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REVIEW ARTICLE

Studying the Structure of Primary School Students' Written Arguments on Electric Circuits

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ABSTRACT

The research that studies the development of the structure of primary school students' written arguments on science issues is particularly limited. The present paper aimed to study the effect of a teaching intervention for electric circuits on the structure of primary school students' written arguments. Instructional material was developed based on the constructivist approach to learning with the use of science and engineering practices and was implemented with 34 students aged 11 years old. The research data included the 340 written arguments the students produced in their attempt to answer the questions included in a questionnaire, they were given before and after the teaching intervention. Data analysis was carried out by classifying the sufficiency of the components of the arguments into levels. The analysis showed that the teaching intervention significantly contributed to improving the structure of students' written arguments.

KEY WORDS: science and engineering practices; written arguments; constructivist approach; electric circuit; primary school

INTRODUCTION

The necessity for the students to construct and evaluate arguments has been acknowledged as a particularly important science practice over the past 10 years and has become one of the main objectives of science education (Driver et al., 2000; Henderson et al., 2018; National Research Council, 2012; Organization for Economic Co-operation and Development, 2013). The new framework of the US National Research Council for science education refers to students' engagement in arguments based on evidence and highlights the importance of the specific practice of understanding science ideas and concepts (National Research Council, 2012). This practice aims to enable the students to both document their claims through evidence and reasoning and evaluate arguments of third persons. It has been suggested that the learning process should contribute to developing and enhancing students' ability to evaluate and construct arguments of sufficient structure and appropriate content (McNeill and Krajcik, 2007).

The present paper focuses on students' arguments on the conceptual area of electric circuits. Although the production of arguments by students has been recognized as significant (Erduran et al., 2015; Cetin, 2014; National Research Council, 2012), the research that has been conducted on the quality of written arguments developed by students is limited (McNeill and Krajcik, 2007; Sandoval, 2003; Sandoval and Reiser, 1997; Songer and Gotwals, 2012). Moreover, there are no research papers studying the quality of students' arguments on electric circuits and their development. The purpose of the present paper was to study the effect of a teaching intervention for electric circuits on the structure of written arguments produced by primary school students.

THEORETICAL BACKGROUND

Teaching Science through Practices

Children grow in their natural and social environment, so when they enter the educational process they already possess a number of formed conceptions about the world (Driver et al., 1985). Those conceptions form a set of knowledge coming from complex and informal learning processes that have been adopted by their family, their peers or the media. They are semantic networks with fixed rules of operation and powerful interpretive systems, according to which experiences are interpreted and the information provided is absorbed (Wandersee et al., 1994). According to Hammer (1996), conceptions "(1) are strongly held, stable cognitive structures; (2) differ from expert conceptions; (3) affect in a fundamental sense how students understand natural scientific explanations; and (4) must be overcome, avoided, or eliminated for students to achieve expert understanding" (p. 1318).

Recording students' conceptions about the main fields of the scientific knowledge taught has become the object of extensive empirical research in the past 40 years (Driver et al., 1985; Driver et al., 1994; Duit, 2009). It was found that in most cases, students' prior conceptions differ from scientific knowledge and students often resist modifying them.

According to the constructivist approach to learning, students are not passive recipients of knowledge, but they actively construct knowledge through cognitive, social, and cultural processes (National Research Council, 2012). In particular, students construct new knowledge of natural phenomena through an interactive process between their prior conceptions and the conceptions they receive from their learning

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environment (Glasersfeld, 1995; Salomon and Perkins, 1996). Therefore, the problem of learning has been raised as a problem of changing their already formed conceptions.

The intellectual work related to processing and revising conceptions is based on students' engagement in science and engineering practices (National Research Council, 2012). Science and engineering practices are the main practices used by scientists while studying and constructing models and theories for the natural world. The following eight practices have been proposed for science education (NGSS Lead States, 2013): (1) Asking questions and defining problems, (2) developing and using models, (3) planning and carrying out investigations, (4) analyzing and interpreting data, (5) using mathematics and computational thinking, (6) constructing explanations and designing solutions, (7) engaging in argument from evidence, and (8) obtaining, evaluating, and communicating information.

It is alleged that the active engagement of students in science and engineering practices can improve learning outcomes. More specifically, students' engagement in such practices can help them construct science ideas and concepts, understand the process for developing scientific knowledge, arouse their curiosity and interest, and motivate them for further research (Duschl et al., 2007; National Research Council, 2012).

Components of Students' Arguments

Engaging in argument from evidence is one of the eight science and engineering practices. The main dimension of this practice is the construction of arguments by the students (National Research Council, 2012).

According to Toulmin (1958), arguments include claims or conclusions, data supporting the claims, warrants proving why the data supports the claims, backings that strengthen the warrants (i.e., information supporting the warrants), qualifiers that represent the confidence that is warranted by the argument, and rebuttals indicating the conditions under which the data together with the warrants do not lead to claims. Although Toulmin's model (1958) has been used for both evaluating students' arguments, mainly in upper grades of secondary education and in university, and supporting them in producing arguments (Erduran et al., 2004; Garcia-Mila et al., 2013; Nielsen, 2013; Simon, 2008), it has been noted that it is difficult to use the specific model to analyze arguments of younger students (difficulties in distinguishing among warrants, backings, and qualifiers in students' speech) (Keith and Beard, 2008; McNeill et al., 2006). A modified version of this model has been proposed instead. According to this version, an argument has four components (McNeill and Krajcik, 2012): The claim, the evidence, the reasoning, and the rebuttal (Figure 1). More specifically, according to McNeill and Krajcik (2012), the claim is a conclusion answering a question, the evidence is the data supporting the claim, the reasoning connects the claim with the evidence and reveals the reason why the data are considered evidence supporting the claim with the help of scientific principles, and the rebuttal explains how or why an alternative claim is wrong.

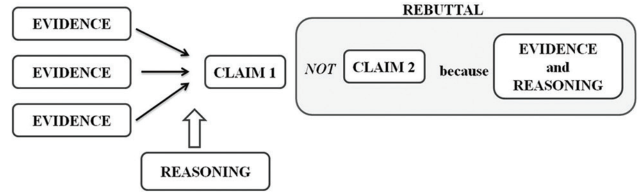

Figure 1: Framework for Scientific Argument (adapted from McNeill and Krajcik, 2012)

The criteria for the quality of an argument are the structure and the content of the argument. The structure of an argument is related to the presence and the sufficiency of its components (McNeill and Krajcik, 2012; Duschl, 2008). An argument is considered sufficient when it includes a claim, the evidence supporting the specific claim, the reasoning involving scientific principles through which the evidence is connected to the claim and a rebuttal including another claim that is supported by evidence and reasoning (McNeill et al., 2006**).** The content of an argument is related to the adequacy of its components when the latter is evaluated with regard to school knowledge (Sandoval and Millwood, 2005).

LITERATURE REVIEW

Research on Students' Written Arguments

Research studying students' difficulties in constructing written arguments concluded that students suggest claims without justifying them (Jiménez-Aleixandre et al., 2000; Jiménez-Aleixandre and Erduran, 2008; Sadler, 2004) or propose evidence insufficient and unsuitable for documenting the claims (Angeloudi et al., 2018; Bell and Linn, 2000; Chinn and Brewer, 2001; Heng et al., 2015; Jiménez-Aleixandre et al., 2000; McNeill and Krajcik, 2012; Moje et al., 2004; Sadler, 2004; Sandoval, 2003; Sandoval and Millwood, 2005). Moreover, rarely do students use reasoning in the arguments they construct (Lizotte et al., 2003; McNeill and Krajcik, 2007, 2012; Moje et al., 2004; Sadler, 2004; Songer and Gotwals, 2012; Zeidler, 1997) and their ability to construct rebuttals is particularly limited (McNeill and Krajcik, 2012; Osborne et al., 2013; Zeidler, 1997).

Research on Students' Conceptions of Electric Circuits

Regarding electric circuits, research has been carried out investigating primary and secondary education students' conceptions on a number of issues, such as the connection of a battery to a lamp, the concepts of electric current, voltage and resistance, the direction and the retention of electric current in an electric circuit as well as the luminescence of lamps connected in series and in parallel (e.g.: Cosgrove et al., 1985; Duit, 1985; Glauert, 2009; Kärrqvist, 1985; Osborne, 1981; Psillos et al., 1987; Shipstone, 1984; 1985; 1988; Shipstone et al., 1988; von Rhöneck, 1981; von Rhöneck and Grob, 1991). It has found that students have and use conceptions that are frequently different from the views of scientific knowledge.

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Besides, research studying the contribution of teaching interventions for electric circuits that are based on the constructivist approach to learning in students' conceptions has been conducted (e.g.: Afra et al., 2009; Carter et al., 1999; Chiu and Lin, 2005; Engelhardt and Beichmer, 2004; Osborne, 1983; Psillos et al., 1988; Ronen and Eliahu, 2000; Shepardson and Moje, 1999). The results showed that teaching interventions contributed to changing students' conceptions of electric circuits.

Critical Evaluation of Literature Review

Although students' difficulties in constructing arguments have been studied and the importance of students' engagement in the practice of constructing arguments has been recognized, the research that investigated the contribution of teaching interventions to the improvement of the quality of students' written arguments remains limited (Chen et al., 2016; McNeill et al., 2006; Sampson et al., 2013; Sampson and Walker, 2012; Sandoval, 2003; Walker and Sampson, 2013). This research focused on secondary education students, as such research regarding primary education students are extremely limited (Angeloudi et al., 2018; Martin and Hand, 2009). In addition, no research can be found that focuses on the discreet evaluation of the structure and the content of students' written arguments.

Importantly, although students' conceptions of electric circuits have extensively been investigated and research studying the contribution of teaching interventions on these students' conceptions has been conducted, there are no research papers studying the contribution of teaching interventions to the quality of students' arguments in the conceptual area of electric circuits.

PURPOSE AND RESEARCH QUESTIONS

The present paper aimed to study the structure of students' written arguments. The purpose of the present research was to study the effect of a teaching intervention for electric circuits, which was based on the constructivist approach to learning with the use of science and engineering practices, on the structure of written arguments produced by primary education students (students aged 11 years old).

In particular, the following research questions were asked:

a. What is the effect of the proposed teaching intervention on the sufficiency of the claims of students' written arguments?
b. What is the effect of the proposed teaching intervention on the sufficiency of the evidence of students' written arguments?
c. What is the effect of the proposed teaching intervention on the sufficiency of the reasoning of students' written arguments?

METHODOLOGY

Design of the Study

A single group pre-test and post-test quasi-experimental design was adopted. The research was carried out in two phases. In the first stage, the instructional material, and a questionnaire, both related to electric circuits, were developed. In the second phase (main research), the instructional material was implemented in the students and the questionnaire was completed before and after the teaching intervention.

Before proceeding with the teaching intervention, we obtained permission from the school principal and the teacher of the classes. Furthermore, we obtained the consent before beginning the study of the students as well as their parents. Both students and parents were provided with information about the aims, the content, the practical work activities, and the procedures of the teaching intervention.

Participants

The research was carried out with the participation of 34 primary school students of mainland Greece, aged 11 years (18 boys and 16 girls). All the children could speak and write in Greek, while before the teaching intervention, the students had never been taught electric circuits.

Instructional Material

The instructional material about electric circuits was developed based on the constructivist approach to learning with the use of science and engineering practices. It included five units, which correspond to an equal number of subjects related to electric circuits (Table 1).

The development of each unit used the instructional model 5E by Bybee et al. (2006), which includes five phases: Engagement, exploration, explanation, elaboration, and evaluation. Table 2 presents the teaching phases and the respective science practices involved in them.

In the engagement phase, the students experienced activities that aimed to highlight their conceptions and help them realize the disagreements they had with each other. Through group discussions and class negotiations, they asked the questions they were going to investigate.

In the exploration phase, the students became familiar with the processes of planning and carrying out investigations: They asked research questions and made research assumptions, they distinguished among variables (independent variable, dependent variable, and control variables), and they described and followed an experimental process.

In the explanation phase, the students processed the data and recognized tendencies within the data. It was planned that the students would construct arguments (based on the evidence

Table 1: Instructional material units and their subjects

Unit	Subject
1	Electric circuit
2	Electric current
3	Conductors and insulators
4	Connecting lamps in series
5	Connecting lamps in parallel

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collected from the research). The components of an argument (claim, evidence, and reasoning) are presented and explained to the students, the necessity of constructing arguments was discussed, and the students constructed and evaluated arguments (with the help of self-evaluation sheets and under the guidance of the teacher). The components of the arguments that were presented to the students did not include rebuttal. Rebuttal is suggested for secondary education students, after the latter has become familiar with the rest of the components (Berland and McNeill, 2010).

In the elaboration phase, the students processed problems different from those they had initially negotiated so that they could check the extent to which they systematically activate new knowledge in case of new problems. The students became familiar with activities carried out for identifying the components of the argument, and they developed and evaluated arguments.

In the evaluation phase, the students contrasted the new knowledge with their original conceptions to improve self-control and realize their cognitive progress.

The instructional material was implemented in primary schools for a period of 6 weeks totaling 18 h.

Data Collection

Data collection used written questionnaires. At first, a small number of students (three 11-year-old students), two primary education teachers, and two science instruction researchers were provided with the original version of the questionnaire so that the internal validity of the questionnaire could be determined. The remarks and the comments of the above were taken into account in the final form of the questionnaire, which included five problems that asked for the students' predictions and justifications on issues related to electric circuits (Table 3). Every problem included one question and data related to the question. The students were asked to answer the question and justify their answers. The Appendix includes a typical problem about the illumination of lamps connected in series.

The written arguments produced by the students in their attempt to answer the questions that were included in the questionnaire constituted the research data. The students were provided with the questionnaire both before and after the teaching intervention (pre-test and post-test). They were allotted 1 h to complete each of the questionnaires. A total of 170 written arguments were collected before the teaching intervention and 170 written arguments after the teaching intervention.

Data Analysis

The evaluation of the structure of students' arguments required the presence and the sufficiency of the components of students' arguments (claim, evidence, and reasoning), regardless of their conceptual content. Each component of the argument was classified, according to McNeill and Krajcik (2012), into one of the two levels (Level 1 and Level 2). In particular, a component of an argument (claim, evidence, or reasoning) was classified into Level 1 if it was absent or insufficient, while it was classified Level 2 if it was sufficient. It should be noted that the evaluation of arguments was restricted to three out of the four components of the arguments, that is, the claim, the evidence, and the reasoning.

Two researchers that worked independently evaluated students' arguments. The interrater agreement was above 97% for claim, 90% for evidence, and 88% for reasoning. Their differences were settled through discussions.

Two arguments used by the students are set out below concerning the question included in the Appendix, accompanied by their evaluations of their structures.

Argument 1: "*Yes, their illumination is affected because the electric current is split.*"

Evaluation of argument 1: As for its structure, it includes a claim ("*Yes, their illumination is affected*") and a piece of evidence ("*the electric current is split*"). More specifically, a claim considered sufficient was included (Level 2), insufficient evidence was included (Level 1), while no reasoning was included (Level 1).

Table 2: Teaching phases and the respective science and engineering practices

Teaching phases	Science and engineering practices
Engagement	Asking questions and defining problems
	Obtaining, evaluating, and communicating information
	Developing and using models
Exploration	Planning and carrying out investigations
	Analyzing and interpreting data
	Developing and using models
	Using mathematics and computational thinking
	Obtaining, evaluating, and communicating information
Explanation	Constructing explanations and designing solutions
	Obtaining, evaluating, and communicating information
	Using mathematics and computational thinking
	Analyzing and interpreting data
	Engaging in argument from evidence
Elaboration	Obtaining, evaluating, and communicating information
	Using mathematics and computational thinking
	Constructing explanations and designing solutions
	Engaging in argument from evidence
Evaluation	Engaging in argument from evidence
	Obtaining, evaluating, and communicating information

Table 3: Issues investigated about electric circuits and the respective problems of the questionnaire.

Problems	Issues related to electric circuits
1	Method of connecting the battery with the lamp in a simple electric circuit
2	Conservation of electric current
3	Conductivity of materials
4	Illumination of lamps connected in series
5	Illumination of lamps connected in parallel

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Argument 2: "*Yes, their illumination is affected. When there are two lamps, they provide less light, while if there are three lamps, they provide even lesser light. This happens because in case of lamps connected in series, their illumination depends on their number. As a result, if there are a lot of lamps, they provide less light, while if there are few of them, they provide more light. Therefore, their number affects their illumination.*"

Evaluation of argument 2: As for the structure of the argument, it includes a claim ("*Yes, their illumination is affected*"), evidence ("*When there are two lamps, they provide less light, while if there are three lamps, they provide even lesser light*"), and reasoning ("*This happens because in case of lamps connected in series, their illumination depends on their number. As a result, if there are a lot of lamps, they provide less light, while if there are few of them, they provide more light. Therefore, their number affects their illumination.*") More specifically, a claim considered sufficient was included (Level 2), evidence required for supporting the claim was included (Level 2), and sufficient reasoning connecting the evidence with the claim was also included (Level 2).

The next step after the arguments was analyzed was to create tables presenting the frequencies and the percentages of the levels that refer to the sufficiency of the main components of students' written arguments in the questionnaire that was handed to the students both before and after the teaching intervention. McNemar's test was used for contrasting the levels (Level 1 and Level 2) of the components of students' arguments in the pre-test and the post-test.

RESULTS

Table 4 presents the frequencies and the percentages of the levels referring to the sufficiency of claims, evidence, and reasoning of students' written arguments in the pre-test and the post-test.

With regard to the sufficiency of the claims included in students' arguments in the pre-test and the post-test, it emerged that, while in the pre-test most claims were classified Level 1 (97.1%), in post-test most claims were classified Level 2 (61.8%). Indeed, McNemar's test finds a statistically significant correlation between the sufficiency levels of students' claims in the pre-test and the post-test, $\chi^2(1) = 18.0500$, $\rho = 0.0001$. For example, when asked whether the number of lamps connected in series in a circuit affected their illumination, a student's pre-test claim was: "*It might affect it.*" This claim was considered insufficient. The respective post-test claim of the same student was: "*The number of lamps affects their illumination.*" This claim was considered sufficient.

As for the sufficiency of the evidence included in students' arguments, it was found that although in the pre-test all the evidence was classified as Level 1 (100%), in the post-test the percentage of evidence classified Level 1 decreased (58.8%), while the percentage of Level 2 increased (41.2%). Furthermore, McNemar's test shows that there was a statistically significant correlation between the sufficiency levels of students' evidence in the pre-test and the post-test, $\chi^2(1) = 12.0710$, $\rho = 0.0005$. For example, when asked whether the number of lamps connected in series in a circuit affected their illumination, a student's pre-test argument was: "*Yes, it affects it.*" This argument includes only a claim but does not include any evidence. The respective post-test argument of the same student was: "*Of course, it affects it. When there is only one lamp, it illuminates brightly; when there are two lamps, each of them illuminates less brightly; when there are three lamps, each of them illuminates even less brightly.*" This argument included both a claim ("*Of course, it affects it*") and evidence ("*When there is only one lamp, it illuminates brightly; when there are two lamps, each of them illuminates less brightly; when there are three lamps, each of them illuminates even less brightly*"). The evidence in this argument was considered sufficient. While in the pre-test the student suggested an argument including only a claim, in the post-test, the student suggested an argument including not only a claim but also sufficient evidence.

As regards the sufficiency of the reasoning included in students' arguments in the pre-test and the post-test, it was found that although in the pre-test all the reasoning was classified Level 1 (100%), in the post-test, despite the high percentage classified in Level 1 (76.5%), the percentage classified in Level 2 increased (23.5%). As a matter of fact, McNemar's test found that there was a statistically significant correlation between the sufficiency levels of students' reasoning in the pre-test and in the post-test, $\chi^2(1) = 6.1250$, $\rho = 0.0133$. For example, when asked whether the number of lamps connected in series in a circuit affected their illumination, a student's pre-test argument was: "*Yes, the number of lamps affects their illumination.*" This argument included only a claim but did not include any evidence or reasoning. The respective post-test argument of the same student was: "*The answer is yes. It affects it. When two lamps were connected, they illuminated*

Table 4: Sufficiency levels of claims, evidence, and reasoning of students' written arguments before and after the teaching interventions: Frequencies and percentages

Levels	Claim				Evidence				Reasoning			
	Pre-test		Post-test		Pre-test		Post-test		Pre-test		Post-test	
	f	%	f	%	f	%	f	%	f	%	f	%
Level 1	165	97.1	65	38.2	170	100	100	58.8	170	100	130	76.5
Level 2	5	2.9	105	61.8	0	0	70	41.2	0	0	40	23.5

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less brightly, and when three lamps were connected, they illuminated even less brightly. Therefore, because when the number of lamps increases, their illumination becomes less bright, we can conclude that the number of lamps connected in series in a circuit affects their illumination." Apart from a claim ("*The answer is yes. It affects it*") and evidence ("*When two lamps were connected, they illuminated less brightly, and when three lamps were connected, they illuminated even less brightly*"), the student's argument included reasoning that links claim to evidence ("*Therefore, because when the number of lamps increases, their illumination becomes less bright, we can conclude that the number of lamps connected in series in a circuit affects their illumination*").

As a result, a significant improvement was found in the sufficiency of students' claims, evidence, and reasoning from the pre-test to the post-test.

DISCUSSION AND CONCLUSIONS

The present paper aimed to study the effect of a teaching intervention for electric circuits that was based on the constructivist approach to learning with the use of science and engineering practices on the structure of primary school students' written arguments (aged 11 years). After studying the results of the research, it was found that the students, before the teaching intervention (as shown by the pre-test), produced mainly insufficient arguments with respect to their structure. In particular, the majority of the students did not suggest any claims or suggested insufficient claims, did not suggest any evidence supporting the claim or suggested insufficient evidence, and did not suggest any reasoning or, in case they did so, the reasoning failed to sufficiently connect the evidence with the claim.

This study's results are in line with the results of other research papers, which have shown that the quality of the arguments produced by students of different ages is low (McNeill and Krajcik, 2007, 2012; Moje et al., 2004; Osborne et al., 2013; Sandoval and Millwood, 2005; Songer and Gotwals, 2012). The finding that most of students' arguments are insufficient with regard to their structure may be attributed to the fact that during science teaching the students are usually not taught the structure of an argument and rarely are they asked to record and evaluate arguments (Driver et al., 2000).

Following the implementation of the teaching intervention (as it resulted from the post-test), it was found that the structure of students' written arguments was improved. More specifically, the students improved their ability to develop sufficient claims, present sufficient evidence supporting the claims, and develop sufficient reasoning, through which they connected the evidence with the claims.

The improvement in the structure of students' written arguments could be attributed to the learning activities used. Through these activities the students had the opportunity to become acquainted with the main components of an argument (claim, evidence, and reasoning), the way these components are connected with each other as well as the way the students themselves can evaluate an argument and detect its strong and weak points. Research has shown that these processes can contribute to improving the structure of written arguments (Chen et al., 2016; Clark and Sampson, 2007; Cross et al., 2008; McNeill and Krajcik, 2012; Zohar and Nemet, 2002). Furthermore, through the activities of the instructional material, the students had the opportunity to become familiar with the practice of planning and carrying out investigations and especially with its dimensions that are related to formulating a research question, identifying and controlling variables, describing the experimental process, collecting and analyzing data, and extracting conclusions. The familiarization of the students with this practice possibly contributed to improving the structure of the arguments they produced. Science practices are not unconnected with each other. On the contrary, students' familiarization with some of these practices contributes to improving other practices (National Research Council, 2012).

The present paper supported that the structure of 11-year-old students' written arguments was actually improved through a teaching intervention for electric circuits that were based on the constructivist approach to learning with the use of science and engineering practices. Furthermore, it was also noted that the students find greater difficulty in providing evidence and mainly constructing reasoning.

It should be pointed out that the results of the present research are subject to the restrictions of a small sample, which may not be considered representative of the total population of students. An additional restriction is the use of the questionnaire as the only data collection tool. The present research was exclusively focused on studying the structure of students' written arguments without examining their content. Further research is required, which will study the progress on the content of students' arguments and will contrast it with the progress on their structure. Furthermore, the present paper was exclusively concentrated on studying written arguments. In terms of research, it would be interesting to study the progress on students' oral arguments and contrast them with their written arguments. Finally, this paper was centered on studying students' arguments before and after the teaching intervention. It is therefore suggested that the structure and the content of students' arguments be studied throughout the instruction so that students' progress can be studied and the activities significantly contributing to improving the quality of their arguments can be specified.

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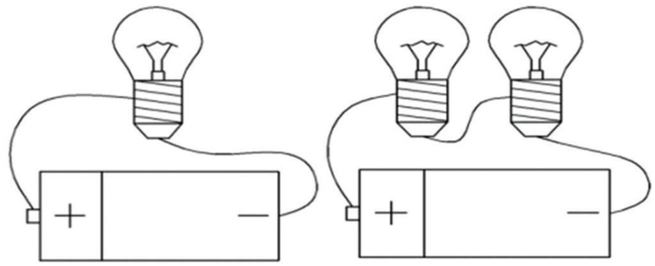
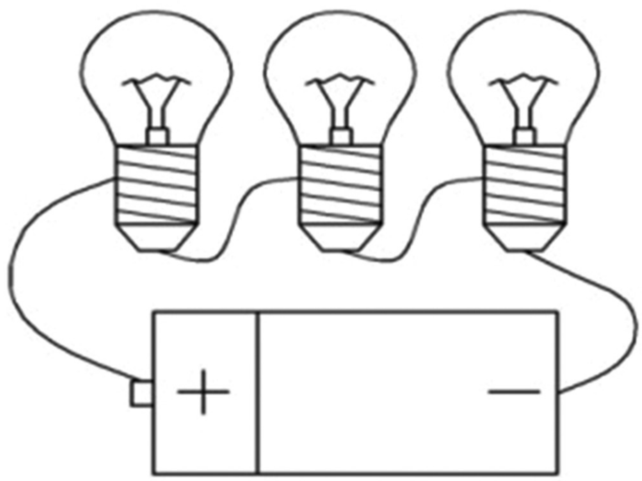
APPENDIX

A Typical Question of the Questionnaire

Pigi with her fellow students are working at the science laboratory. They want to study whether the number of lamps connected in series in a circuit affects their illumination. They make the following electric circuits with exactly the same batteries and the same lamps.



They notice that the illumination of the lamps in the second circuit decreases when they activate the circuit. They connect three lamps in series and notice that the lamps of the third circuit illuminate more feebly than the lamps of the other two circuits.



Pigi and her fellow students need your help. Use the above information to write and justify your answer to the following question of Pigi:

Does the number of lamps connected in series in a circuit affect their illumination?

While writing your answer to Pigi, do not forget to justify it as thoroughly as you can.