect on students' learning is still controversial (Ding & Harskamp, 2011) and research findings in the effectiveness of practical work in enhancing the development of conceptual understanding in science remain ambiguous (Abraham & Millar, 2008; Abrahams & Reiss, 2012).

Although in literature a number of goals in laboratory instruction have been identified (Jenkins, 1999; Singer et al., 2006), the main purpose of all lab works for students should be to establish links between two 'domains' of knowledge: objects and observables and ideas (Tiberghien, 2000; Tiberghien et al., 2001). A useful model to develop and evaluate the effectiveness of laboratory work developed by Millar et al. (1999) is represented by Figure 1.

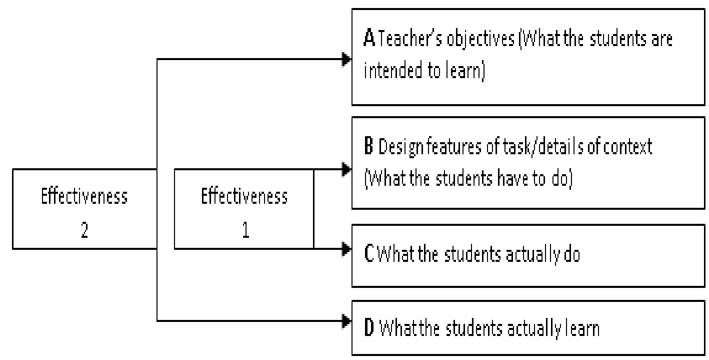


Figure 1.

Models of the Process of Design And Evaluation of a Practical Task by Millar et al. (1999)

The starting point, Box A, is the teacher's learning objectives,what the teacher wants the students to learn. The next step, Box B, is to design practical tasks that might enable students to achieve the desired learning objectives. Box C asks 'what the students actually do' and Box D, the final stage of the model, concerns 'what students learn as a result of the tasks'. This model distinguishes two category of effectiveness. Effectiveness 1 is the extent to which the students' actions match those intended by the teacher. A second and rather stronger measure of effectiveness 2 is the extent to which students' learning matches the learning objectives.

It is seen that this model will be a useful tool for us to assess the effectiveness of guided inquiry laboratory instruction in PSTs' procedural and conceptual understandings of direct current circuits. Effectiveness 1 is about procedural understanding and Effectiveness 2 is related to a better conceptual understanding resulting from different lab approaches (Lazarowitz & Tamir, 1995; Psillos & Niedderer, 2002). In effectiveness model, differently experimental studies, the relationship between the instructor's expectations from teaching and the learners' achievements is evaluated as effectiveness. Therefore, in this study, answers were sought for the following two research questions:

- How does guided inquiry based laboratory instruction contribute to prospective science teachers' procedural understanding about direct current circuits?

- How does guided inquiry based laboratory instruction contribute to prospective science teachers' conceptual understanding of direct current circuits?

Methods

Context and Participants

Designed lab activities were conducted with prospective science teachers of the teacher training program in a state university. Because current scientific education curriculum encourages instructors to adopt inquiry-based teaching methodologies, integrating inquiry approaches into teacher training procedures is critical. PSTs graduated from primary and secondary schools with teaching programs which require designing learning environments to be based on inquiry. The PSTs participating in this study had some prior knowledge about DC circuits obtained in primary and secondary education.

In addition, science courses in the teacher training program of the university where this research was conducted are run using generally the didactic approach and the laboratory works are conducted using traditional approaches of verifying the facts taught in lectures or written in textbooks. The rationales for adopting this pedagogical approach have been examined in the context of various studies (e.g. Arslan et al., 2014; Feyzioğlu et al., 2014, Feyzioğlu, 2019): Limitations in time and resources such as tutors and materials and crowded classes naturally affected experimental activities which students were requested to complete step by step, reach certain results and write lab reports until the next session. Following the new regulations in accepting students to teacher training programs, a decrease in the number of prospective science teachers occurred. This decrease provided better opportunities for our participants to be engaged in inquiry-based lab approach.

This study was realized during the first year of teacher training program with participation of all the PSTs (eight PSTs) who attended the Physics II course, four hours in a week, and the Physics II Laboratory, two hours in a week. Although there were many subjects within the scope of this course, the subject of simple electric circuits appropriate for experiment was selected which is common in primary and secondary education programs with alternative conceptions (Engelhart & Beichner, 2004; Lee & Law, 2001). The subject of current and circuits was intentionally not taught theoretically in the Physics II lectures until the activities in the lab ended because the researcher planned not to be involved in the subject before the lab instruction.

Process

Because laboratory work includes a wide variety of tasks, to question the effectiveness of laboratory activities it is recommended that specific learning objectives (LO) be specified (Millar et al., 2002). During lab activities, participants were tasked with devising and constructing electrical circuit mechanisms aimed at elucidating the correlation between current and potential difference in both series and parallel circuits concerning electric current. To achieve this goal, a series of studies during five weeks was designed in a progressive manner.

Week 1: Setting up a simple electric circuit consisting of a single bulb and a battery, observing the brightness of the bulb, drawing the circuit diagram and measuring the current.

Week 2: Measurement of current in a series-connected circuit and exploration of the impact of varying potential difference on current.

Week 3: Measurement of current in a parallel-connected circuit and investigation of the influence of potential difference charges on current.

Week 4: Examination of potential values variations between different circuit elements in a series-connected circuit (between battery terminals, between individual bulb ends, and across the end points of the series combination), along with an analysis of how changes in potential difference affect these measurements.

Week 5: Evaluation of potential difference between the ends of different circuit elements in a parallel-connected circuit (between battery terminals, between individual bulb ends, and across the end points of the series combination), and an exploration of the impact of potential difference changes on these measurements.

Considering the general structure of inquiry-based activities, the inquiry process was carried out every week within the framework of the following steps:

Step 1: The first stage involves presenting the problem upon which the experimental setup is based.

Step 2: Following that, a comprehensive group discussion is conducted to determine the characteristics of the electrical circuit that can be designed in accordance with the problem.

Step 3: Subsequently, each participant engages in the individual design and assembly of electrical circuits that are suitable for addressing the problem.

Step 4: During this step, the lecturer observes the students' work and provides guidance as needed.

Step 5: Finally, there is an evaluation of the completed experimental setups. In this phase, the instructor assesses the accuracy of the students' work. If any setup is found to be incomplete or incorrectly configured, the instructor asks probing questions to help the students identify and rectify the issues. For instance, if the lamp isn't lighting up, the instructor might inquire about the circuit's correct setup and potential mistakes, guiding the students accordingly. Depending on the specific situation, various forms of guidance are provided. For instance, students may be asked to draw a parallel-connected electrical circuit diagram first and then use it as a reference to construct the actual electrical circuit using real materials.

The difficulties observed during the inquiry process and the interventions are summarized below:

In the first week of the lab activities PSTs use of a power supply in setting up the required electric circuit was observed, with the result that the bulbs were not lighted, because inappropriate terminals on the power supply were used (Difficulties 1). For example, one end of the circuit was inserted in the port DC/1.5V while the other end was put in AC/1.5V or in DC/3V. The lecturer reminded PSTs to work with direct current (DC) quantities while the abbreviation AC stands for alternating current. A number of PSTs were observed to have some difficulties in measurement with an ammeter. In one of them some PSTs used the ammeter with mA (miliAmpere) scale instead of A scale and were not able to determine the current (Difficulties 2). The other difficulty aroused in estimating the current values corresponding to intermediate divisions on the ammeter (Difficulties 3). The lecturer supplied guidance on reading of the intermediate positions of the pointer and the fact that the current values would be too large for a mA device to measure.

In the first three weeks PSTs performed activities on current measurements in one and two loop circuits, reading the potential differences displayed on the supplying source without using a voltmeter. During the activities with two loop circuits the majority of ammeter connections were erroneous as exemplified in Figure 2.

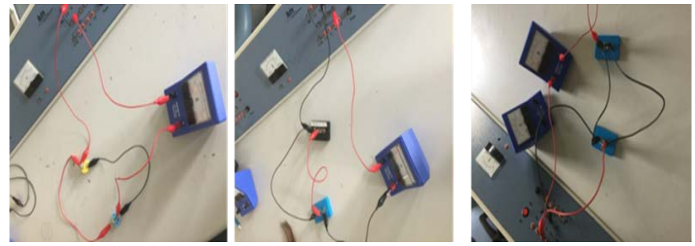
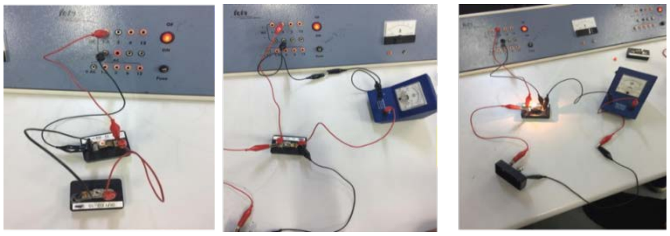


Figure 2.
Experimental Configurations set up by PSTs

A tendency of PSTs to connect one end of the ammeter to the power source was observed which can be attributed to the effect of the connecting style used in a single loop, where it was valid (Difficulties 4). The very tendency may be seen in measuring the current through a single loop circuit with two bulbs in series, too, where one would normally expect to insert the ammeter between the two bulbs. But none of the PSTs carried out such a connection.

In the third week, it was observed that PSTs had difficulty mostly in connecting the ammeter in parallel-connection circuits to measure the currents through various bulbs (Difficulties 5). Most PSTs initially set up their parallel circuit as in Figure 3a and connected the ammeter as in Figure 2 and, following guidance from the lecturer, set up the circuit as shown in Figure 3b, thus were able to measure the current through the main branch (Difficulties 6). Similarly, they became able to connect the ammeter correctly and measure the currents through the second bulb as shown in Figure 3c. To measure the current through the bulb near the power supply they connected the ammeter as shown in Figure 3b which means a repetition of the measurement of the main current, and thus failed to measure the intended current. The lecturer drew attention to the connection points in the circuit diagram and suggested the use of additional connection cables in circuit as shown in Figure 3a, thus contributed to the measurement of the current through the nearby bulb.

In the last two weeks PSTs measured potential differences in circuits connected in series and in parallel using a voltmeter. Although at the beginning some PSTs were not able to connect the voltmeter correctly to the series circuit, afterwards they did not in general have difficulty in using the voltmeter (Difficulties 7). It was observed that PSTs measured potential differences only between the ends of the bulbs, but they did not measure the potential difference between the terminals of the battery while the battery was supplying current to the circuit (Difficulties 8) . When they were asked why they did not, they stated that the potential difference (emf) of the battery or power supply was already known!



a b c

Figure 3.

Experimental Configurations set up by PSTs

During the execution of the inquiry-based activities, prospective teachers were also required to maintain laboratory diaries. These diaries had to document the circuits they constructed, the accompanying diagrams, and the measurements they obtained. The purpose of these diaries was to facilitate reflection and self-assessment.

Throughout the teaching process, the instructor played a crucial role by reviewing these diaries. The instructor's primary goal was to identify elements that could hinder the PSTs' scientific learning, such as errors, difficulties, or mistakes. The instructor intervened constructively, aiming to help PSTs recognize and rectify their shortcomings during the learning process.

Data Collection Instruments and Analysis

In this study, two sources were used as research data: the observation notes taken during practical exams were used to analyse participants' procedural learning and laboratory reports were used to analyse participants' conceptual learning.

Observations notes taken in the practical exam

Observations notes were used both to see the activities of PSTs, provide guidance on the challenges they faced, and assess performances in the practical exam; this exam was carried out three weeks after laboratory activities. In this exam, participants were required to perform independent laboratory activities, similar to the ones they conducted previously during the laboratory process, without any external assistance (such as such as configuring parallel and serial circuits and conducting the requisite measurements).

Laboratory Reports

The other data source was lab reports, important for researchers to make decisions about the next step in teaching, to assess and interpret student performance and the effects of laboratory experience on learning (Lunetta et al., 2007). These reports, containing data obtained from all experiments and general results deduced from data, were written by PSTs following experimental activities. Data obtained from diaries and lab reports were analysed using deductive content analysis (Patton, 2002) with consideration of learning objectives. Firstly, data such as values of currents and potential differences in lab reports and diaries were compared for consistency and then diaries and lab reports together were analysed to understand how PSTs drew conclusions from their data. The laboratory reports encompass the data obtained by the PSTs from all the experiments they conducted throughout the entire instructional process and the results obtained by correlating these data with each other.

In summary, within these reports, PSTs are anticipated to establish the correlation between potential difference and current in a basic electrical circuit, as well as the correlation between potential difference and current in parallel and series-connected circuits.

Ethics committee approval was obtained from Giresun University Local Ethics Committee (Date: 28.04.2022, Number: E-50288587-050.01.04-87709). Written informed consent was obtained from pre-service teachers who participated in this study.

Data Analysis

In this study, the 'effectiveness' within the adopted Effectiveness model is assessed in terms of the correspondence between the instructor's expectations and the learners' achievements. To this end, the study first established objectives set by the instructor, determined from the course content, encompassing both procedural and conceptual learning and subsequently, compared the PSTs' attainment of these objectives.

According to Hunt et al. (2012), practical lab skills should be assessed by observing what the students are actually performing in the laboratory rather than assessing written lab reports or written lab examinations. Data from observing the practical exam in the lab were analysed using deductive content analysis considering the activities targeted by the instructor, while data from observing activities were analysed using inductive content analysis. In this analysis, the performance of the participants in each experimental study according to the objectives of the course (Table 1) was described as successful or unsuccessful, and then the participants were individually evaluated.

Table 1.
Courses' Objectives Regarding Procedural Learning

	Learning Objective	Successful / Unsuccessful
PLO_1	Setting up a simple direct current circuit	
PLO_2	Setting up an electric circuit with a series connection	
PLO_3	Measuring current in a circuit with a series connection	
PLO_4	Measuring potential differences in a circuit with a series connection	
PLO_5	Setting up an electric circuit with a parallel connection	
PLO_6	Measuring electric current through the main branch of a circuit with a parallel connection	
PLO_7	Measuring electric current through the branches of a circuit with a parallel connection	
PLO_8	Measuring potential differences in an electric circuit with a parallel connection	

Data obtained from lab reports were analysed using deductive content analysis with consideration of learning objectives. Based on the steps described by Patton (2002) regarding content analysis, at this stage, the Learning Objectives of the Physics II course, summarized below, were taken into consideration and the achievement of the objectives was evaluated by examining the participants' reports.

Table 2.
Courses' Objectives Regarding Conceptual Learning

	Learning Objective	Successful / Unsuccessful
CLO_1	For the same resistor, increasing applied potential difference increases current, decreasing applied potential difference decreases current (Ohm's law)	
CLO_2	For the same potential difference, a **series** combination of two resistors (bulbs) increases the equivalent resistance and decreases the electric current	
CLO_3	In a circuit consisting of equivalent bulbs connected in **series**, the currents through the bulbs are equal	
CLO_4	For the same potential difference, connecting a second equivalent resistor in **parallel** changes (decreases) the equivalent resistance and increases the current through the main branch	
CLO_5	In a circuit consisting of equivalent bulbs connected in **parallel**, the currents through all bulbs are equal	
CLO_6	In a circuit consisting of equivalent bulbs connected in **parallel,** the sum of the currents through the bulbs is equal to the current through the main branch	
CLO_7	In a circuit consisting of equivalent bulbs connected in **series**, potential differences between the ends of each of the bulbs are equal	
CLO_8	In a circuit consisting of equivalent bulbs connected in **series**, the sum of the potential differences between the ends of the bulbs is equal to the potential difference between the terminals of the battery	
CLO_9	The potential differences between the ends of the bulbs connected in **parallel** are equal to each other	
CLO_{10}	The potential difference between the ends of equivalent bulbs connected in **parallel** is equal to the potential difference between the terminals of the battery	

Role of the Researchers

Lab activities were administered by one of the researchers alone without teaching assistants and technicians. The researcher was the complete participant taking on the role of an insider, becoming a member of the group being studied and spending a sufficient but not too long to cause bias a time with PSTs. Use of triangulation methods and assigning the researcher the role of a complete participant are known to contribute to the internal validity of the study. In this study, the second researcher was involved in the identification and categorization of learning objectives, as well as in the validation of data analysis. In this context, the data analysis conducted by the first researcher was subjected to random verification, resulting in a high degree of consistency.

Results

Findings about prospective science teachers are presented in three sections, procedural and conceptual understandings and holistic analysis of achievement.

Prospective Science Teachers' Procedural Understanding

In this section findings obtained from the activities of PSTs in the practical exam, Effectiveness 1 which is related to procedural understanding, are presented in Table 3. According to Table, all of PSTs were able to set up a circuit containing a single bulb, circuits with two bulbs connected in series and in parallel and measure the values of current in the series connection.

Table 3.
Type of Activities in the Practical Exam and Successful PSTs

Types	Type of activity	Succeeding PSTs
PLO_1	Setting up a simple direct current circuit	8 PSTs
PLO_2	Setting up an electric circuit with series connection	8 PSTs
PLO_3	Measuring current in a circuit with series connection	8 PSTs
PLO_4	Measuring potential differences in an circuit with series connection	6 PSTs
PLO_5	Setting up an electric circuit with parallel connection	8 PSTs
PLO_6	Measuring electric current through the main branch of a circuit with parallel connection	5 PSTs
PLO_7	Measuring electric current through the branches of a circuit with parallel connection	5 PSTs
PLO_8	Measuring potential differences in an electric circuit with parallel connection	6 PSTs

According to Table 3 a minority of PSTs were unable to measure the potential differences in series and parallel connections, the main current and branch currents in a circuit with parallel connections.

It is seen that all of PSTs, except PST4, PST7 and PST8, set up all circuitry needed and measured the values of current and potential differences. While PST4 did not carry out type 6 and type 7 activities, PST7 and PST8 did not carry out type 4, 6, 7 and 8 activities. These PSTs did not succeed in measuring the potential differences in a series circuit, the currents and potential differences in a parallel circuit.

The data obtained during practical exam observation indicate that certain difficulties previously identified and intervened during the practice course have been resolved (Difficulties 1-4). The ongoing difficulties that are still encountered in the practical exam are summarized below.

- Difficulties 5 about connecting the ammeter in parallel-connection circuits to measure the currents through various bulbs.
- Difficulties 6 relating to measuring the current through the main branch,
- Difficulties 7 on connecting the voltmeter correctly to the series circuit.
- Difficulties 8 about measuring the potential difference between the terminals of the battery while the battery was supplying current to the circuit.

Prospective Science Teachers' Conceptual Understanding

In this section findings, obtained from reports, on Effectiveness 2 which is related to conceptual understanding giving the degree of matching between students' learning and the learning objectives, are presented (Table 4). The conceptual understanding would be known that the data obtained from the ammeter readings can be understood in terms of scientific ideas, i.e the flow of electric charge is conserved in a parallel circuit (Abrahams & Reiss, 2015).

Table 4 reveals that certain objectives (CLO5 and CLO7) were attained by every PST, while several (CLO1, CLO2, and CLO9) were nearly universally achieved by the participants. However, a few PSTs accomplished others (CLO4 and CLO10). The attainment of the remaining learning objectives is outlined as follows: (CLO3, CLO6, and CLO8).

It is seen that CLO5 and CLO7 are achieved by all PSTs who measured equal currents through identical resistances in a parallel circuit, for example:

Since i1=i2=0,4 A in C-6, the currents throu gh the bulbs are equal (PST3, lab report)

Table 4.
Learning Objectives and PSTs' Outcomes

LO	Details of Learning Objective (number of succeeding PSTs)	Succeeding PSTs
CLO_1	For the same resistor, increasing applied potential difference increases current, decreasing applied potential difference decreases current (Ohm's law)	7 PSTs
CLO_2	For the same potential difference, a **series** combination of two resistors (bulbs) increases the equivalent resistance and decreases the electric current	7 PSTs
CLO_3	In a circuit consisting of equivalent bulbs connected in **series**, the currents through the bulbs are equal	5 PSTs
CLO_4	For the same potential difference, connecting a second equivalent resistor in **parallel** changes (decreases) the equivalent resistance and increases the current through the main branch	2 PSTs
CLO_5	In a circuit consisting of equivalent bulbs connected in **parallel**, the currents through all bulbs are equal	8 PSTs
CLO_6	In a circuit consisting of equivalent bulbs connected in **parallel,** the sum of the currents through the bulbs is equal to the current through the main branch	4 PSTs
CLO_7	In a circuit consisting of equivalent bulbs connected in **series**, potential differences between the ends of each of the bulbs are equal	8 PSTs
CLO_8	In a circuit consisting of equivalent bulbs connected in **series**, the sum of the potential differences between the ends of the bulbs is equal to the potential difference between the terminals of the battery	3 PSTs
CLO_9	The potential differences between the ends of the bulbs connected in **parallel** are equal to each other	7 PSTs
CLO_{10}	The potential difference between the ends of equivalent bulbs connected in **parallel** is equal to the potential difference between the terminals of the battery	1 PSTs

On the other hand, all PSTs could set up a circuit containing two equivalent bulbs connected in series and measure the related currents as well as potential differences between the ends of each bulb and thus achieved CLO7:

Because values of potential differences between the ends of the bulbs are V1=V2=0, 5 volts, potentials are equal in C-3 (PST6, lab report).

But only three PSTs, PST2, 3, and 6, achieved CLO8 which states that the sum of the potential differences between the ends of the bulbs is equal to the potential difference between the terminals of the battery in a circuit of resistors in series. PST6 stated that 'because the potential differences between the ends of bulbs (V1=V2=0.5 volts) and this value is about half the battery voltage (1.5 V), the total potential difference across the chain of bulbs (1.0 V) will approximately be equal to the potential difference between the terminals of the battery in C-3'. While PST6 did not mention the reason of this difference, 0.5 volts, PST2 stated that the reason for this difference was either the internal resistance of the battery or the heat losses in the bulbs:

In C-4, the potential difference for the combined two bulbs is V = 2 volts, the potential difference between the terminals of the battery is 3V. The sum of the potential differences between the ends of the resistors is approximately equal to the potential difference of the battery. The reason why the total potential difference is measured as 2V instead of 3V is due to internal resistance of the battery or heat loss in the bulbs (PST2, lab report).

It was determined that PST2, like other PSTs, did not measure the potential difference between the terminals of the battery while the battery was supplying current to the circuit. They compared the potential difference between the terminals of the battery while the battery was not supplying current to the circuit with the potential difference between the ends of the chain of bulbs. The explanation of PST3, who had achieved CLO8, was based on a partition of voltage:

In C-4, the voltage values between the ends of individual bulbs are equal to half of the voltage of the battery. The voltage generated by the battery decreases inversely proportional to the number of bulbs connected in series. This causes the two bulbs connected in series to be less bright than a single bulb (PST3, diary).

PST3 explained using only the partition of the voltage of the battery by two bulbs, missing the effect of the decreasing current. Because of this reasoning, PST3 was not able to achieve CLO2 and CLO4 which are related to a change in the equivalent resistance and thus in the current. While all PSTs, except PST3, achieved CLO2, only two PSTs achieved CLO4. Whereas most PSTs, PST4, 5, 6, 9 and 10, measured the current through the main branch and determined an increase when an identical bulb is connected in parallel:

The currents in the main branches for C-2 and C-6 were, respectively, i2 = 0.2 A, and i3 = 0.4 A (PST4, diary).

The current for the main branches: in C-2, i2 = 0.24 A, in C-6, i3 = 0.44 A (PST5, Diary).

The current through the main branch of C-2 was increased from 0.32 A to 0.52 A, in C-6 (PST7, diary).

The current through the main branch of C-2 was increased from 0.2 A to 0.4 A, in C-6 (PST8, diary).

Although these PSTs measured the correct current values during practical work, they were not able to achieve CLO4. Most of these PSTs, PST4, 5, 9, and 10, also were not able to achieve CL06 targeting the equality of the sum of the currents through identical bulbs connected in parallel to the current in the main branch. CLO4, CLO8 and CLO10 were the learning objectives achieved by a small number of PSTs and the CLO3, targeting the equality of currents through identical bulbs connected in series, was achieved by half of PSTs as seen in Table 5. This table summarizes the total number of CLOs achieved by each PST and the achievement record (+, -) of each CLO.

Holistic analysis of prospective teachers' achievement of learning goals

Within this section, the outcomes of individual analysis, focusing on each participant, concerning the attainment of procedural and conceptual course objectives through inquiry laboratory practices among PSTs, are presented.

Table 5.

Prospective Science Teachers' Achievements of Learning Objectives

PSTs	Procedural Learning Objective (PLO)								
	1	2	3	4	5	6	7	8	T
PST_1	+	+	+	+	+	+	+	+	8
PST_2	+	+	+	+	+	+	+	+	8
PST_3	+	+	+	+	+	+	+	+	8
PST_4	+	+	+	+	+	-	-	+	6
PST_5	+	+	+	+	+	+	+	+	8
PST_6	+	+	+	+	+	+	+	+	8
PST_7	+	+	+	-	+	-	-	-	4
PST_8	+	+	+	-	+	-	-	-	4

+: Achieved LO; - : Not achieved LO

Upon examining the participants' attainment levels of the established objectives (Table 5), it becomes evident that the level of achievement for procedural learning objectives surpasses that of the conceptual learning objectives. Consequently, it is observed that a majority of the prospective teachers successfully met all of the procedural learning objectives, while only one PST managed to accomplish all of the conceptual learning objectives.

Table 5 and 6 also indicate that one PST successfully attained all of the course's (procedural and conceptual) learning objectives. Additionally, four of the participants achieved a total of 13 or more objectives; two prospective teachers reached over half of the targeted objectives and one PST attained only half of the targeted objectives.

Table 6.

Prospective Science Teachers' Achievements of Learning Objectives

PSTs	Conceptual Learning Objectives (CLO)										
	1	2	3	4	5	6	7	8	9	10	T
PST1	+	+	+	+	+	+	+	+	-	-	8
PST2	+	+	+	+	+	+	+	+	+	+	10
PST3	-	-	-	-	+	+	+	+	+	-	5
PST4	+	+	+	-	+	-	+	-	-	-	5
PST5	+	+	+	-	+	-	+	-	+	-	6
PST6	+	+	-	-	+	+	+	+	+	-	7
PST7	+	+	+	-	+	-	+	-	+	-	6
PST8	+	+	-	-	+	-	+	-	+	-	5

Discussion and Conclusion

In this study, data obtained from observations at the beginning of lab works showed that most of PSTs were able to set up simple electric circuits but had various difficulties for example in measuring with an ammeter and selecting the appropriate terminals on the power supply. These difficulties disappeared later and PSTs did not display problems of this type in the next weeks and in the practical exam. During lab activities, most PSTs were able to set up the electric circuits containing one or two resistors connected in series and measure the currents but they had difficulties in setting up the circuit with two resistors to be connected in parallel and in measuring the currents. In the following practical exam, it was observed that all PSTs were able to set up the circuit containing two resistors to be connected in parallel but three of them were not able to measure the currents in this circuit. Most PSTs also had difficulty in connecting the voltmeter to the circuit with series bulbs during activities, but in the practical exam, only two of them were unsuccessful in measuring the potential differences. This fact points out that lab activities contributed to all PSTs' procedural understanding of setting up the needed circuits and measuring the current in a single loop circuit. The same is not valid for all PSTs' procedural understanding of measuring potential differences in circuits with series and parallel resistors and the electric currents in circuits with parallel resistors, similar to the results of Kariotoglou (2002) emphasizing partial achievements in reaching the procedural knowledge. The lab activities carried out without circuit diagrams or instruction manuals to follow were generally effective in enabling PSTs to do with objects and materials in single loop circuits, but effective for only the majority of PSTs in a two-loop circuit containing resistors in parallel.

Effectiveness 2 related to conceptual understanding means the degree of matching of what PSTs are intended to learn and what they actually learn (Table 4). Findings showed that all of PSTs reached almost half or more of the learning objectives. The CLOs reached by a small number of PSTs are related to the decrease in equivalent resistance when the number of bulbs connected in parallel is increased, and the connection between potential differences across the bulbs and the battery in series and parallel circuits. PSTs observed that an increase in the number of bulbs connected in series increased the resistance and decreased the current reached CLO2. However, the fact that the brightness of bulbs remained unchanged when the number of bulbs was increased in a parallel circuit might mask the decrease in equivalent resistance although the currents through the battery and resistor branches were measured by PSTs. This reminds the fact that practical work may be ineffective in directing students to reach scientific conclusions depending on their observations and data, no matter how carefully these are guided and constrained (Abrahams & Millar, 2008; Abrahams & Reiss, 2012; Pardo & Parker, 2010; Solomon, 1994). Among the reasons for most of PSTs to miss the internal resistance of the battery, and accordingly the relevant CLOs, one can mention the possibility that PSTs did not learn or remember this concept in their previous education and the lecturer did not supply any guidance on the issue. This supports the result that theoretical knowledge may influence and direct some PSTs about the experimental activities (Kariotoglou, 2002). If PSTs had been given extensive scaffolding and guidance (Hmelo-Silver et al., 2007) about measuring and comparing the potential differences across the battery while current circuit was or was not flowing through, more PSTs might possibly achieve CLO8 and CLO10. This finding is parallel to other results (Alfieri et al., 2011; Kirshner et al., 2006; Mayer, 2004) expressing that minimally guided instruction in a learning context in which learners must discover themselves does substantially not benefit them in improving learning outcomes. It seems that multiple scaffolding such as organising activities, supplying experimental tools and giving hints by the lecturer during lab activities contributed to continuing the flow of activities and to achieving most CLOs by PSTs (Darling-Hammond et al., 2020; Hmelo-Silver et al., 2007; Puntambekar & Kolodner, 2005; Quintana et al., 2004). However, scaffolding did not affect all PSTs to the same extent in achieving learning goals, in other words, ‘gains were not uniform over all learner profiles’ (Fernandez, 2017; Kariotoglou, 2002).

In spite of the fact that laboratory instruction plays an important role in the achievement of learning objectives, practical activities alone may not be sufficient to develop a fully scientific model of a circuit system (Hofstein & Lunetta, 1982; Sanches et al., 2016; Sanches et al., 2018; Van den Berg et al., 1994). Because the conceptual and procedural knowledge are not separated but intertwined so that students are led to the knowledge of one level by making use of the knowledge of the other (Millar, 1998; Séré, 1999), some PSTs had difficulties to develop a conceptual understanding of electric currents in parallel branches of an electric circuit in the domain of ideas, and they were not able to carry out the activities in a parallel circuit in the practical exam, the domain of observables. Although some studies using the twofold effectiveness showed that practical work was highly effective in the domain of observables because ‘recipe style’ tasks were widely used by teachers and less effective in the domain of ideas (Abrahams & Millar, 2008; Abrahams & Reiss, 2012) but in this study lab activities seemed to show similar effectiveness in both domains. The use of an effectiveness model by Millar et al. (1999) especially contributed to the awareness of the lecturer about the difficulties of PSTs in procedural and conceptual understanding and led to improvements in inquiry-based lab implementations. This situation supports the results of Nivalainen et al., (2013) pointing out that the instructors as well as preservice teachers need real experiences in implementing inquiry-based laboratory approaches.

Although PSTs did not carry out extensive pre-university practical work and did not yet face with theoretical background at the university on direct current circuitry, guided inquiry laboratory instruction is considered to be promising in improving the majority of PSTs’ procedural and conceptual understanding of the chosen subject and achievement of most LOs.

This study supports previous research indicating that directed inquiry improves secondary school students' scientific process abilities (Sağdıç et al. 2019) and conceptual understanding (e.g., Kale & Güzel, 2022; Yetiş, 2023;). Other studies, too, reported that guided inquiring laboratory instruction was more effective compared to traditional and more structured-guided inquiry instruction in developing content knowledge and process skills (Blanchard et al., 2010; Bunterm et al., 2014).

Based on the results of this study, it is recommended that future studies use various styles of inquiry, such as structured and confirmation, to suit participants' characteristics. Furthermore, future studies may provide comparative analyses of learning settings that use various types of inquiry.

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Genişletilmiş Özet

Giriş

Öğretim ortamlarının tasarlanmasında kullanılması gereken stratejilerden biri olan sorgulamanın, öğrenenlere bilgi, beceri ve bilimsel düşünme gibi farklı alanlarda kazanım sağlaması nedeniyle öğretim faaliyetleri kapsamında kullanılması gerekmektedir (Andersson, 2017; Wilcox & Lewandowsky, 2016). Bir öğrenme stratejisi olarak sorgulama, açık uçlu uygulamalar ve öğretmen desteği ile iç içe geçmiş bir yapıda olduğundan (Darling-Hammond ve ark., 2020), öğrenmenin sorumluluğunun öğretmenden öğrenciye, ardından tekrar öğretmene geçtiği bir öğrenme ortamı gerektirmektedir (Molohidis & Hatzikraniotisr, 2018). Bu geçişlerde yer alan rehberlik boyutu, öğrencilere neyin bırakılacağına göre değişkenlik gösteren bir destek olarak tanımlanmaktadır. Bir rehberlik sürecinin parçası olarak düşünülen sorgulamaya dayalı öğretim sürecinde, bir uçta geleneksel öğretmen önderliğindeki öğretimle sınırlandırılan doğrulayıcı sorgulama bulunurken, diğer tarafta öğrencilerin keşfederek öğrenmelerine imkan sağlayan aktiviteleri içeren açık sorgulama yer almaktadır (Minner ve ark., 2010). Bu iki düzey arasında, rehberliğin seviyesine göre rehberli sorgulama çeşitleri bulunmaktadır (Herron, 1971; Martin-Hansen, 2002; Schwab, 1962). Bu sorgulama çeşitleri öğrenenlere işlemsel, kavramsal, epistemik ve sosyal olmak üzere farklı alanlarda katkı sağlamakla birlikte, sorgulamaya dayalı öğretimin etkililiği genellikle sorgulamanın kavramsal alanına odaklanan ve iki grubun öğrenme sonuçlarının karşılaştırıldığı deneysel çalışmalar olmaktadır (Furtak ve ark., 2012). Ancak sorgulama ile öğrenenlerin sadece belirli öğrenme sonuçlarına ulaşmaları değil aynı zamanda bilimsel sorular geliştirmeleri, sonuca varabilmeleri için gerekli verileri toplayabilecekleri planlamaları yapmaları ve uygulamaya koymaları beklenmektedir (Lederman & Lederman, 2012). Bu nedenle bu çalışmada sorgulamanın yönergeleri yürütme ve veri toplama gibi özelliklerle ilişki olan işlemsel alanı ve belirli öğrenme sonuçlarına ulaşma anlamına gelen kavramsal anlama alanlarına odaklanılmıştır. Çalışmanın amacı açık rehberli sorgulamaya dayalı laboratuvar etkinliklerinin fen bilimleri öğretmen adaylarının basit elektrik devreleri konusundaki kavramsal ve işlemsel anlamalarına etkisini incelemektir.

Yöntem

Laboratuvar öğretimiyle ilgili literatürde pek çok amaç tanımlanmış olsa da (Singer ve ark., 2006) laboratuvar etkinliklerinin temel amacı ‘nesneler ve gözlemlenebilen olaylar’ ile ‘fikirler’ şeklindeki iki bilgi alanı arasında bağlantı kurmaktır. (Tiberghien et al., 2001). Bu çalışmada laboratuvar çalışmalarının etkinliğinin değerlendirilmesi için Millar ve ark. (1999) tarafından geliştirilen çift yönlü bir etkililik modeli kullanılmıştır. 2 farklı etkililiğin tanımlandığı bu modelde, işlemsel anlamayla ilgili Etkililik 1 öğrencilerin davranışlarının öğretmenin hedeflediği davranışlarla, kavramsal anlamaya odaklı Etkililik 2 ise öğrenci öğrenmesinin öğretmenin hedeflediği öğrenme ile ne ölçüde uyumlu olduğu anlamına gelmektedir (Psillos & Niedderer, 2002).

Çalışma kapsamında bir devlet üniversitesinin öğretmen yetiştirme programın ilk yılında öğrenim gören sekiz fen bilimleri öğretmen adayı Fizik 2 dersi kapsamındaki laboratuvar etkinliklerine katılmıştır. Basit elektrik devreleri konusunun teorik dersteki öğretiminden önce yapılan laboratuvar çalışmaları haftada 2 saat olmak üzere 5 haftada tamamlanmıştır. Laboratuvar etkinlikleri kapsamlı görevler içerdiğinden, bu çalışmaların etkinliğinin sorgulanması için belirli öğrenme hedeflerinin belirlenmesi gerekmektedir (Millar ve ark., 2002). Etkinlikler sırasında, katılımcılara, elektrik akımı ile potansiyel fark arasındaki ilişkiyi açıklığa kavuşturmayı amaçlayan elektrik devrelerini tasarlama ve oluşturma görevleri verilmiştir. Bu hedefe ulaşmak için, beş hafta boyunca aşamalı bir şekilde tasarlanmış deneysel çalışmalar yapılmıştır.

Çalışmada veri toplama aracı olarak uygulamaları sınav sırasında alınan gözlem notları ile laboratuvar raporları kullanılmıştır. Gözlem notları katılımcıların işlemsel anlamalarını, laboratuvar raporları ise kavramsal anlamalarını analiz etmede kullanılmıştır. Laboratuvarda gerçekleştirilen uygulama sınavından elde edilen gözlem verileri, öğretmenin hedeflediği etkinlikler dikkate alınarak tümdengelimli, adaylar tarafından yapılan etkinliklerin gözlemlenmesinden elde edilen veriler ise tümevarımsal içerik analizi kullanılarak çözümlenmiştir.

Bulgular ve Sonuç

İşlemsel anlamayla ilgili Etkililik1 için elde bulgular başlangıçta adayların çoğunun basit elektrik devreleri kurabilme yeteneğine sahip olduğunu ancak bir ampermetre ile ölçüm yapma ve güç kaynağındaki uygun terminalleri seçme gibi zorluklar yaşadığını göstermiştir. Bu zorluklar sonraki haftalarda uygulamalı sınavda sergilenmemiştir. Laboratuvar faaliyetleri sırasında, çoğu adayın seri bağlı bir veya iki direnç içeren elektrik devrelerini kurabilme ve akımları ölçme konusunda yetenekli olduğu ancak iki direncin paralel bağlanmasını gerektiren devre kurulumunda ve akımların ölçümünde zorluklar yaşadıkları gözlenmiştir. Uygulama sınavında tüm adayların iki direnci paralel olarak bağlayabildikleri ancak üç adayın bu devrede akımları ölçemedikleri gözlenmiştir. Ayrıca, çoğu adayın süreçte seri bağlı devreye voltmetreyi bağlamakta zorlandığı fakat uygulamalı sınavda sadece ikisinin bu probleminin devam ettiği belirlenmiştir. Bu bulgu laboratuvar faaliyetlerinin tüm adayların gerekli devreleri kurma ve tek gözlü devrelerde akım ölçme konusundaki işlemsel anlamalarına katkı sağladığını göstermiştir. Aynı durum seri ve paralel dirençler içeren devrelerde potansiyel farkları ve paralel dirençler içeren devrelerde elektrik akımlarını ölçme konusundaki tüm adayların işlemsel anlamaları için geçerli olmamıştır. Devre şemaları veya yönergeler olmadan gerçekleştirilen laboratuvar faaliyetleri genellikle adayların tek gözlü devrelerde nesneler ve malzemelerle iş yapabilme becerisini sağlamada etkili olurken, dirençlerin paralel bağlandığı iki gözlü devrelerde daha az etkili olmuştur.

Kavramsal anlamayla ilgili Etkililik 2 için elde edilen bulgular, tüm adayların öğrenme hedeflerinin neredeyse yarısını veya daha fazlasına ulaştığını göstermiştir. Az sayıda aday tarafından ulaşılan öğrenme hedefleri paralel bağlanan lamba sayısı arttıkça eşdeğer direncin azalması ve seri ve paralel devrelerde lambalar arasındaki potansiyel farklarla pil arasındaki bağlantı ile ilgili olmuştur. Aktivitelerin düzenlenmesi, deneysel araçların sağlanması ve laboratuvar faaliyetleri sırasında ipuçları verilmesi gibi desteklerin her birey için farklı olmakla birlikte adayların öğrenme hedeflerine ulaşma sürecini sürdürmeye ve tamamlamaya katkıda bulunduğu görülmüştür.

İşlemsel ve kavramsal bilgi iç içe olduğundan öğrenenler bir alandaki bilgiyi diğer alandaki bilgiyi kullanarak analiz etmektedir. Bu nedenle laboratuvar etkinlikleri tek başına bir devre sisteminin bilimsel bir modelini geliştirmek için yeterli olamamaktadır. Bu nedenle, bazı adaylar fikirsel olarak bir elektrik devresinin paralel kollarındaki elektrik akımlarının kavramsal bir anlayışını geliştirmekte zorluk yaşamışlar ve gözlemlenebilirler alanda paralel bir devredeki faaliyetleri de gerçekleştirememişlerdir. Etkililik 1-2 modelini kullanan bazı çalışmalar, yönerge doğrultusunda yapılan laboratuvar faaliyetlerinin öğretmenler tarafından yaygın bir şekilde kullanılması nedeniyle pratik çalışmanın gözlemlenebilirler alanında oldukça etkili olduğunu ve fikirler alanında daha az etkili olduğunu göstermiştir. Ancak, bu çalışmada açık rehberli laboratuvar etkinliklerinin her iki alanda benzer etkililik gösterdiği görülmektedir. Adaylar ders kapsamında doğru akım devreleri hakkında teorik bir arka planla karşılaşmamış olmalarına rağmen, rehberli sorgulama laboratuvarı yöntemi, seçilen konunun çoğu adayın işlemsel ve kavramsal anlamalarını geliştirmede ve çoğu öğrenme hedefine ulaşmada umut vaat edici olarak değerlendirilmiştir.