

AN ACTIVITY RELATED TO THE USE OF ARGUMENTATION-DRIVEN INQUIRY METHODS IN ELECTRICITY ENERGY TOPIC¹

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ABSTRACT

This study reports on the implementation of an activity that used argument-driven inquiry methods and its effects on students' learning. "Let's Examine the Serial Circuits" activity on the "Electricity Energy" unit was developed and implemented in a science lesson with the participation of 32 seventh grade students. As a result of participating in the activity, the students comprehended that the brightness of a lamp depends on the total resistance of the circuit and the current flowing through the lamp when the voltage is constant in series connected circuits. Also, the students improved their teamwork and communication skills. As a result of this study, we suggest (1) applying the argument-driven inquiry method to teach the other science units and examining the effects on student learning (2) determining the effects of the argument-driven inquiry method on the acquisition of other skills important in 21st century such as creativity and innovation.

Keywords: argumentation based inquiry, electricity energy, science education.

ARGÜMANTASYONA DAYALI SORGULAMA YÖNTEMİNİN ELEKTRİK ENERJİSİ KONUSUNDA KULLANIMINA İLİŞKİN ETKİNLİK ÖRNEĞİ

ÖZ

Bu çalışmada, fen derslerinde argümantasyona dayalı sorgulama yönteminin kullanımına ilişkin bir etkinliğin uygulama örneği ve uygulamanın öğrencilerin öğrenmeleri üzerindeki etkileri hakkında bilgilere yer verilmesi amaçlanmıştır. Bu amaçla 7. sınıf "Elektrik Enerji" ünitesi ampul parlaklığı ile direnç ilişkisi konusuna yönelik olarak "Seri Bağlı Devreyi İnceleyelim" etkinliği geliştirilmiştir. Geliştirilen etkinlik, 7. sınıfta öğrenim gören 32 öğrencinin katılımıyla fen bilimleri dersinde uygulanmıştır. Uygulamalar sonucunda öğrencilerin, seri bağlı devrelerde gerilim sabit iken ampul parlaklığı ile devrenin toplam direnci ve ampulün üzerinden geçen akım arasındaki ilişkiyi anlamlı şekilde öğrendikleri görülmüştür. Aynı zamanda öğrencilerde takım çalışması, iletişim becerisi gibi becerilerin geliştiği belirlenmiştir. Bu çalışma sonucunda argümantasyona dayalı sorgulama yönteminin, (1) Fen bilimleri dersi kapsamında yer alan diğer ünitelerin öğretiminde de uygulanması ve öğrenci öğrenmeleri üzerindeki etkisinin belirlenmesi ve (2) Yirmi birinci yüzyıl becerileri kapsamında ele alınan yaratıcılık ve yenilikçilik gibi diğer becerilerin öğrencilere kazandırılmasındaki etkisinin belirlenmesine yönelik benzer çalışmaların gerçekleştirilmesi önerilebilir.

Anahtar kelimeler: argümantasyona dayalı sorgulama, elektrik enerjisi, fen bilimleri eğitimi.

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INTRODUCTION

Both the nature and the focus of science courses have shifted in the way how students perceive the concept of science, how they develop new knowledge, how they can credit the source of the information, and how they should relate it to the real world, rather than being just information buyers without such special interests. And this raised the issue that teachers are in need of new teaching methods that allow students to apply a “design-carry out-evaluation” approach onto a science problem, to develop their arguments throughout this process and to discuss and criticize those arguments with their peers (Sampson, Grooms, & Walker, 2009). It can be said that the Argument-Driven Inquiry [ADI] is an effective method that meets the need issued. The ADI is a method in which students determine their own guiding question for the investigation, design-carry out-evaluation the most appropriate method to solve this question and discuss all stages of this process with their peers (Sampson & Gleim, 2009).

The ADI consists of eight interrelated stages. *The first stage* is the identification of the task and a guiding question. At this stage, the teacher introduces a surprising case and a problem to be solved about this case to the students (Sampson & Walker, 2012). The students identify a guiding question to solve the problem given. *The second stage* involves designing a method and collecting data. Students work in small groups to design and carry out the most appropriate method to answer their guiding question and also collect data to solve the problem (Sampson et al., 2014). *The third stage* is the data analysis and the production of a tentative argument. The groups analyze and interpret the data and then develop their tentative arguments (Walker, Sampson, Grooms, Anderson, & Zimmerman, 2012). *The fourth stage* is an argumentation session. Each group shares, discusses, and evaluates its own argument with other groups and revises the argument if needed (Sampson, Enderle, Grooms, & Witte, 2013). *The fifth stage* is an explicit and reflective discussion in which a large group discussion (class discussion) is held. Under the guidance of the teacher, the students share what they have learned about their guiding questions and, based on this experience, exchange ideas on

the nature of science or the nature of scientific research (Sampson et al., 2009). *The sixth stage* is the creation of a written investigation report. Students work individually to write their investigation reports experiencing the writing process of a scientist (Sampson et al., 2014; Wallace, Hand, & Prain 2004). The students are encouraged to use tables and graphs to organize the data they have collected, and to make use of them in their reports. In writing their reports, the students answer the questions “What question were you trying to answer and why?”, “What did you do and why?” and “What is your claim after the scientific inquiry?” *The seventh stage* includes a double-blind peer review of these reports to ensure quality. The students have the opportunity to read different reports and discover new ways of organizing and presenting information (Sampson et al., 2011). *The final stage* is the revision of the report considering feedbacks after peer reviews, and submitting the final paper. These eight stages are presented in detail in Appendix 1.

The review of related literature revealed that the ADI has positive impacts mostly on university and high school level students in terms of advancing their scientific writing and metacognitive skills, learning the concepts of science subjects, and the development of their oral and written argument skills (Enderle, Groom, & Sampson, 2013; Erenler, 2017; Sampson et al., 2011; Sampson & Walker, 2013; Walker et al., 2012). Besides, only two research studies have been spotted regarding the application of ADI method in primary and middle school education. In the first one, the effects of ADI method on fourth grade students' learning of the science and their willingness to participate in argumentation were investigated (Chen, Wang, Lu, Lin, & Hong, 2016). The other study aimed to identify contributions of the ADI to the academic achievements of seventh-grade students, and to determine its impacts on students' willingness to participate in the discussion and their argumentation level (Aktaş, 2017). Accordingly, it can be concluded that the number of local and international studies regarding the use of the ADI method among middle school students is limited. Therefore, the aim of this study is to introduce a sample science activity which used the ADI method with the participation of middle school

students, and to give information about the effects of this application on the students' learning. We argue that the application of ADI method in middle school science courses will contribute to students' learning of science concepts and it will have influences on their developing certain life skills.

ACTIVITY IMPLEMENTATION

“Let’s Examine a Series Circuit” activity concerns the “Electricity Energy” unit in the seventh grade and the topic of “the relation between the light bulb brightness in series circuits”, aiming the standard “7.6.1.7. *Relates the brightness difference with electrical resistance in cases where the bulbs are connected serial and parallel.*” (Ministry of National Education [MoNE], 2013, p. 36). As mentioned above, this activity was designed and implemented by using “Argument-Driven Inquiry method” in science teaching. The study was carried out with 32 students studying in the seventh grade in a state middle school located in the Aegean Region in Turkey. Throughout this activity, students conducted a scientific inquiry study in the science laboratory and the activity covered 6 class hours.

The main purpose of this study was to examine the implementation of an activity related to the use of ADI method in science courses and how it is applied in detail. Another aim of this study was to evaluate the effects of ADI methods in science courses on students' learning and development (conceptual understanding, life skills, etc.). For this purpose, while designing the “Let’s Examine a Series Circuit” activity, we focused on not only students' learning of science concepts such as total resistance, lightbulbs brightness, and current but also their enhancement of some life skills (teamwork, communication with argument). With the given prospects, in the fifth step of the activity (direct reflective class discussion), students were elaborately guided to adopt a standpoint about what an experiment by modelling the investigations of their own and their peers is meant to be, what the features of the experimental studies are, how significant experiments are in science and whether data and evidence concepts are the same. During the whole activity, students were frequently reminded about the essential features of an

argument and a inquiry process, by expressing the questions like what can be said about the brightness of the bulbs in the series circuits, what inquiry to undertake in order that they could recognize the brightness differences of the light bulbs in these circuits, how they can prove those differences to their peers. Within these circumstances, the activity was developed by the researchers (authors) and supported by science teachers and faculty members who were experts in physics.

Tools and Equipment

- The activity worksheet (Appendix 2)
 - Peer-review guide and instructor scoring rubric (Sampson et al., 2014)
 - Evaluation Questions (Appendix 3)
- Up to the number of groups;
- Lightbulbs and holders with different resistances
 - Switch
 - Conductor connection cables
 - Battery or power supply with voltages of various sizes (1.5V, 3V, 9V, etc.)
 - Battery holders
 - Ammeter
 - Voltmeter
 - Light sensor
 - Smart board or tablet computer

Application Steps

The first stage. At the beginning of this phase, the teacher creates heterogeneous groups of 3-4 students whose academic achievement level is different (weak-medium-good). However, the most important point here is that although the student group is formed by the teacher, the students work individually. The only purpose of grouping here is to create groups for the group work that will be carried out at latter stages of ADI method. In addition, the previously prepared activity sheet (Appendix 2) is delivered to each student. After that, brief information is given about the activity and what the students are expected to do. The students are then asked to take a look at the cartoon image on the “Let’s Examine a Series Circuit” activity sheet individually. It is about children called Alp, Hilal, Yavuz, and Simge, who talk about the brightness of the bulbs in series circuits. Here, the teacher can also read the activity him/herself or ask another student

to read aloud. Next, the teacher stimulates each student to get into topic, by asking questions such as “What is this cartoon about?” “What do you think this cartoon urges you to do?” “What do you think the problem illustrated in the concepts cartoon is or what should we investigate here?” “What do you think our guiding question should be here?” Immediately after that, students are asked to develop a guiding question. In this process, students' thoughts are not judged in a good-bad or right-wrong way and they are not told what to do directly. The students are encouraged to exchange ideas with their peers. At this stage, students are expected to develop a guiding question in order to find out the effect(s) of resistance onto lightbulbs' brightness and the effect(s) of current while voltage is constant in series circuits. Here, students are aimed to come up with the question “What are the variables that affect the brightness of the bulb while the voltage is constant in series-connected circuits?” One of the guiding questions developed in the current practice is “How does the brightness of the lamps change according to the connection styles of the circuits?” More examples are given in Appendix 4.

The second stage. At this stage, students work with the groups formed earlier at the first step. First, electrical circuit materials that students can use in their studies are distributed and lists containing them are handed out to each group. However, whether or not they will be used in this activity, these materials are given to the students in a mixed way so that they are able to decide which materials they are to use in their methods. The reason is not to influence students in their investigation methods. In addition to all these, a few minutes in the lesson might be spared to instruct in details how the students should use the components of the circuits most effectively. It is not as they are unfamiliar with those materials, but to prevent students from using them unconsciously and without following safety measures, as some students tend to test the functions of the batteries with their tongues or the crocodile clip of the conductor cables with their noses, like it had been observed previously. Also, during the activity, bulbs not functioning and lighting were detected in certain groups since they had 1.5 V batteries while their lamps required 2.5 V voltage. In

case of such incidents, the teacher should explain the use of circuit elements in order to prevent invalid or incomplete data collection.

When preparations and instruction mentioned above are completed, each student in the group reads his/her own guiding question for the investigation to the small group friends. Then, with the small groups of students, they make a short brainstorming on what they know about serial connection, current, voltage, and the measurement of current and voltage. The decision on what kind of information they need to investigate in order to determine the factors possibly affecting the brightness of the bulb in the series circuits follows the brainstorming period. Immediately thereafter, each student in the group states which way (among the ways in the cartoon of the warm-up session) he/she finds more reasonable to implement in the research, because speech bubbles in the concept cartoon contain alternate learning expressions about the brightness of the bulbs connected in series that appear common among students. In other words, in these speech bubbles, the arguments which are possible to be developed by the students within the scope of this activity are illustrated and students are guided what to inquire about in this activity. Therefore, during the activity, students are expected to choose one of the expressions in the concepts cartoon and to match it with the guiding question, then to design and operate a test arrangement to base their evidence and justifications. At this point, the teacher leads each student to brainstorm with the small groups of students about what they can do to resolve the guiding question they have identified.

In this part of the lesson, students need to be guided by the following questions:

- What is your guiding question in this research?
- What equipment will you need to collect the data you need?
- What data do you need to collect in your research?
- How will you measure the brightness of the bulb?
- In addition to serial circuit, which other factors might possibly alter the the brightness of the bulb?

However, the teacher never directly instructs how to do the experiment and never judges the validity and feasibility of the research method students designed. If there is an error or shortcoming in the students' background knowledge of the subject of electricity, small reminders or brief instructions about what the current and voltage are and how they are measured can be given. Figure 1 presents an example of the research methods they designed.

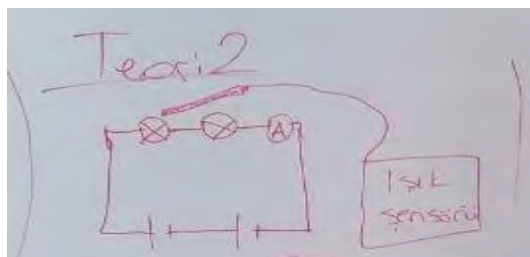


Figure 1. One Group's Research Method

Now, as the students have designed series circuit arrangements, data collection process can start. Here, just like illustrated in the cartoon, the students are expected to design three different serial circuits in which the ammeter and the voltmeter are used correctly and contain a varying number of bulbs in each. However, in the process, some of the students were able to design circuit arrangements as in the concepts cartoon, while others formed different circuits independent of the source design. This is because each group was given freedom to choose any methods to adopt in their research. Hence, the teacher can accept any types of circuit arrangement (1-2-4 bulb circuit or 1-3-5 bulb series circuits etc.) which provide the correct result. The focal point here is the fact that each group is able to collect data. To do this, each group can be guided through asking such questions below:

- How are you going to organize your data?
- How often should you measure the current in your circuits repeatedly?
- Between which two points should you measure the voltage?
- Where exactly in the circuit do you have to connect the ammeter in order to measure the current?
- When do you need to measure the current or the voltage again?
- Considering the brightness, what data that is measured by the light sensors should be recorded?

It should be emphasized that students must record their data regularly and re-make their measurements as much as possible. During the data collection process, students should be encouraged to use measurement tools such as ammeter, voltmeter, and light sensor, as it is very difficult to perceive the change in the brightness of the bulbs by the sense organs and to comprehend the reason for the difference in brightness in a series circuit is related to the electrical resistance. Some examples of the data collected by the students are given in Appendix 4.

The third stage. It is the process in which students work in small groups and analyze the data they collected in the previous stage and develop their tentative arguments. At this stage, firstly, the students evaluate the current and voltage related measurements (data) they have collected about the brightness of the bulbs in series circuits. Here, the teacher should guide the students by questions concerning how to compare and analyze data with each other. To give examples;

- What can be the reason why the bulb brightness is different in each measurement in the series circuit? What variables do you need to compare to explain this?
- When the battery voltage in the series circuit is considered stable, what is the reason for the change in the brightnesses of the bulbs every time you add a new one to the circuit? What values need to be compared to explain this?
- Why can the values in the ammeter be varying from the previous measurements?
- What kind of table or chart can you create to understand your data?

As a result of the data analysis, the students can make inferences such as "In series circuits, the brightness of the bulb decreases if the number of bulbs increases."

When the data analysis process is completed, each student group discusses with their peers in their group in order to reach a common point, which also stands for their tentative argument. This phase is defined as tentative argument process as students have not come together with the peers in other groups and have not received any criticism or feedbacks. During this period, each group might develop different arguments based on the data and analysis results they have, which results in more

debates among the groups, predicating the possible factors for the change in the brightness. The guiding questions that have led students to create different arguments also enable them to have a critical evaluation of alternative explanations for the problem. Each student group forms the argumentations again within their groups, in order to determine the best evidence and justifications to explain and support their claims. After the evaluation of their claims, evidence and justifications is over, they use A3 sheets given by the teacher and start preparing a poster, using the diagram in the sixth question of the worksheet. Therefore, each group makes the guiding question, claim, evidence and justifications distinctive and comprehensible for all groups. Examples of the posters designed by the students are presented in the Appendix 4.

After all, the teacher expects students to put forward a scientifically valid claim.

Claim: In a series circuit with a constant voltage, the total resistance of the circuit increases, and the brightness of the bulb A decreases if more bulbs are added to the circuit.

Evidence: The circuit in the first shape is a simple electrical circuit. In this circuit, the total voltage provided by the battery is 8V and the circulating current is 4 amps. If an identical bulb with the Bulb A in the first figure is connected in series, the battery voltage is equally shared by the two bulbs in the circuit, and the voltage at both ends of each bulb is 4V (see Fig. 2 in Appendix 2). It is due to the increase in total resistance while the voltage provided by the battery (difference of potential) is constant. Hence, if a bulb is added to the circuit while the battery voltage in the circuit is constant, the total resistance increases, the current decreases, and the brightness of the Bulb A decreases. In other words, the bulb's brightness decreases as the voltage in Bulb A decreases. In the meantime, the current in the circuit is measured as 2Amper. The current passing through the Bulb A is 2A. Three more bulbs identical with Bulb A were added in Figure 3. The value of the voltmeter connected to Bulb A in that new circuit is 2A, which means the voltage of the battery is one-fourth of the value in Figure 1. When the resistance of Bulb A is constant, the brightness decreases since the voltage of the lightbulbs and the current passing through it

decrease. This is due to the increase in the total number of bulbs in the series circuit, which also relates to the increase in the total resistance.

Justification: The Ohm's Law ($V = IR$) requires an inverse proportion between resistance and current when the voltage is constant in a circuit.

During the process of developing a tentative argument, students need an approval or a support given by the teacher. Begging for an approval, they may persistently make statements like "Sir/Ma'am, there must be a relationship between the voltage and the brightness, right?" or "Are we supposed to sum up the current and the voltage values?" or "Then, Dilem must be wrong and we should do it my way, am I right?" Therefore, what needs to be done is to go around all the groups and help the students with guiding questions. In such cases, the teacher is advised to ask guiding questions such as;

- What are we trying to figure out about the Bulb A?
 - What is the main reason for the different brightness of the Bulb A? What might have caused the difference in brightness?
 - What credits do you give to the explanation of your claim? What's your evidence here? (For example, the brightness of the Bulb A and the amount of voltage difference between the two ends of the lightbulbs, etc.)
 - Is your evidence sufficient to validate this claim? What other evidence would you need?
- In the beginning at this stage, the students may struggle to see the relation between the voltage and the current, and they may not reason the decrease in brightness as the number of bulbs increases (as the resistance increases). Therefore, the teacher should make sure that the students interpret the raw data accurately and precisely and they associate the claims with the evidence efficiently.

The fourth stage. This stage is the argumentation session. The group members come together with the peers from different groups. That is, one member of the group stays on his desk to share the group's argument, while other group members visit different groups to listen and criticize theirs. In these new groups, each student states their group's tentative argument, evidence and justification, evaluates their own argument, and finally

revises their argument. At this stage, the teacher should visit all groups individually and participate in their discussion to model / manage a good scientific debate because students may not be expressing themselves fully while telling other groups about their own arguments. For example, they may sometimes not be able to present their evidence adequately, or they may need to check their data once again while trying to persuade the opposing group, or even sometimes they forget to mention the reasons and the supporting ideas for their claims. The teacher's role here is to convince the students to use the experimental data they gathered in their research and to share their evidence with other students. To do so, he/she can encourage them to ask scientific questions such as "How did you analyze your data?" "Could it be that the data you collected didn't support your claim?" or "You used an ammeter on your circuit. You have not mentioned any of the data you collected. Tell me about them a little bit!" and to participate in the debate.

According to the observations, the students were able to make scientific dialogues with their peers while presenting group arguments to other classmates and defending their arguments or refuting the arguments of other groups. To illustrate, when presenting the argument to other groups, student group A noticed the mistakes that they had made in their own processes. They explained as follows.

We only measured the voltage between the two points onto which the battery was connected. Of course, this gave us the wrong result. Because Group B measured both the voltage between the two ends of the Bulb A and the two ends of the battery. So their data was more reliable...

Another student explained the communication with the other group as follows:

In the activity, my friend from group C really got me. Almost outwitted me. I mean the only difficulty for me was to explaining my idea or putting it forward. But he listened to me and I was convinced when he made his arguments clear..." (Student 16).

When the exchange of arguments and criticism parts are over, the students return back to their own groups, share the criticism received, and

revise their arguments over again. They may have to change their arguments, and analyze the data again or collect additional data.

The fifth stage. This is the stage of *explicit and reflective discussion*, in which students engage in class discussions with their classmates. At this stage, each research question-argument-proof-justification quartet developed by the groups is shown to the whole classroom, by either writing on the board or reflecting on the interactive board. In order to do this, the teacher should categorize all of the arguments by classifying similar/different ones, which requires a close tracking of the whole works done by the groups in the third and fourth stages of the activity; and he/she writes 3-5 arguments on the blackboard. The teacher should take care of two things here. First, the arguments written by the teacher on the board should be determined so as not to ignore the claim-proof-justification of any student groups. In other words, each group's argument must be written on the blackboard. The second is that if the students expose no arguments or scientifically valid arguments, he/she must write a new argument of his/her own to the blackboard. It shouldn't be underestimated that the arguments here can either be one of the early statements (like Yavuz's, Simge's) or a different argument from those. For example, a student can only end up with the conclusion that "I think the light bulb brightness in all circuits is different because the bulb closer the battery than Bulb A consumes a part of the bulb current before it." Such overgeneralizations might stem from two reasons that are (1) inability of each student to learn the same subject at the same level, or (2) potential student mistakes in analyzing the research question, methods, or data.

Then, each group tries to convince other groups about the validity of their argument. Students must provide sufficient justifications for the evidence they have chosen to use for the persuasion, and they must state why they chose what evidence to explain their arguments. While presenting evidence for their arguments, it is essential for students to clarify the underlying assumptions of their data analysis and interpretations. At that stage, according to observations, students tend to make such statements as the following for the justification of their evidence:

- We identified that the current measured by all ammeters in the circuit is the same. This also gives us the value of the main branch current in the circuit. So, the magnitude of the current passing through the lightbulbs is equal to each other.
- We calculated that the sum of the potential difference read between the ends of the Bulb A, B and C in Figure 3 is equal to the voltage of the battery.
- We identified that the current in Figure 3 is half of the current in Figure 2 when the Bulb C and D are connected.

In the course of the reflective class discussion, it is essential for students to reflect on the strengths and weaknesses of the research they have carried out in order to associate the links between the argument-evidence-justification and the assumptions behind them. Thus, students should be invited to discuss issues such as measurement errors in the research process, misinterpretation of data, and adequacy of data collected for the argument. For example, the teacher might ask the following questions:

- How did you collect your data?
- Why did you use this method?
- What have you done to make sure that the data you collect is reliable? What did you do to reduce the measurement error?
- Is this the only way to interpret your analysis results?
- How sure are you that your claims are valid? What did you do for this?

These questions can be directed not only by the teacher but also by the students to their peers who make presentations to give out the argument-proof-justification. At this point, the teacher should invite students to ask questions to their peers presenting at the board.

Even though some student groups successfully gathered their data during this activity period, it was observed that they had difficulty in interpreting and converting them into evidence. For example, in one case, the student was able to highlight that the sum of the values he read from the voltmeter connected to each bulb in separate circuits was equal to the voltage of the battery, but he could not relate it to his explanations for the comparison of the brightnesses of the Bulb A. In another case, the students mentioned the differences they had

measured in the values of the ammeters they used to determine the current passing through the Bulb A in different circuits, but they could not form a relationship between the brightness of the Bulb A and the current. Furthermore, some groups had difficulty in defending their arguments as they had insufficient data. For example, they used just one voltmeter in each circuit so they were able to measure only the battery voltage. As a result, they failed to explain the link between the brightness of the bulb and the voltage. In such situations, it is highly important for teachers to give effective guidance for reaching the scientific information. After all the arguments-evidence-justifications suggested by the students are discussed in detail, the scientifically valid knowledge (with the best reasons and the most reasonable justifications) could be reached. In short, students are able to end up with the fact “In series circuits, when the total voltage of the circuit is constant, the current decreases as total resistance of the circuit increases, and the bulb brightness decreases as the current decreases.” Next, depending on the students’ understandings, the teacher may revise the alternate notions of the students. Figure 2 illustrates one image of the reflective discussion process.



Figure 2. An Image of the Reflective Discussion Process.

Another essential thing at this stage is that the theme “nature of the science” can be explained through the students’ research processes. For this purpose, considering their own experimental studies - in which they tested the brightness, the current, the voltage of the Bulb A (dependent variable) and the addition of resistance into the circuit (independent variable) or such issues – a discussion takes place underlying not only the nature and the significance of science but also the differences between the data and evidence. In this respect,

the teacher can address several questions such as; “What type of task do you think it was?”, “Do you think the study in this activity was experimental or observational?”, “Why do you think it was an experimental study?”, “What are the features of experimental studies?”, “What are variables in your study?”, “What kind of graphics would you create for interpreting your data?”, “What is the evidence which supports this claim?” It was observed that the students, at the beginning of this activity, defined what an experiment is in bookish statements; however, in latter discussions they were able to direct the argumentation by referring back to their own experiments with examples. Besides, while students were phrasing the values read in ammeter and voltmeter as “data”, they occasionally confused “evidence” with “proof”; and they uttered the words interchangeably. However, during the discussion, the distinction between those two words was elaborately examined by using examples from the activity.

The sixth stage. In this part of the activity, students work individually to write their *investigation reports*. For this purpose, students use the free space given in the activity sheets (see Appendix 2). At this stage, students can also write any off-topic information in addition to the data, arguments and evidence they collected. Therefore, the teacher can take a look at some parts of the reports while they are being written, and give feedback to the students. Consequently, the teacher can ensure that the student will write the rest of the report more concisely. Appendix 5 shows an investigation report written by one of the students. Report writing process can be carried out during the class hour, or given as homework or even performed continuously in parallel with the first five steps of the activity. For example, in the first step of the activity, as soon as the students determine the guiding questions, they can be given 2 minutes to write the guiding questions onto the free space in their report sheets; or in the second step, the students can be given 15 minutes to write the relevant information onto the relevant sections immediately after the design-execution-termination processes are completed. Throughout the current practice of this activity, the report writing and the research process were conducted simultaneously.

The seventh stage. It is stage of double-blind peer review. Each student report is replicated to three copies. The report is also duplicated to the total number of copies from the referee's guideline. At this stage, the “Peer-Review Guide and Instructor Scoring Rubric” developed by Sampson et al. (2014) was used. The teacher then randomly distributes the reports and the referee's guide to the students so that each student evaluates the report of three different peers who are not in the same group. The teacher explains in detail to the students how to evaluate their peers' reports according to the referee's guide. At this point, the teacher warns the students to focus on the reports' being revision not required, acceptable, or not acceptable. The teacher can advice the students/referees that they are allowed to write a constructive referee feedback about why and how those statements should be revised, considering the criteria in the referee's guide. The teacher should remind them to write down their feedback onto the given spaces on the guidelines or on the report itself. During those readings, the teacher should invite students to critically review if the explicitness of their arguments (the brightness of Bulb A in the series circuit decreases) is sufficient, if the evidence supporting the argument (the total resistance increases and the current decreases, or total resistance increases and the voltage of Bulb A decreases) is provided, and if the justifications (when the total voltage of the circuit is constant, the current decreases if the resistance increases) are reasonable and strong enough.

In this part of the activity, students can work individually or in groups. This stage can be carried out within the class hour or given as homework. In our teaching practice, this part was given to students as homework. When the referee's guidelines from the students were examined, it was seen that they usually gave positive feedbacks to their peers. However, from the teachers' point of view, those reports needed to be corrected in terms of expressing the results in scientific language.

The eighth stage. The students revise their investigation reports taking the peer review feedbacks into account, and then submit the reports. The teacher might encounter two cases: First, some students write research reports well and may have received no

feedbacks or revisions by their peers. In this case, the student/author will delete the pen name in his report and write his own name, and submit the report and the referee guideline, which his peers evaluated, to his teacher. Second case, which is more common in classrooms, is that the reports need revisions although the peers who reviewed identified them as valid. In such cases, the student/author revises and rewrites his report considering the feedbacks given by the peers. There, the student/author has to write a *legend* which points out the revisions done. Subsequently, each student submits the final version of the report, the first version of the report, the referee guidelines and the commentary that the peer evaluates. The procedures in the eighth stage can be carried out during the class hours or given as homework. In this activity, this phase was carried out within the lesson. Table 1 presents the grading map which demonstrates the scores each student gave to their peers based on the referee guidelines.

Table 1. The Points That the Students Gave to Their Peers

	Frequency		
	No	Partially	Yes
Introduction and Guiding Question	2	15	15
Method	5	17	10
The Argument	5	11	16
Mechanics	0	14	18

Finally, using the referee's guide, the teacher evaluates the reports submitted by each student, scores them and ends the process. The teacher can give oral feedback to the students/authors about their reports in this process. The teacher can also use the scores to give a process-oriented grade to the students.

CONCLUSIONS and SUGGESTIONS

Considering the student reports, reflective diaries, and their answers to the evaluation questions, the students, at the end of this activity, have achieved a progress in understanding that bulb brightness is inversely proportional to the resistance and directly proportional to the current and voltage when the voltage is constant in series circuits. Students' use of terms such as ohm's law, tension, and current with 62% (5 out of 8

groups) in order to explain their ideas to their peers throughout the activity shows that there is significant progress in their conceptual learning. In this respect, it can be said that the Argument-Driven Inquiry method has positive effects on students' conceptual understanding aligning with related literature (Aktaş, 2017; Sampson & Gliem, 2009).

Also, when the observations during the process and the data presented in visuals are analyzed; it was determined that the students were communicating and exchanging ideas with their group friends throughout the activity, and they were supporting each other while designing, installing, and testing the circuit assembly. Therefore, "Explaining Series Circuits" activity, which is based on the Argument-Driven Inquiry, has improved teamwork and communication skills of the students (National Research Council, 2010). Consequently, the practice of the ADI method in science courses is effective in middle school students' learning of the factors that determine the brightness in series circuits. In this regard, it is thought that this activity could be used as a model for the future activities in science education to be prepared based on Argument-Driven Inquiry.

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Appendix 1

Stages of the Argument-Driven Inquiry

The First Stage

This stage involves *the identification of the task and guiding question*. This stage starts with (1) teacher's introduction of a surprising case and a problem that needs to be solved in it, and (2) identification of the task to the students. Then, it continues with students' identification of the guiding question to solve the problem given. At this stage, the aim of the teacher is to attract students to the topic, to make them relate their previous knowledge to new information and to encourage them to design and apply a research method throughout the process (Sampson & Walker, 2012).

The Second Stage

This stage is *designing a method and collecting data*. Students work in small groups, and each student group designs and carry out the most appropriate method to answer the research question determined by the group itself. They collect the data that is to be used in the solution of the problem. The main objective here is to provide students with the opportunity to interact with the natural world (or the data obtained from the natural environment) by using appropriate laboratory materials and data collection techniques and to learn how to deal with the uncertainties of experimental studies. Furthermore, it gives students a chance to know why some methods in scientific studies work better than others and how the method used during a scientific research depends on the nature of the research question and the subject being investigated (Sampson et al., 2014).

The Third Stage

This stage includes *the data analysis and the production of a tentative argument*. In the third stage, each group first tries to analyze and interpret the data in their measurements (eg. temperature, volume, etc.) or the observations (color, odor, etc.) they have made earlier. After that, they develop their tentative arguments (Walker et al., 2012). The most important thing here is that each group has a presentation in which they can clearly present their own argument to other groups, and in which each component of the argument is clearly expressed.

The Fourth Stage

The fourth stage is *an argumentation session*. Each group shares, discusses, evaluates its own argument with other groups and re-arranges it. This stage (1) is the most important application of science, and helps students reach the best evidence-based findings as a result of examining, discussing, and criticizing their arguments, (2) contributes to students' extending their knowledge of the content and developing critical thinking skills as they face with alternative ideas (opposing arguments), and (3) enables them to learn to distinguish ideas by using scientific criteria and masters how to develop more scientific habits (remaining skeptical with ideas, insisting on supporting claims with valid evidence, etc.) (Sampson et al., 2013). The role of teachers in this process is to encourage students to discuss, to share their ideas with other students and to ask questions about their arguments.

The Fifth Stage

At this stage there is *an explicit and reflective discussion* in which a whole class discussion is held. The teacher starts the discussion by giving the students an opportunity to share what they have learned about the guiding questions. The teacher should remind the students of important theories, models, or laws that may justify their evidence. Moreover, the teacher should clarify the misunderstandings of students on the subject, and emphasize the keystone concepts of the research. This is the best time to discuss a range of scientific criteria or errors, such as improving the data collection methodology related to the nature of scientific inquiry and science, and reducing measurement errors. In addition, perhaps the most important part is when teachers discuss one or two themes related to the nature of science or the nature of scientific inquiry referring to students' own work (Sampson et al., 2009).

The Sixth Stage

This stage involves *creation of a written investigation report*. Students work individually again. Here, each student writes an individual investigation report on the ultimate argument that has been finalized after each group's presenting the argument and its being criticized and evaluated by others throughout the class discussion process. This phase has four main objectives: (a) writing processes are important parts of science; (b) scientists share their own investigations and other scientists read, understand, and evaluate their investigation from their texts; and (c) students will refine their own metacognition and will understand the content efficiently as they express their thoughts in a clear and concise way; (d) teachers are able to see and evaluate the progress of the students and provide feedback when necessary (Wallace et al., 2004). In these investigation reports, three essential questions await an answer: (1) "What question were you trying to answer and why?" (2) "What did you do and why?" (3) "What is your claim after the *scientific inquiry*?" During this process, it is important to encourage students to use tables and graphs to organize the data they have collected, and to make use of them in the report text by referring to these tables and graphs (Sampson et al., 2014).

Seventh Stage

Students engage in *double-blind peer review* of these reports to ensure quality. It offers students the opportunity to read good and bad reports. Therefore, students are able to discover new ways of organizing and presenting information, which helps them to write better in their subsequent reports. On the other hand, it enables students to develop their reading skills that they need to succeed in science courses and to develop and compare the findings presented in a scientific text with those from other sources. In addition, it allows students to find out what various reasoning ways other writers can establish to support their claims and how they justify the evidence (Sampson et al., 2011).

The Eighth Stage

The final stage involves *revision of the report* considering feedbacks after peer reviews, and submitting final papers. Students will be able to improve both their composition-critical thinking skills and their content knowledge. Also, by providing a process evaluation, this phase reduces the academic pressure on students (Sampson & Walker, 2012).

Appendix 2

Let's Examine A Series Circuit

Erkan teacher gives Alp, Hilal, Simge, and Yavuz to prepare posters for the panel to be prepared at the end of the year. The subject of this poster to be prepared is series circuits. Alp, Hilal, Simge and Yavuz decide to prepare a poster as follows. However, they can not be sure what they will write to the poster about the brightness of lamp A in Figure 1, Figure 2, and Figure 3. They start to argue among themselves. Alp, Hilal, Simge, and Yavuz think about the lamp brightness as follows (Light bulbs and batteries in the figures are identical).

ALP
Lamp A in Figure 3 lights less brightly. Because there are four lamps and the current is divided into four.

HİLAL
The brightness of the A lamp in three circuits is equal. Because they all have the same battery and their currents are equal.

SİMGE
Lamp A in Figure 3 lights less brightly. Because the same battery in all but the more the number of lamps in Figure 3. This causes the current to decrease.

YAVUZ
In Figure 1 and Figure 2, the brightness of lamp A is the same. However, the lamp in Figure 3 is less bright. Because in Figure 3, the other lamp before the lamp A consumes some of the current.

Figure 1
A lamp
PIL

Figure 2
A lamp
PIL

Figure 3
A lamp
PIL

Your TASK

Who do you agree with Alp, Simge, Yavuz and Hilal?

()ALP ()SİMGE ()YAVUZ ()HİLAL

How do you conduct research on the determination of lamp brightness in serial circuits in order to help Alp, Simge, Yavuz and Hilal prepare posters?

The materials that can be used in this research and the safety precautions you need to pay attention to are as follows.

Materials

You may use any of the following materials during your investigation:

- Lightbulbs and holders with different resistances
- Switch
- A sufficient number of conductor connection cables
- Battery or power supply with voltages of various sizes (1.5V, 3V, 9V, etc.)
- Battery holders
- Ammeter
- Voltmeter
- Light sensor

Safety Precautions

1. Wear sanitized safety glasses or goggles during hands-on activity.
2. Use caution when handling bulbs, wires, and batteries. They can get hot and burn skin.
3. Never put batteries in your mouth or on your tongue.
4. Use caution in handling wire ends. They are sharp and can cut or puncture skin.
5. Lightbulbs are made of glass. Be careful handling them. If they break, clean them up immediately and place in a broken glass box.
6. Wash hands with soap and water after completing the lab activity.

INVESTIGATION PROPOSAL

(Sampson et al.'s (2014) study was used in the development of the Investigation Proposal.)

<p>1. The Guiding Question:</p>		
↓	↓	↓
<p>Hypothesis 1:</p> <p>Because:</p>	<p>Hypothesis2:</p> <p>Because:</p>	<p>Hypothesis3:</p> <p>Because:</p>
<p>Let's test our hypothesis !!!</p>		
<p>2. Design our procedure !!!</p>		
<p>a) Materials:</p> <p>b) What safety precautions will you follow?</p>		

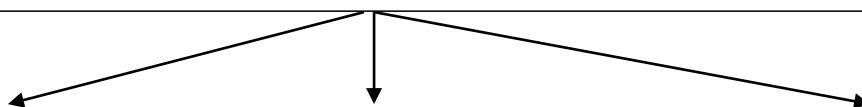
c) Procedure:

d) What data will you collect?

3. What did I do to make sure that I collect reliable data? What did I do to reduce the error in the data collection process?

4. How will you analyze the data?

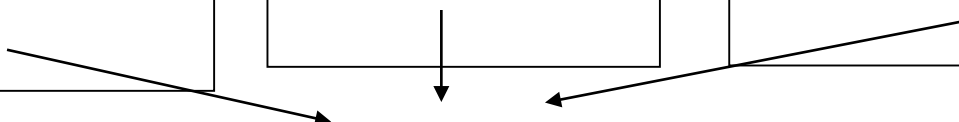
5. The electrical circuit assembly I established in my research



Hypothesis 1 is true. I agree.
Because.....

Hypothesis 2 is true. I agree.
Because.....

Hypothesis 3 is true. I agree. Because.....



6. Claim- Evidence-Justification

The Guiding Question:

Our Claim:

Our Evidence:

Our Justification
of the Evidence:

7. Changing Ideas:

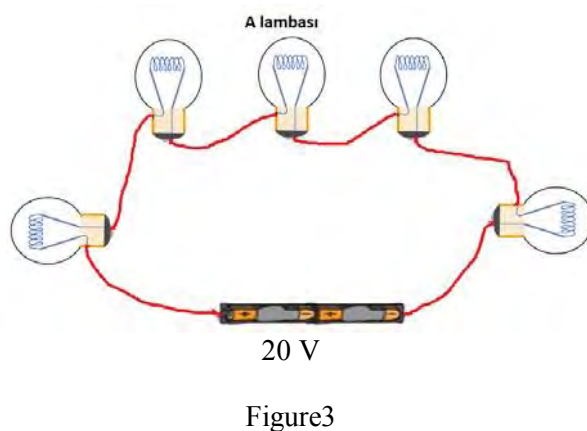
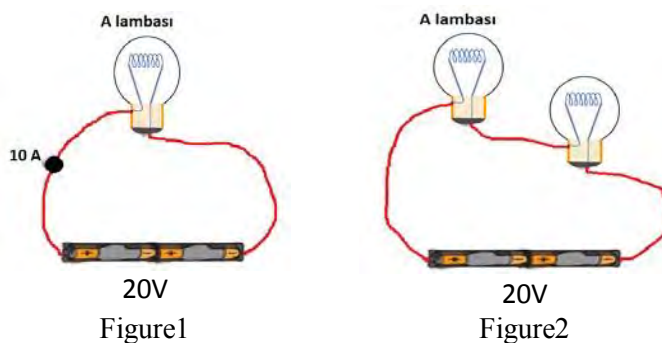
When I compared my thoughts to others, my thoughts changed.....Because.....

Appendix 3

Checkout Questions

(Sampson et al.'s (2014) study was used in the development of Checkout Questions).

1. What can be said about the brightness of the lamp A in Figure 1, Figure 2, and Figure 3? (The lamps and batteries are identical in the electrical circuits in Figure 1, Figure 2, and Figure 3).



2. In science, there is a difference between data and evidence.

Yes, I agree.

No, I do not agree.

Explain the reason for your selection by giving examples from your investigation on serial circuits.

3. The study you carried out is an experimental study.

Yes, I agree.

No, I do not agree.

Explain the reason for your selection by giving examples from your investigation on serial circuits.

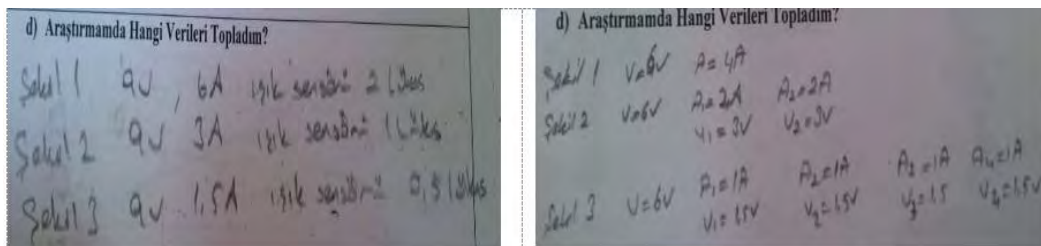
Appendix 4

Samples from Student Work

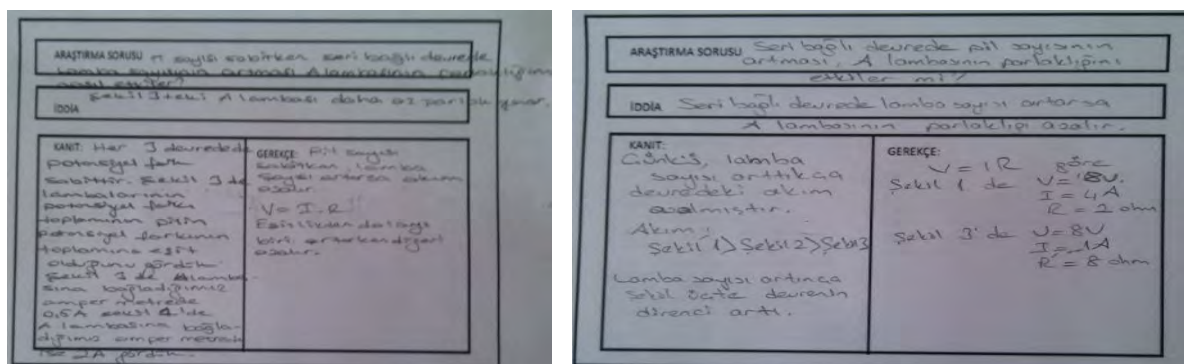
Some examples of the research questions developed by the students

- *How does the lamp brightness change in the way the circuits connect?*
- *How does the connection of the bulbs affect the bulb brightness?*
- *Is the brightness of the lamp A in the simple circuit (1 battery and 1 bulb) the same as the brightness of the lamp A in the series circuit (1 battery and 2 bulbs)?*
- *How does the brightness of the lamp A vary as the number of bulbs increases in the series circuit?*
- *Does the increase in the number of bulbs in the series circuit affect the brightness of the bulb A?*
- *Does the increase in the number of lamps affect the brightness of lamp A when the number of batteries is fixed in the series circuit?*

Some examples of the data collected by the students



Examples of the student posters designed to illustrate the components of their arguments



Appendix 5

A Student's Investigation Report

ARAŞTIRMA ÖNERİSİ
(Simpson, Carlisle, Finkler, Farris, Green, Sutherland, Staflworth, ve Williams, 2014'ten alınmıştır.)

1. Araştırma Sorumuz: Seri kapalı devrelerde, pil sayısı sabit iken A lambasının parlaklığı nasıl değişir?

<p>Hipotez 1: Sinyale bağlı lamba sayısı arttıkça akım azalır. Çünkü: Seri devrelerde akım azalır.</p>	<p>Hipotez 2:</p> <p>Çünkü:</p>	<p>Hipotez 3:</p> <p>Çünkü:</p>
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Hipotezimizi test edelim!!!

2. Uygulamamızı Tasarlayalım!!!

a) Kullanacağımız Malzemeler:
Yolmetre
Ampermetre
Işık sensörü
Ampul
Halter kolu
Işık sensörü

b) Çalışmamızda Dikkat Edilecek Güvenlik Önlemleri:
E

3. Araştırma Yöntemimiz:
Eski pil depolarını ve lambalarını parlaklığı, akım kayıplarını depolarını lamba sayısı, lamba parlaklığı, pil sayısı, her bir kolu

4) Araştırmamızda Hangi Verileri Topladık?
Sahel 1 9V 5A ışık sensörü 0.13km
Sahel 2 9V 3A ışık sensörü 1.2km
Sahel 3 9V 1.5A ışık sensörü 0.913km

3. Topladığımız verilerin güvenilir olduğundan emin olmak için neler yaptım? Veri toplama sürecindeki hatayı azaltmak için neler yaptım?
Gözetimleri her bir kez tekrarladım aynı sonuç çıktı. Ampermetre ve yolmetrede aynı sonuçlar çıktı. Tekrarladıkça

4. Topladığımız verileri nasıl analiz ettim?
Bereyden elde ettiğimiz verileri karşılaştırdık ve ampermetredeki değerleri bildik. Her sayı birbirinin analizi olduğunda her safhada.

