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The Impact of Teaching Interventions for Electrical Circuits on the Structure of Primary School Students' Written Arguments

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Abstract

The present paper aims at investigating the impact of a teaching intervention for electrical circuits, based on the constructivist approach to learning, with the engagement of students in science and engineering practices, on the structure of primary school students' written arguments. Furthermore, the comparison between the learning outcomes (regarding the structure of students' arguments) of this teaching intervention and the respective learning outcomes of another teaching intervention for electrical circuits, which is based on the school textbook primary school students in Greece are taught, is pursued. Instructional material on electrical circuits was developed based on the constructivist approach to learning, with the engagement of students in science and engineering practices, and was implemented with 34 students aged 11 years (experimental group). In addition, according to the school science textbook, which is based on the Guided Research Teaching Model, electrical circuits were taught to 38 students aged 11 years (control group). Data collection was carried out through a questionnaire completed by the students before and after the two teaching interventions. Data analysis used a scale of two-level classified criteria. It emerged that the teaching intervention implemented in the experimental group significantly contributed to improving the structure of students' written arguments. By contrast, the structure of written arguments developed by students belonging to the control group was not significantly improved.

Introduction

It has been emphasised that the engagement of students in science and engineering practices is necessary so that the students can understand science ideas and concepts (National Research Council [NRC], 2012). Such practices also include the engagement of students in arguments. The main dimension of this practice is the construction of evidence-based arguments by the students (NGSS Lead States 2013). The learning process should contribute to developing students' ability to construct arguments of sufficient structure and appropriate content (Henderson, McNeill, González-Howard, Close, & Evans, 2018; McNeill & Krajcik, 2007).

Although the necessity for the students to construct evidence-based arguments has been underlined, research investigating the sufficiency and appropriateness of students' arguments is extremely limited (Cetin, 2014; McNeill & Krajcik, 2007; Sandoval, 2003; Sandoval & Reiser, 1997; Songer & Gotwals, 2012). Moreover, no research has been traced that contrasts the contribution of different teaching interventions for electrical circuits to the quality of students' arguments.

The purpose of the present paper is to contrast the learning outcomes (regarding the structure of students' arguments) of two teaching interventions for electrical circuits that are based on different teaching approaches in the structure of primary school students' arguments.

Theoretical Framework

Argument in School Science

An argument in science intends to justifiably validate or disprove a claim. According to a simplified version of the model of arguments by Toulmin (1958), an argument includes four components: claim, evidence, reasoning and rebuttal (McNeill & 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, through scientific principles, clarifies the reason why the data is considered evidence supporting the claim. The rebuttal justifies how or why an alternative claim is wrong (Figure 1).

The evaluation of the quality of an argument requires taking into consideration both its structure and content. The structure of an argument is determined based on the sufficiency of its components. An argument is considered sufficient when it includes a claim, evidence supporting the specific claim, reasoning connecting the evidence with the claim as well as a rebuttal, which includes a different claim supported by evidence and reasoning (McNeill, Lizotte, Krajcik, & Marx, 2006). The content of an argument is determined based on the appropriateness of its components when the latter are evaluated with reference to school knowledge (Sandoval & Millwood, 2005).

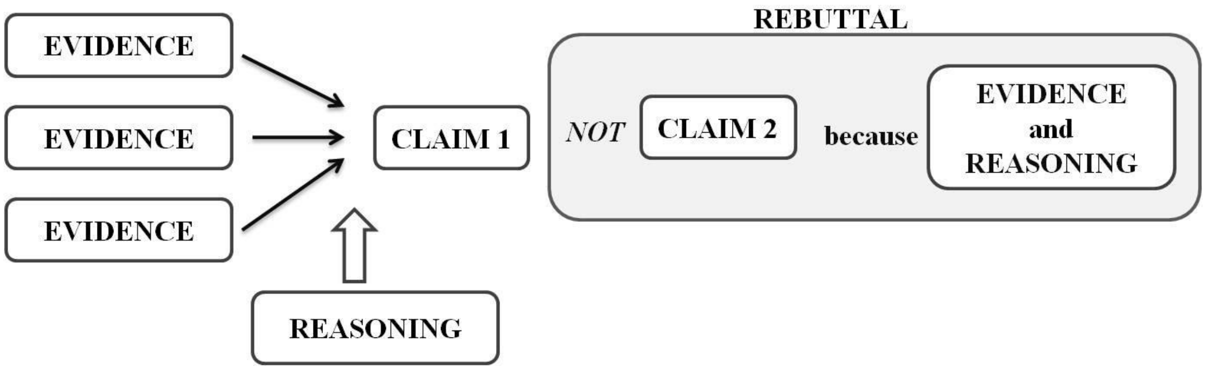

Figure 1: Framework for Scientific Argument (McNeill & Krajcik, 2012)

Science Teaching Approaches

Different science teaching approaches have occasionally been proposed. In particular, there are three dominant science teaching approaches (Antoniadou & Skoumios, 2013; Newton, Driver, & Osborne, 1999): transmission, discovery and constructivist approach.

According to transmission approach, science knowledge is transferred from the teacher to the students (Symington & Kirkwood, 1995). Learning is considered as memorisation and recall of knowledge. The aim of teaching is to make the students able to reproduce all they have been taught.

In the discovery teaching approach, science knowledge is not transferred from the teacher to the student but is discovered by the student under the proper guidance of the teacher (Fleer, 2007). This approach also includes the "Guided Research Teaching Model" (Schmidkunz &

Lindemann, 1992). In this model, the search for information starts with a problem related to a concept. The students are encouraged to ask questions, make assumptions, propose ideas, extract information and find answers in order to solve a problem under the guidance provided by the teacher. According to Schmidkunz and Lindemann (1992), the word “research” in the model description reveals its aim to help students explore the research procedures themselves while the word “guided” emphasises that this research effort will take place as a structured discovery within the frame of organised teaching.

The constructivist approach to learning advocates that knowledge is not gained passively but is actively constructed by students (Widolo, Duit, & Müller, 2002). A basic position of this approach is that the students have already formed their conceptions of the natural world, which are the result of the experiences they had outside the school framework (Forbes, Lange, Möller, Biggers, Laux, & Zangori, 2014). This teaching approach has served as the basis for the model of learning through science practices (NRC, 2012), according to which the intellectual and practical work associated with processing and revising conceptions is based on students’ engagement in science and engineering practices. Science and engineering practices are the main practices used by scientists while studying and constructing models and theories of 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) analysing 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.

Literature Review

Students find difficulty in constructing arguments. In particular, it was found that the students usually propose claims without justifying them (Jiménez-Aleixandre, Rodríguez, & Duschl, 2000; Sadler, 2004) or propose insufficient and inappropriate evidence in order to support their claims (Bell & Linn, 2000; Chinn & Brewer, 2001; Heng, Surif, & Seng, 2015; Jiménez-Aleixandre et al., 2000; McNeill & Krajcik, 2012; Moje et al., 2004; Sadler, 2004; Sandoval, 2003; Sandoval & Millwood, 2005). In addition, students usually fail to include reasoning in the arguments they develop (Bugarcic et al., 2014; Lizotte et al., 2003; McNeill & Krajcik, 2007, 2012; Moje et al., 2004; Sadler, 2004; Songer & Gotwals, 2012; Zeidler, 1997). Furthermore, their ability to evaluate arguments and propose rebuttals was found to be especially restricted (McNeill & Krajcik, 2012; Osborne et al., 2013; Zeidler, 1997).

Although students’ difficulties in constructing arguments have been studied and the importance of students’ engagement in the practice of constructing arguments has been recognised, research investigating the contribution of teaching interventions to improving the quality of students’ written arguments is limited (Chen, Wang, Lu, Lin, & Hong, 2016; McNeill et al., 2006; Sampson et al., 2013; Sampson & Walker, 2012; Sandoval, 2003; Walker & Sampson, 2013).

Research conducted to date has rather been focused on secondary education students, while research focused on primary education students is missing. Furthermore, there is no research focusing on the distinct evaluations of the structure and content of students’ arguments. Also, although research studying the contribution of teaching interventions to students’ conceptions about electrical circuits has been conducted (for example: Afra, Osta, & Zoubeir, 2009; Carter, Thompkins, & Westbrook, 1999; Chiu & Lin, 2005; Cosgrove et al., 1985; Duit, 1985; Engelhardt & Beichmer, 2004; Osborne, 1983; Ramnarain & Moosa, 2017; Ronen & Eliahu, 2000; Shepardson & Moje, 1999; Thorley & Woods, 1997), there is no research studying the contribution of teaching interventions to the quality of students' arguments for electrical circuits.

Purpose and Research Questions

The present paper is focused on studying the impact of two teaching interventions, which are based on different teaching approaches, on the structure of students' arguments. The purpose of the present research is to study the impact of a teaching intervention for electrical circuits that is based on the constructivist approach to learning, with the students' engagement in science and engineering practices, on the structure of primary school students' (11 years old) written arguments. Moreover, the learning outcomes of this teaching intervention (regarding the structure of students' arguments) are compared to the respective learning outcomes of another teaching intervention for electrical circuits that is based on the school textbook 11-year-old primary school students are taught in Greece (which is based on the "Guided Research Teaching Model").

In particular, the following research questions are intended to be answered:
(a) What is the impact of the teaching intervention for electrical circuits that is based on the constructivist approach to learning with the engagement of students in science and engineering practices on the structure of students' written arguments?
(b) What is the impact of the teaching intervention for electrical circuits that is based on the Guided Research Teaching Model on the structure of students' written arguments?
(c) Is there any difference between the learning outcomes (regarding the structure of students' arguments) of the two above teaching interventions?

Methodology

Research Process and Participants

The research methodology was developed from a mixed study perspective that integrated a quasi-experimental and a descriptive-qualitative research design. The quasi-experimental research design purposely manipulates, at least, one independent variable in order to observe its effect with dependent variables (Creswell, 1994; Hernández-Sampieri et al., 2014). In this particular design, students are not assigned to the groups randomly because those groups are already formed before teaching interventions. This research study intended to study the extent to which the implementation of two teaching interventions for electrical circuits that are based on different teaching approaches contribute to the structure of students' arguments. A pre-test and a post-test were administered to both the control and the experimental groups so as to compare the degree of effectiveness of teaching interventions.

The research was conducted in two stages. The first stage included the development of a written questionnaire and instructional material, both related to electrical circuits. The instructional material was based on the constructivist approach to learning with the engagement of students in science and engineering practices. The original versions of the instructional material and the questionnaire were implemented to a small number of students (three 11-year-old students). They were also given to two primary education teachers and two science education researchers. Their remarks and comments were taken into account in the final version of the questionnaire and the instructional material (pilot study).

In the second stage (main research), the instructional material was implemented to the students of the experimental group and the questionnaire was completed before and after the teaching intervention. The teaching intervention for electricity that is based on the school textbook taught to primary school students in Greece was implemented in the students of the control group and the students answered the questions of the questionnaire before and after the intervention.

To ensure compliance with the ethical standards and research rules, approval was granted by the University's ethical committee. Also, before proceeding to teaching interventions, we obtained permission from the school principal and the teachers of the classes. Furthermore, we provided beforehand, the students concerned as well as their parents with information about the goals, the content, the expected duration and the procedures of teaching interventions, and we obtained their consent.

The research sample included 2 groups of students (a total of 72 students 11 years old) who studied in two primary schools of Greece. 34 students (18 boys and 16 girls) formed the experimental group and the other 38 students (21 boys and 17 girls) the control group. All the children could write and speak Greek. Before the teaching intervention the students had never been taught electrical circuits.

Teaching Interventions

Teaching Intervention 1: Constructivist approach to learning with the engagement of students in science and engineering practices

The first teaching intervention was implemented to the students of the experimental group. Instructional material on electrical circuits was developed based on the principles of the constructivist approach to learning with the engagement of students in science and engineering practices. It included five worksheets, which correspond to five units referring to electrical circuits: electrical circuit, electrical current, conductors and insulators, lamps connected in series, lamps connected in parallel.

The instructional material of each unit was developed using the 5E instructional model by Bybee et al., (2006), which includes five phases: engagement, exploration, explanation, elaboration and evaluation. The 5E instructional model has been found to have a broad effect on the academic achievement of students (Sarı et al., 2017; Yaman et al., 2018). Table 1 presents the teaching phases and the respective practices involved in them.

In the phase of engagement, the students were engaged in activities that aimed to highlight their conceptions, help them realise the disagreements they had with each other, and formulate research questions.

In the phase of exploration, 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, control variables), and they described and followed an experimental process.

In the phase of explanation, the students were meant to construct arguments based on the evidence collected from the research. In this phase, and especially in the first unit of the teaching intervention, the components of an argument (claim, evidence, reasoning) were presented and explained to the students, the necessity of constructing arguments was discussed, while with the help of self-evaluation worksheets and under the guidance of a teacher their arguments were constructed and evaluated. An activity from the phase of explanation is included in Appendix 1. The components of the argument that were presented to the students did not include rebuttal. The rebuttal is suggested for secondary education students after they have become familiar with the other components of arguments (Berland & McNeill 2010).

Table 1: 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 Analysing 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 Analysing 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

In the phase of elaboration, the students processed new problems so that the extent to which they systematically activate new knowledge could be checked. The students became familiar with activities carried out for identifying the components of the argument and developed and evaluated arguments.

In the phase of evaluation, the students processed activities through which they contrasted the new knowledge with their original conceptions in order to improve self-control and realise their cognitive progress.

Teaching Intervention 2: Guided Research Teaching Model

The second teaching intervention was implemented with the students of the control group and was based on the instructional material on electricity that is included in the science school textbook taught to primary school students in Greece. It included the same units as the first teaching intervention. The instructional material of each unit is based on the "Guided Research Teaching Model". This teaching model includes five teaching stages: (a) bringing up the phenomenon to a problem, (b) suggestions for confrontation with the problem, (c) implementation of a suggestion, (d) abstraction of the finding, and (e) consolidation (Schmidkunz & Lindemann, 1992).

Data Collection
The questionnaire was the data collection tool. Data collection was carried out by indexing the written arguments the students produced in their attempt to answer the questions included in the questionnaire.

The questionnaire included five problems that asked the students to make predictions and provide reasons for issues related to electrical circuits. Every problem included a question and relevant data. The students were asked to answer the question and justify their answer. An example of a question is included in Appendix 2.

The questionnaire was provided to the students of the experimental group both before and after the teaching intervention with the instructional material constructed and to the students of the control group both before and after the teaching intervention that was based on their school textbook. A total of 170 arguments were collected before and after the teaching intervention in the case of the experimental group and 190 arguments in the case of the control group.

Data Analysis
The evaluation of the structure of students' arguments required the presence and the sufficiency of the components of students' arguments (claim, evidence, reasoning), regardless of their conceptual content. In particular, a component of an argument (claim, evidence, reasoning) is classified into Level 1 as long as it is absent or insufficient, while it is classified into Level 2 as long as it is sufficient. It should be noted that only three out of the four components of the arguments were evaluated, i.e. claim, evidence and reasoning.

Three arguments used by the students concerning the question on the illumination of the lamps connected in series (see Appendix 2) are set out below, accompanied by the evaluations of their structures.

Argument 1: "The number of lamps affects their illumination."
As for the structure of the argument, it includes a claim ("The number of lamps affects their illumination"), which is considered sufficient (Level 2). Neither evidence (Level 1) nor reasoning (Level 1) is included.

Argument 2: "Yes, their illumination is affected. When there are two lamps, each of them provides less light."
As for the structure of the argument, it includes a claim ("Yes, their illumination is affected") and evidence ("When there are two lamps, each of them provides less light"), while there is no reasoning. In particular, a claim is included, which is considered sufficient (Level 2), evidence is included, though it is considered insufficient (Level 1), while no reasoning (Level 1) is included.

Argument 3: "The answer is yes, it is affected. When two lamps were connected, they provided less light and when three lamps were connected, they provided even less light. Therefore, because when there are more lamps, their illumination becomes weaker, it can be concluded that the number of lamps connected in series in a circuit affects their illumination."
As for the structure of the argument, it includes a claim ("The answer is yes, it is affected"), evidence ("When two lamps were connected, their illumination was weaker, and when three lamps were connected, their illumination was even more weaker") and reasoning ("because when there are more lamps, their illumination becomes weaker, it can be concluded that the

number of lamps connected in series in a circuit affects their illumination"). More specifically, a claim considered sufficient is included (Level 2), evidence required for supporting the claim is included (Level 2) and sufficient reasoning connecting the evidence with the claim is also included (Level 2).

Students' arguments were evaluated by two researchers that worked independently. Their differences were settled through discussions. After the arguments were formulated by the students of the experimental and the control groups, tables presenting the frequencies and the percentages of the levels referring to the sufficiency of the components of written arguments were created. McNemar's test was used as statistical criterion for contrasting the sufficiency levels (Level 1, Level 2) of the components of students' written arguments (claims, evidence and reasoning) between the pre-test and the post-test in each group. McNemar test is the most appropriate tool for analysing pre-test and post-test differences in dichotomous items (e.g., Level 1 or Level 2) (Berenson & Koppel, 2005). Pearson's chi-square test with Yates's correction is used to compare the distribution of the sufficiency levels (Level 1, Level 2) of the components of students' written arguments (claims, evidence and reasoning) between the experimental and the control groups in pre-test (in order to determine ıf there were no difference in pre-test between groups). The Pearson's chi-square test is a test of the independence between dichotomous categorical variables to assess the difference between two independent proportions and the Yates's correction was designed to adjust the Pearson chi-square test of independence to make it applicable to 2×2 contingency tables with very small expected frequencies (Cohen, 1988).

Results

The Impact of Teaching Intervention 1 on the Structure of Arguments

Table 2 presents the frequencies and the percentages of the levels referring to the sufficiency of claims, evidence and reasoning of the written arguments of the students of the experimental group (where Teaching Intervention 1 was applied) in pre-test and post-test.

Table 2: Sufficiency Levels of Claims, Evidence and Reasoning of Written Arguments of Experimental Group Students in Pre-test and Post-test: 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	%
1	165	97.1	65	38.2	170	100	100	58.8	170	100	130	76.5
2	5	2.9	105	61.8	0	0	70	41.2	0	0	40	23.5

Table 2 shows that in the pre-test the components of most students' arguments were classified into Level 1 with regard to their sufficiency. However, the post-test showed an increase in the percentages of the components of arguments classified into Level 2.

In particular, while in the pre-test most claims were classified Level 1 (97.1%), in post-test most claims were classified Level 2 (61.8%). 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: "Maybe, their illumination is affected." This claim was considered insufficient (Level 1). The respective post-test claim of the same student was: "Yes, their illumination is affected." This claim was considered sufficient (Level 2).

Also, 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%). 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: "Yes, it affects it. When there are two lamps, they illuminate less, and when there are three lamps, they illuminate even less." This argument included both a claim ("Yes, it affects it") and evidence ("When there are two lamps, they illuminate less, and when there are three lamps, they illuminate even less"). The evidence in this argument was considered sufficient (Level 2).

Moreover, 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%). 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: "Their illumination is affected." This argument included only a claim but did not include any evidence or reasoning. The respective post-test argument of the same student was: "Their illumination is affected. When there is one lamp, it provides lighter, when there are two lamps, they provide less light, and if there are three lamps, they also provide even less light. Because if we increase the number of lamps then the brightness decreases, the number of lamps should affect their brightness." This argument includes a claim ("Their illumination is affected"), evidence ("When there is one lamp, it provides lighter, when there are two lamps, they provide less light, and if there are three lamps, they also provide even less light"), and reasoning that links claim to evidence ("Because if we increase the number of lamps then the brightness decreases, the number of lamps should affect their brightness"). The reasoning in this argument was considered sufficient (Level 2).

Furthermore, the McNemar test shows that there is a statistically significant correlation between students' pre-test and post-test sufficiency levels of claims [$\chi^2(1)=18.05$ and $p<0.05$], evidence [$\chi^2(1)=12.07$ and $p<0.05$], and reasoning [$\chi^2(1)=6.12$ and $p<0.05$]. As a result, a significant improvement was made in the sufficiency of students' claims, evidence and reasoning from the pre-test to the post-test.

The Impact of Teaching Intervention 2 on the Structure of Arguments

Table 3 presents the frequencies and the percentages of the levels referring to the sufficiency of claims, evidence and reasoning of the written arguments of the students of the control group (where Teaching Intervention 2 was applied) in pre-test and post-test.

Table 3: Sufficiency Levels of Claims, Evidence and Reasoning of Written Arguments of Control Group Students in Pre-test and Post-test: 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	%
1	190	100	180	94,7	190	100	190	100	190	100	190	100
2	0	0	10	5,3	0	0	0	0	0	0	0	0

Table 3 shows that both before and after Teaching Intervention 2, the components of most students' arguments were classified into Level 1. The McNemar test shows that there is no statistically significant correlation between students' pre-test and post-test sufficiency levels of claims [$\chi^2(1)=0.50$ and $p>0.05$], evidence [$\chi^2(1)=0.00$ and $p>0.05$], and reasoning [$\chi^2(1)=0.00$ and $p>0.05$]. As a result, no significant improvement was made in the sufficiency of students' claims, evidence and reasoning from the pre-test to the post-test.

Comparing Impacts of Teaching Interventions on the Structure of Arguments

Pearson's chi-square test (with Yates's correction) shows that there is no statistically significant correlation between the performances of experimental group students and control group students in the pre-test with regard to the sufficiency of claims [$\chi^2(1)=3.72$ and $p>0.05$], evidence [$\chi^2(1)=0.003$ and $p>0.05$] and reasoning [$\chi^2(1)=0.003$ and $p>0.05$]. As a result, there was no significant difference between the arguments of the students of the two groups with regard to the sufficiency of their claims in the pre-test.

The comparison of learning outcomes with regard to the structure of students' arguments (using McNemar's test) shows that, after Teaching Intervention 1, the ability of the students to produce arguments with sufficient components (claims, evidence, reasoning) was significantly improved in the experimental group, while a respective significant improvement was not made by the control group. The above mean that Teaching Intervention 1 produced significantly better results (with regard to the structure of arguments) than those produced by Teaching Intervention 2.

Discussion and Conclusions

After studying the results of the research, it was found that most of the arguments produced by the students of the experimental group and the control group before the teaching intervention were insufficient with regard to their structure. This finding may be attributed to the fact that during science teaching the students are not usually taught the structure of an argument and rarely are they asked to record and evaluate arguments (Driver et al., 2000). These results are in line with results of other research (McNeill & Krajcik, 2007, 2012; Moje et al., 2004; Sandoval & Millwood, 2005; Songer & Gotwals, 2012).

This paper shows that the structure of students' written arguments can be improved through a teaching intervention for electrical circuits based on the constructivist approach to learning with the students' engagement in science and engineering practices. In particular, the students improved their ability to write sufficient claims, sufficient evidence supporting the claims, and sufficient reasoning that links claim to evidence. However, there was no respective improvement in the structure of students' arguments after the teaching intervention for electrical circuits based on the "Guided Research Teaching Model". Most of the students did not write any claims or wrote insufficient claims, did not write any evidence supporting the claim or wrote insufficient evidence, and did not write any reasoning or the reasoning failed to sufficiently link the evidence with the claim.

The improvement in the structure of the written arguments developed by the students of the experimental group could be attributed to the activities of the instructional material 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 & Sampson, 2007; McNeill & Krajcik, 2012; Zohar & Nemet, 2002). On the other hand, the students of the control group did not have these opportunities through the instructional material used.

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 limitation is the use of the questionnaire as the only data collection tool.

The research that has been conducted on the impact of teaching interventions on the quality of students' arguments is particularly limited. The present paper and its findings are part of the research on studying the impact of teaching interventions on the quality of students' arguments and particularly on the structure of arguments, an issue lacking empirical data.

The present research was focused on studying the structure of students' written arguments without examining their content. Further research is required, which studies the progress of the content of students' arguments and contrasts it with the progress in their structure.
Also, the present paper exclusively concentrated on studying written arguments. In terms of research it would be interesting to study the progress of students' oral arguments and contrast them with their written arguments.

Finally, this paper was centered on studying students' arguments before and after teaching interventions made through questionnaires. It is therefore suggested that the structure and the content of students' arguments be studied throughout the instruction so that their progress can be studied and the activities significantly contributing to improving the quality of students' arguments can be specified.

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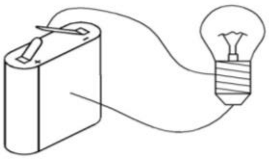
Appendix 1

An Activity from the Phase of Explanation

A fellow student has designed the following electrical circuit.



Will the lamp illuminate or not?

Write your argument concerning the above question.

Claim (write a statement that responds to the question)	
Evidence (provide scientific data to support your claim)	
Reasoning (explain why your evidence supports your claim)	

Provide your personal evaluation of the above argument based on the following.

Did you record a claim? □ YES □ NO

Did you report in your claim that the lamp will not illuminate? □ YES □ NO

Did you record evidence supporting the claim? □ YES □ NO

Did you report in the evidence that the one pole of the battery is not connected to the one contact of the lamp while the other pole of the battery is connected to the contact of the lamp? □ YES □ NO

Did you record reasoning connecting the evidence reported with the claim proposed? □ YES □ NO

Did you report in your reasoning that in order for a lamp to illuminate in an electrical circuit, the one pole of the battery should be connected to its one contact, while the other pole of the battery should be connected to the other contact and that because only the one pole of the battery is connected to the lamp in the circuit of the figure, the lamp will not illuminate? □ YES □ NO

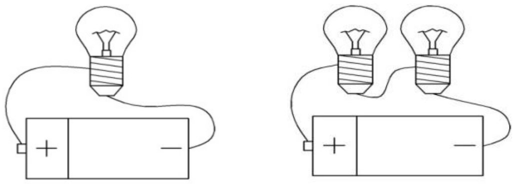
Record your argument again.

Claim (write a statement that responds to the question)	
Evidence (provide scientific data to support your claim)	
Reasoning (explain why your evidence supports your claim)	

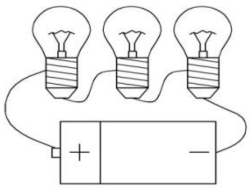
Appendix 2

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.