www.ijres.net

Improving Elementary School Students' Knowledge of Electromagnets and their Abilities to Design Science Investigations

Evdokia Andrikopoulou
University of the Aegean, Greece

Michael Skoumios
University of the Aegean, Greece

To cite this article:

Andrikopoulou, E. & Skoumios, M., (2021). Improving elementary school students' knowledge of electromagnets and their abilities to design science investigations. *International Journal of Research in Education and Science (IJRES), 7*(4), 1167-1183. https://doi.org/10.46328/ijres.2398

International Journal of Research in Education and Science (IJRES) is affiliated with the **International Society for Technology, Education, and Science (ISTES): www.istes.org**

2021, Vol. 7, No. 4, 1167-1183 https://doi.org/10.46328/ijres.2398

Improving Elementary School Students' Knowledge of Electromagnets and their Abilities to Design Science Investigations

Evdokia Andrikopoulou, Michael Skoumios

Article Info

Article History

Received:
21 March 2021
Accepted:
18 September 2021

Keywords

Science investigations
Electromagnets
Elementary school
Science education

Abstract

The research that studies the improvement of elementary school students' science knowledge and the development of elementary students' abilities to use the scientific and engineering practices is restricted. The purpose of this research is to study the effects of an instructional intervention on the knowledge of the students of elementary school about electromagnets and their abilities to design science investigations. Instructional material about electromagnets was developed, based on an inquiry-based approach using the scientific and engineering practices, which was applied to 76 students of elementary school (12 years old). To evaluate the students' knowledge of electromagnets as well as their abilities to design science investigations, a questionnaire was developed which was completed by the students both before and after the instructional intervention. The data of the research were the answers of the students to the questionnaires. The data analysis showed that the students' knowledge about electromagnets as well as their abilities to design science investigations was improved, through the instructional intervention for electromagnets.

Introduction

According to the Framework for K-12 Science Education proposed by the US National Research Council, students' science knowledge is achieved through their involvement with scientific and engineering practices (NRC, 2012). Therefore, it is necessary to study not only the knowledge of students but also the scientific and engineering practices that they develop. However, the research that is focused on the development of science instructional material and studies the effect of its application on improving the students' knowledge especially in elementary school, and on the development of their scientific and engineering practices, is limited (Marshall, Smart & Alston, 2017; Schwarz, Passmore & Reiser, 2017). This paper is focused on the development of instructional material and the study of its application on the knowledge of elementary school students about the electromagnets and the development of their practice in designing science investigations.

Theoretical Framework

The constructivist views of learning claim that the student does not receive passively but constructs actively knowledge through cognitive, social and cultural processes (Akcay & Yager, 2010; Duit, 2009). It has been argued that students have conceptions of the physical world that have been shaped by their experiences (Driver et al., 1985). These initial conceptions of the students are the background for the design and development of the instructional material and the teaching process. It is necessary for students, through the instructional material and the teaching process, to realize their initial conceptions and the conceptions of their classmates, to negotiate and modify them (Duschl et al., 2007; Samaresh, 2017).

The intellectual work associated with interrogating and refining conceptions is grounded in scientific and engineering practices (NRC, 2012). In this inquiry-based approach (teaching science as practice), the main aim is students' engagement in scientific and engineering practices in order to construct and use knowledge (Schwarz et al., 2017). This approach has shifted from students' knowing science content to students' using knowledge, along with scientific and engineering practices to understand the world (Berland et al., 2016).

The scientific and engineering practices refer to the main practices in which scientists engage as they study and construct models and theories for the natural world and the key set of engineering practices that engineers use as they design and build models and systems (NRC, 2012). The following eight scientific and engineering practices have been proposed for science education (NGSS Lead States, 2013): (a) asking questions and defining problems, (b) developing and using models, (c) planning and carrying out investigations, (d) analyzing and interpreting data, (e) using mathematics and computational thinking, (f) constructing explanations and designing solutions, (g) engaging in argument from evidence, and (h) obtaining, evaluating, and communicating information. It has been pointed out that students through their involvement with scientific and engineering practices can build and use science knowledge in order to interpret phenomena, solve problems and make decisions.

Among the scientific and engineering practices that have been proposed is the practice of planning investigations. Through this practice students are sought to be able: (a) to construct scientific questions (which can be empirically tested), (b) to make hypotheses, (c) to control variables (recognizing the independent variable, the dependent variable and the control variables) and (d) to invent and describe the experimental process in order to answer a scientific question (NRC, 2012). It is necessary to develop the above abilities for understanding science ideas and concepts (Mercer et al., 2004; OECD, 2013), the nature of science (NRC, 2012; Pearson et al., 2010), as well as constructing scientific explanations (NRC, 2012; Windshitl, 2017) and increasing interest in science (Duschl & Bybee, 2014).

Literature Review

Although the research regarding students' conceptions about electricity (Feyzioğlu et al., 2018; Psillos et al., 1987; Shipstone, 1984, 1985, 1988; Shipstone et al., 1988) and magnetism (Atwood, Christopher, Combs and Roland, 2010; Barrow, 1987; Borges & Gilbert, 1998; Hickey & Schibeci, 1999; Kähkönen et al., 2020) is quite extensive, the corresponding research about students' conceptions of electromagnetism is restricted and mainly focused on secondary schools' students (Anderson, 1986; Galili, 1995; Selman et al., 1982; Smaill & Rowe, 2012; Thurn et al., 2020). Therefore, research data on elementary students' conceptions of electromagnets is restricted and, according to them, students do not connect electric current with the appearance of a magnetic field and consider the electromagnet as a permanent magnet with a constant strength. There is also a lack of research investigating the contribution of instructional interventions to elementary students' conceptions of electromagnets.

In addition, students' abilities related to the practice of planning science investigations have been explored. It has been confirmed that students have difficulties related to the identification of research questions (Avsar Erumit et al., 2019), control variables and the invention and description of the experimental procedure they must follow (Kruit et al., 2018, Pedaste et al., 2021). Students often plan experiments that do not associate with their research question (Lawson, 2002) and they change many variables, making it difficult to formulate conclusions (Glaser et al., 1992).

To overcome these difficulties and help students with the processes of planning science investigations it is necessary to develop instructional interventions include giving them proper guidance (Taibu et al., 2021; van Riesen et al, 2018; Zacharia et al., 2015). However, the research that is examining the contribution of instructional interventions to students' abilities regarding planning investigations focuses mainly on secondary school students and on the control of variable ability (Arnold, Kremer & Mayer, 2014; Cayvaz et al., 2020; Chen & Klahr 1999; Edelsbrunner et al., 2018; Kazeni et al., 2018; Klahr & Nigam, 2004; Lazonder & Harmsen, 2016; Lubiano & Magpantay, 2021; Roth & Roychoudhury, 1993; Schneider et al., 2002; Zion et al., 2004). It has been pointed out that further study of this issue is necessary with elementary school students (Schalk et al., 2019).

As a result, the research that systematically studies the effects of instructional interventions about electromagnets both on elementary school students' knowledge and on their abilities to design science investigations is restricted.

Aim and Research Questions

The present study aims to assess the effects of an instructional intervention, based on an inquiry-based approach using scientific and engineering practices (teaching science as practice), on (12 years old) elementary school students' knowledge about the electromagnets and their abilities to design science investigations.

In particular, the research questions of this study are the following:

(a) What is the contribution of the instructional intervention to students' knowledge of the meaning, parts and operation of an electromagnet?

(b) What is the contribution of the instructional intervention on students' abilities to formulate a research question and a hypothesis, recognize and control variables, and to describe the experimental procedure to be followed in order to answer this research question about the factors that affect the strength of an electromagnet?

Method

General Background and Participants

The present study is a single group quasi-experimental research using pre-test and post-test (Cohen, Manion, & Morrison, 2011). It was carried out in three stages. Initially, instructional material about electromagnets and a questionnaire ware developed (Stage I). Then, the implementation of the instructional material took place and the completion of questionnaires by students before and after instructional intervention (Stage II). Subsequently, data analysis and drawing conclusions was carried out (Stage III).

Before the survey permission was asked from school principals. The teachers and the parents of the students were also informed about the goals of the research and their consent was given. The present research was additionally approved by the ethics committee of the University of the Aegean of Greece. The research involved 76 students (40 boys and 36 girls) of the last grade of elementary school (12 years old). The sample was a convenience sample: the students (from varying socio-economic backgrounds) attended four classes of two public elementary schools of Greece.

The Instructional Material and the Instructional Intervention for Electromagnets

The instructional material for electromagnets was designed based on an inquiry-based approach using the science and engineering practices (teaching science as practice). Specifically, the instructional material included two sections. The first section ("Connecting electricity to magnetism") concerned the didactic elaboration of the students' conception about the relationship between electric current and magnetic field (students do not connect electric current with the appearance of a magnetic field). Students were sought to build the conception that an electric current in a wire generates a magnetic field around the wire. The second section ("The electromagnet and the factors that affect its strength") concerned the didactic elaboration of the students' conception who believe that an electromagnet is a permanent magnet and has a constant strength, in order to build the conception that the electromagnet only works when it is leaking electric current and its strength depends on the number of batteries to which it is connected, the number of turns of wire on the core, the nature of the core material and the shape and size of the core.

The development of the instructional material of each section was based on the educational model 5E (Bybee et al., 2006) which included the following five phases which are presented below by a brief description.

Engage

The first phase aimed to challenge the students' interest, to highlight their initial conceptions, to help them realize the disagreements they had with each other and to formulate research questions. More specifically, in the first section a problem was posed to the students asking them to make predictions and explanations about what will happen to the deflection of the compass needle when an electric current passed through a metallic wire placed nearby. In the second section, students were asked to make pre-dictions and justifications about what would happen if an electromagnet approaches paper clip. Initially, students worked individually and recorded their answers. Then, they discussed with their classmates and compared their answers. There was a confrontation of the students in their attempt to support their views. The group representatives announced the results of their group discussions to all the students in the class. This phase was completed with students discussing and formulating research questions.

Explore

The second phase aimed at designing and carrying out science investigations by students in order to check their initial conceptions and answer the questions they had asked. More specifically, the students designed and conducted investigations with the help of the questions that were found in their worksheets (Hackling, 1998). For example, in the second section of the instructional material, students were asked to answer the question of what affects the strength of an electromagnet. Specifically, the students designed and conducted investigations to verify if the number of batteries, the number of turns of wire on the core, the nature of the core material and the shape and size of the core affects the strength of an electromagnet. Each worksheet for science investigation incorporated three main parts: planning (part A), experimenting and data analysis (part B) and evaluation (part C).

In the part A of a worksheet for science investigation (see Figure 1), the students formulated a research question, made a prediction, and identified the variables which were involved in the investigation (identified the independent variable, the dependent variable and the control variables).

Part A. Planning

What am I going to investigate?

……………………………………………………………………………………………………..

What I think will happen?

……………………………………………………………………………………………………..

Why I think it will happen?

……………………………………………………………………………………………………..

I fill in the Table:

What am I changing?	What do I keep?	What do I control?

Figure 1. The Part A of a Worksheet for Science Investigation: Planning

In the part B of a worksheet for science investigation (see Figure 2), the students described the experimental procedure they would follow, identified materials and equipment needed for their investigation, performed experiments through educational software (see Figure 3) and recorded their observations and measurements in tables.

Part B. Experimenting and data analysis

What will I need?

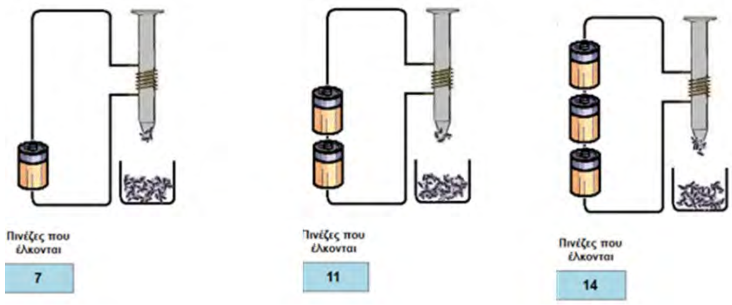
……………………………………………………………………………………………………

What will I make?

……………………………………………………………………………………………………

Can your results be presented in a table?

Figure 2. The Part B of a Worksheet for Science Investigation: Experimenting and Data Analysis



Αριθμός μπαταριών	Σπείρες πηνίου	Υλικό του πυρήνα	Αριθμός πινεζών που έλκονται
1	5	Σίδηρος	7
2	5	Σίδηρος	11
3	5	Σίδηρος	14

Figure 3. Electromagnet Lab

In the part C of a worksheet for science investigation (Figure 4), the students processed the tables with the data, identified trends in the data, drew conclusions from them and compared them with their initial predictions.

C. Evaluation

What do your results tell you? Are there any patterns or trends in your results?

……………………………………………………………………………………

Can you explain the patterns or trends in your results?

……………………………………………………………………………………

What did you find out about the problem you investigated? Was the outcome different from your predictions?

……………………………………………………………………………………

What difficulties did you experience in doing this investigation?

……………………………………………………………………………………

How could you improve this investigation?

……………………………………………………………………………………

What else do you want to investigate?

……………………………………………………………………………………

Figure 4. The Part C of a Worksheet for Science Investigation: Evaluation

Explain

In this phase, teachers asked students to share what they learned during the Explore phase. Under the teacher's guidance, the students were asked to compile explanations based on the data they collected.

Elaborate

This phase sought the application of the knowledge acquired by the students to new problems and the feedback of the students. In particular, students processed problems differently from those originally negotiated. During the implementation of these activities, the students discussed their answers with their classmates and where disagreements occurred, they performed experiments and confronted ideas with their classmates.

Evaluate

This phase aimed at the reflection of the students on the learning process that was followed. Initially, it was asked from the students to consider their answers to questions that had been treated in the past in problems raised in the initial phase of teaching. Students were asked to compare their initial answers with their current answers. They discussed any similarities or differences between their answers with their classmates. Additionally, students were invited to participate in design activities for the electromagnets to help other classmates who have not being taught about them.

Instrument and Procedures

A questionnaire was used for data collection. At first, the questionnaire was implemented in ten students (pilot research). It was also given to two science education researchers. Any necessary changes based on the remarks were made and the final questionnaire was developed, which consisted of two parts.

The first part of the questionnaire (included three open-ended questions) related to the investigation of students' conceptions of electromagnets and in particular what an electromagnet is (question 1), which parts comprises an electromagnet (question 2) and how it works (question 3). The second part of the questionnaire (see Appendix) was about exploring students' abilities to design science investigations about electromagnets. It included an introductory text (in which two students disagreed on whether an electromagnet could become stronger by using more batteries) and five questions that explored the students' abilities to formulate a relevant research question (question 4), to express a related prediction (question 5), identify the independent variable (question 6), the dependent variable (question 7), the control variables (question 8) and describe the experimental procedure to be followed (question 9).

The questionnaire was given to the students two weeks before the instructional intervention (pre-test). The instructional intervention lasted 6 hours. The same questionnaire was given to students two weeks after the teaching intervention (post-test).

Data Analysis

The research data were the answers of the students to the questionnaires, before and after the instructional intervention (pre-test and post-test). The analysis of students' responses was performed with the help of an analysis framework (coding scheme) based on the work of Arnold, Kremer & Mayer (2014). The analysis framework categorizes students' responses into four levels. Table 1 shows the framework of analyzing students' answers in questions 1, 2, 3, 4, 6 and 9.

Table 1. The Analysis Framework (Issues, Levels and Description) of Students' Responses that Focuses on the Questions 1, 2, 3, 4, 6 and 9

Issues	Levels	Description
What an electromagnet is (question 1), which parts comprises an electromagnet (question 2) and how it works (question 3)	Level 1	The student does not suggest an answer
	Level 2	The student suggests an irrelevant answer
	Level 3	The student suggests a relevant but incomplete answer
	Level 4	The student suggests a relevant and complete answer
Formulation of a research question (question 4)	Level 1	The student does not suggest a research question
	Level 2	The student suggests an irrelevant research question
	Level 3	The student suggests a relevant but incomplete research question
	Level 4	The student suggests a relevant and complete research question
Identifying an independent variable (question 6)	Level 1	The student does not suggest the independent variable or mentions more than one independent variable.
	Level 2	The student suggests an irrelevant independent variable or proposes a relative independent variable without clarifying whether it is a quantitative or qualitative.
	Level 3	The student suggests the independent variable in qualitative terms.
	Level 4	The student suggests the independent variable in quantitative terms.
Description of experimental procedure (question 9)	Level 1	The student does not suggest an experimental procedure.
	Level 2	The student suggests an irrelevant experimental procedure.
	Level 3	The student suggests an experimental procedure and make clear reference to one to two of the following: the independent variable, the control variables and the dependent variable
	Level 4	The student suggests an experimental procedure and make clear reference to the independent variable, the control variables and the dependent variable

The analysis of students' responses was performed by two researchers who worked independently. Any disagreements should be noted and resolved by consensus among researchers or by arbitration by an additional independent researcher. For statistical analysis purposes, the levels of responses for questions 1-9 were converted to scaled numeric values. Level 1 was assigned a numeric value of 1, Level 2 was assigned a numeric value of 2, Level 3 was assigned the numeric value 3, and Level 4 was assigned a numeric value of 4. Survey responses were analyzed using descriptive statistics which included means, and standard deviations for each of the 9 questions. The t-test was used to study the differences between the means of students' answers before and after the instructional intervention (in the pre-test and in the post-test).

Results

The Contribution of Instructional Intervention to Students' Knowledge of Electromagnets

In Table 2 the results of a paired-samples t-test are presented. The t-test was conducted to investigate the effect of instructional intervention on students' knowledge about the meaning of the electromagnet, its parts and its function. Table 2 shows that there are differences in the mean value for each issue before and after the instructional intervention. To examine whether these differences were statistically significant a paired samples t-test was conducted. The results of this test showed that there were statistically significant differences between the pre-test and the post-test.

Table 2. Paired Samples t-Test on Pre-Test and Post-Test of the Students' Knowledge About the Electromagnet

Issues	Pre-test		Post-test		t	*p*
	M	*SD*	*M*	*SD*		
Electromagnet meaning	1.84	1.26	3.86	1.24	-4.98	<.0001
The parts of an electromagnet	1.74	0.56	3.59	0.69	-9.07	<.0001
How electromagnet work	1.79	1.08	3.47	1.07	-4.82	<.0001

The Contribution of Instructional Intervention to Students' Abilities to Design Investigations about the Factors that Affect the Strength of an Electromagnet

In Table 3 the results of a paired-samples t-test are presented. It was conducted to investigate the effect of instructional intervention on students' abilities to formulate a research question and a prediction, identify and control variables, and describe the experimental procedure must be followed to answer the research question. Table 3 shows that there are differences in the mean for each issue before and after the instructional intervention. These differences were found to be statistically significant with a paired samples t-test.

Table 3. Paired Samples T-Test on Pre-Test and Post-Test for the Students' Ability to Design Investigations about the Factors that Affect the Strength of an Electromagnet

Issues	Pre-test		Post-test		t	*p*
	M	*SD*	*M*	*SD*		
Formulation of a research question	2.63	0.76	3.42	0.69	-3.34	.0019
Formulation of a prediction	2.37	0.90	3.32	0.48	-4.07	.0002
Identification of an independent variable	1.37	0.96	3.37	1.26	-5.52	<.0001
Identification of a dependent variable	1.63	0.96	3.05	0.97	-4.55	<.0001
Identification of control variables	1.05	0.23	3.11	1.05	-8.34	<.0001
Description of experimental procedure	1.37	0.83	2.63	1.07	-4.08	.0002

Discussion

The present study showed that before the implementation of the instructional intervention most students had and used conceptions different from school knowledge about what the electromagnet is, which parts it is composed from and how it works. The above findings agree with the conclusions of the research concerning students' conceptions about science concepts and phenomena. Accordingly, the students before learning about a subject, they have shaped conceptions about it based on their sensory experiences from the natural and social environment, and in most cases the initial conceptions of students differ from the views of scientific knowledge and its school version (Driver et al., 1985; Duit, 2009). In addition, it has been found that some of the conceptions recorded by the research seem to be quite widespread among students (Driver et al., 1994; Taber, 2015).

However, after the instructional intervention was applied to the students, it emerged that most students developed conceptions about electromagnets that are consistent with school knowledge. The findings of this study can be attributed to reasons related to teaching procedures that were implemented and activities included in the instructional material developed. The instructional intervention provides opportunities for students to record and expresses their initial conceptions, to work in groups and to process their conceptions by comparing them with the conceptions of their classmates and with the experimental results. The structure of the activities contributed to the creation of controversies between the students. During the implementation of the activities, the students of each group tried to support their views and convince their classmates about them. It probably helped the students to be actively involved in a confrontation of ideas that contributed to the change of their conceptions (Howe et al., 2013; Skoumios, 2009). In addition to the above, the use of scientific and engineering practices by students in the instructional intervention (such as their involvement in asking questions, developing and using models, designing and carrying out investigations, analyzing and interpreting data), may have contributed to changing conceptions about electromagnets. It has been argued that the intellectual and practical work associated with processing and revising conceptions is based on students’ engagement in scientific and engineering practices (NRC, 2012; NGSS Lead States, 2013).

Although the instructional intervention contributed significantly to the change most students' conceptions of electromagnets, there were students who did not change their conceptions. It seems that students' conceptions are durable. Indeed, research data demonstrate the durable nature of students' conceptions in various teaching approaches (Chi et al., 2012; Dedetürk et al., 2021; Gunstone et al., 1992).

In addition, from the findings of the present study, it was found that before the implementation of the instructional intervention most students have not developed their abilities to design science investigations. Indeed, most students were not able to formulate a research question and a prediction, identify and control variables, and describe the experimental procedure that must be followed to answer the research question. The above findings are in line with the conclusions of research that refer to the above abilities of secondary school students. According to them, students have significant difficulties related to the identification of scientific questions, the control of variables and the description of the experimental procedure (Arnold et al., 2014;

Cayvaz et al., 2020; Chen and Klahr, 1999; Lubiano & Magpantay, 2021). The limited development of these abilities may be due to the fact that students do not engage in experimental design practices since usually the teacher acts as holder and bearer of knowledge using questions and answers, without involving students in inquiry processes (Cherbow et al., 2021; Zuljan et al., 2021). Mainly, students follow instructions written in the lab manual step by step and the outcome of lab activities is pre-determined. The ineffectiveness of this type of activities has been well documented in the research literature (Abrahams & Millar, 2008; Todas & Skoumios, 2014).

However, after the instructional intervention was applied to the students, it emerged that most students significantly improved their abilities to design investigations. The improvement of abilities to design investigations, through the instructional intervention that was applied, can be attributed to the activities that were developed. These activities provided students with opportunities to formulate research questions, make predictions, identify the independent variable, control variables and dependent variable in each research, as well as describe the experimental procedure they must follow to answer a research question. It has been found that these activities can help improve students' abilities in designing science investigations (Cayvaz et al., 2020; Edelsbrunner et al., 2018; Roth & Roychoudhury, 1993).

Conclusions and Recommendations

The purpose of this research was to study the effects of an instructional intervention with instructional material for electromagnets, based on an inquiry-based approach using the scientific and engineering practices, on 12 years-old students' knowledge about the electromagnets and the development of their abilities to design investigations. From the results of this study, it can be concluded that it is possible to improve the knowledge of many elementary school students about electromagnets, as well as to develop their abilities to design investigations, through the instructional intervention that was developed and implemented. The present survey with its results contributes to the research concerning the study of the impact of instructional interventions on elementary school students' knowledge about electromagnets and their abilities to design science investigations, which are issues with restricted empirical data.

However, it should be noted that the results of this study are subject to limitations. In particular, 76 students of the last grade of elementary school participated in this research and therefore its findings are subject to the limitations of the sample. Also, a major limitation of this study is the lack of a control or comparison group. In addition, the research was conducted only with the use of a questionnaire completed by students before and after the instructional intervention and this is an additional limitation.

This work focused on investigating the effects of the instructional intervention on students' knowledge about the electromagnets and the development of their abilities to design science investigations. Further research is needed to study the effects of the instructional intervention on other scientific and engineering practices, beyond the practice about planning investigations, such as practices related to developing and using models, analyzing and interpreting data, constructing explanations and designing solutions, and engaging in argument from evidence.

In addition, in the present work the learning outcomes were evaluated through the use of a questionnaire before and after the instructional intervention. It would be interesting to study the evolution of students' knowledge of electromagnets as well as the evolution of their abilities to design investigations through the analysis of students' written and oral speech, during the instructional intervention. This research would allow to study the "learning paths" of students and to identify the activities that contributed significantly to both the building of knowledge and the development of students' abilities.

Acknowledgements

The authors are grateful to all participants in the research and colleagues for support in creation of this paper.

References

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education*, *30*(14), 1945-1969. https://doi.org/10.1080/09500690701749305

Akcay, H., & Yager, R. E. (2010). The impact of a science/technology/society teaching approach on student learning in five domains. *Journal of Science Education and Technology*, *19*(6), 602-611. https://doi.org/10.1007/s10956-010-9226-7

Andersson, B. (1986). The experiential gestalt of causation: a common core to pupils' preconceptions in science. *European Journal of Science Education*, *8*(2), 155–171. https://doi.org/10.1080/0140528860080205

Arnold, J. C., Kremer, K., & Mayer, J. (2014). Understanding Students' Experiments—What kind of support do they need in inquiry tasks? *International Journal of Science Education*, *36*(16), 2719-2749. https://doi.org/10.1080/09500693.2014.930209

Atwood, R. K., Christopher, J. E., Combs, R. K., & Roland, E. E. (2010). In-service elementary teachers' understanding of magnetism concepts before and after non-traditional instruction. *Science Educator*, *19*, 64–76.

Avsar Erumit, B., Fouad, K.E. & Akerson, V.L. (2019). How do learner-directed scientific investigations influence students' questioning and their nature of science conceptions? *International Journal of Education in Mathematics, Science and Technology (IJEMST)*, *7*(1), 20-31. https://doi.org/10.18404/ijemst.509246

Barrow, L. H. (1987). Magnet concepts and elementary students' misconceptions. In *Proceedings of the Second International Seminar on misconceptions and educational strategies in Science and Mathematics* (Vol. 3, pp. 17-22). Ithaca, NY: Cornell University Press.

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082– 1112. https://doi.org/10.1002/tea.21257

Borges, A. T., & Gilbert, J. K. (1998). Models of magnetism. *International Journal of Science Education*, *20*(3), 361–378. https://doi.org/10.1080/0950069980200308

Bybee, R., Taylor, J., Gardner, A., Van Scotter, P., Carlson Powell, J., Westbrook, A., & Landes, N. (2006). *The BSCS 5E Instructional Model: Origins and Effectiveness*. Colorado Springs.

Cayvaz, A., Akcay, H., & Kapici, H.O. (2020). Comparison of simulation-based and textbook-based instructions on middle school students' achievement, inquiry skills and attitude. *International Journal of Education in Mathematics, Science and Technology (IJEMST)*, *8*(1), 34-43.

Chen, Z., & Klahr, D. (1999). All other things being equal: Acquisition and transfer of the control of variables strategy. *Child development*, *70*(5), 1098-1120. https://doi.org/10.1111/1467-8624.00081

Cherbow, K., Lowell, B. R., & McNeill, K. L. (2021). Redesign or relabel? How a commercial curriculum and its implementation oversimplify key features of the NGSS. *Science Education*, *105*(1), 5-32. https://doi.org/10.1002/sce.21604

Chi, M.T.H., Kristensen, A. K., & Roscoe, R. (2012). Misunderstanding emergent causal mechanism in natural selection. In K. Rosengren, S. Brem, & G. Sinatra (Eds.), *Evolution Challenges: Integrating Research and Practice in Teaching and Learning about Evolution* (pp. 145-173). Oxford University Press.

Cohen, L., Manion, L., & Morrison, K. (2011). Surveys, longitudinal, cross-sectional and trend studies. *Research Methods in Education,* 7th edition. Abingdon: Routledge.

Dedetürk A., Saylan Kirmizigül A., & Kaya H. (2021). The effects of STEM activities on 6th grade students' conceptual development of sound. *Journal of Baltic Science Education*, *20*(1), 21-37. https://doi.org/21-37. 10.33225/jbse/21.20.21

Driver, R., Guesne, E., Tiberghien, A. (1985). Some features of children's ideas and their implications for teaching. In R. Driver, E. Guesne, & A. Tiberghien (Eds.). *Children's ideas in science*. (pp. 193-201). Milton Keynes, UK: Open University Press.

Driver, R., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science—research into children's ideas*. London: Routledge.

Duit, R. (2009). *Bibliography: Students' and Teachers' Conceptions and Science Education*. Kiel, Germany: Leibniz Institute for Science Education.

Duschl, R.A., Schweingruber, H.A., & Shouse, A.W. (2007). *Taking Science to School: Learning and Teaching Science in Grades K-8*. Washington, DC: National Academies Press.

Duschl, R. A., & Bybee, R. W. (2014). Planning and carrying out investigations: An entry to learning and to teacher professional development around NGSS science and engineering practices. *International Journal of STEM Education*, *1*(1), 1-9. https://doi.org/10.1186/s40594-014-0012-6

Edelsbrunner, P. A., Schalk, L., Schumacher, R., & Stern, E. (2018). Variable control and conceptual change: A large-scale quantitative study in elementary school. *Learning and Individual Differences*, *66*, 38-53.

Feyzioğlu, E. Y., Akpinar, E., & Tatar, N. (2018). Effects of technology-enhanced metacognitive learning platform on students' monitoring accuracy and understanding of electricity. *Journal of Baltic Science Education*, *17*(1), 43-64.

Galili, I. (1995). Mechanics background influences students' conceptions in electromagnetism. *International Journal of Science Education*, *17*(3), 371–387. https://doi.org/10.1080/0950069950170308

Glaser, R., Schauble, L., Raghavan, K., & Zeitz, C. (1992). Scientific reasoning across different domains. In E. de Corte, M. C. Linn, H. Mandl, & L. Verschaffel (Eds.), *Computer-based learning environments and problem solving* (pp. 345–371). Berlin: Springer.

Gunstone, R., Gray, R., & Searle, P. (1992). Some long-term effects of long-term uninformed conceptual change. *Science Education*, 76, 175-197. https://doi.org/10.1002/sce.3730760206

Hackling, M. W. (1998). *Working scientifically: Implementing and assessing open investigation work in science*. Perth: Education Department of Western Australia.

Hickey, R., & Schibeci, R. (1999). The attraction of magnetism. *Physics Education*, *34*(6), 383–388. https://doi.org/10.1088/0031-9120/34/6/408

Howe, C., Devine, A., & Tavares, J.T. (2013). Supporting conceptual change in school science: A possible role for tacit understanding. *International Journal of Science Education*, *35*(5), 864–883. https://doi.org/10.1080/09500693.2011.585353

Irwanto, Rohaeti, E., & Prodjosantoso, A. K. (2018). Undergraduate students' science process skills in terms of some variables: A perspective from Indonesia. *Journal of Baltic Science Education*, *17*(5), 751–764.

Kähkönen, A. L., Sederberg, D., Viiri, J., Lindell, A. & Bryan, L. (2020). Finnish secondary students' mental models of magnetism, *Nordina – Nordic Studies in Science Education*, 16(1), 101-120. https://doi.org/10.5617/nordina.5566

Kazeni, M., Baloyi, E., & Gaigher, E. (2018). Effectiveness of individual and group investigations in developing integrated science inquiry skills. *South African Journal of Education*, *38*(3), 1–12. https://doi.org/10.15700/saje.v38n3a1549

Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction: Effects of direct instruction and discovery learning. *Psychological Science*, *15*(10), 661-667. https://doi.org/10.1111/j.0956-7976.2004.00737.x

Kruit, P.M., Oostdam, R.J, Berg, E., & Schuitema, J.A. (2018). Assessing students' ability in performing scientific inquiry: instruments for measuring science skills in primary education, *Research in Science & Technological Education*, 36(4), 413-439.

Lawson, A. E. (2002). Sound and faulty arguments generated by preservice biology teachers when testing hypotheses involving unobservable entities. *Journal of Research in Science Teaching*, *39*, 237–252. https://doi.org/10.1002/Tea.10019

Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning. *Review of Educational Research*, *86*(3), 681-718.

Lubiano, M. L. D., & Magpantay, M. S. (2021). Enhanced 7E Instructional Model towards enriching science inquiry skills. *International Journal of Research in Education and Science (IJRES)*, *7*(3), 630-658. https://doi.org/10.46328/ijres.1963

Marshall, J.C., Smart, J.B., & Alston, D.M. (2017). Inquiry-based instruction: A possible solution to improving student learning of both science concepts and scientific practices. *International Journal of Science and Mathematics Education*, 15(5), 777–796. https://doi.org/10.1007/s10763-016-9718-x

Mercer, N., Dawes, L., Wegerif, R., & Sams, C. (2004). Reasoning as a scientist: Ways of helping children to use language to learn science. *British Educational Research Journal*, *30*(3), 359-377. https://doi.org/10.1080/01411920410001689689

National Research Council. [NRC] (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The

National Academies Press.

Organisation for Economic Co-operation and Development [OECD]. (2013). *OECD skills outlook 2013: First results from the survey of adult skills*. Paris: OECD Publishing.

Pearson, D. M., & Gorman, J. T. (2010). Exploring the relevance of a landscape ecological paradigm for sustainable landscapes and livelihoods: a case-application from the Northern Territory Australia. *Landscape Ecology*, *25*(8), 1169-1183. https://doi.org/10.1007/s10980-010-9498-6

Pedaste, M., Baucal, A. & Reisenbuk, E. (2021). Towards a science inquiry test in primary education: development of items and scales. *International Journal of STEM Education,* 8(19), 1-19.

Psillos, D., Koumaras, P., & Valassiades, O. (1987). Pupils' representations of electric current before, during and after instruction on DC circuits. *Research in Science and Technological Education*, 5(2), 185-199. https://doi.org/10.1080/0263514870050209

Roth, W. M., & Roychoudhury, A. (1993). The development of science process skills in authentic contexts. *Journal of Research in Science Teaching*, *30*(2), 127-152. https://doi.org/10.1002/tea.3660300203

Samaresh, A. (2017). Effectiveness of constructivist approach on academic achievement in science at secondary level. *Educational Research and Reviews*, *12*(22), 1074–1079. https://doi.org/10.5897/err2017.3298

Schalk, L., Edelsbrunner, P. A., Deiglmayr, A., Schumacher, R., & Stern, E. (2019). Improved application of the control-of-variables strategy as a collateral benefit of inquiry-based physics education in elementary school. *Learning and Instruction*, *59*, 34-45.

Schneider, R. M., Krajcik, J., Marx, R. W., & Soloway, E. (2002). Performance of students in project- based science classrooms on a national measure of science achievement. *Journal of Research in Science Teaching*, *39*(5), 410-422. https://doi.org/10.1002/tea.10029

Schwarz, C., Passmore, C., & Reiser, B. J. (Eds.). (2017). *Helping students make sense of the world using Next Generation Science and Engineering Practices*. NSTA Press.

Selman, R. L., Krupa, M. P., Stone, C. R., & Jaquette, D. S. (1982). Concrete operational thought and the emergence of the concept of unseen force in children's theories of electromagnetism and gravity. *Science Education*, *66*(2), 181-194. https://doi.org/10.1002/sce.3730660205

Shipstone, D. (1988). Pupils' understanding of simple electrical circuits. *Physics Education*, 23, 92-96. https://doi.org/10.1088/0031-9120/23/2/004

Shipstone, D.M. (1984). A study of children's understanding of electricity in simple DC circuits. *European Journal of Science Education*, 6(2), 185-198. https://doi.org/10.1080/0140528840060208

Shipstone, D. M. (1985). On childrens' use of conceptual models in reasoning about current electricity. In R. Duit, W. Jung, C. von Rhöneck (Eds.), *Aspect of Understanding Electricity* (pp. 73-83). Keil: Schmidt & Klaunig.

Shipstone, D.M., Rhöneck, C.V., Karqvist, C., Dupin, J., Johsua, S., & Licht, P. (1988). A study of student' understanding of electricity. *International Journal of Science Education*, 10(3), 303-316. https://doi.org/10.1080/0950069880100306

Skoumios, M. (2009). The Effect of Sociocognitive Conflict on Students' Dialogic Argumentation about Floating and Sinking. *International Journal of Environmental and Science Education*, *4*(4), 381–399.

Smaill, C. R., Rowe, G. B., Godfrey, E., & Paton, R. O. (2012). An investigation into the understanding and skills of first-year electrical engineering students. *IEEE Transactions Education*, *55*(1), 29-35. https://doi.org/10.1109/TE.2011.2114663

Taibu, R., Mataka, L., & Shekoyan, V. (2021). Using PhET simulations to improve scientific skills and attitudes of community college students. *International Journal of Education in Mathematics, Science, and Technology (IJEMST)*, *9*(3), 353-370. https://doi.org/10.46328/ijemst.1214

Thurn, C. M., Hänger, B., & Kokkonen, T. (2020). Concept Mapping in Magnetism and Electrostatics: Core Concepts and Development over Time. *Education Sciences*, 10(5), 129.

Todas, A., & Skoumios, M. (2014). Practical Work in Primary Science: Actions and Verbalized Knowledge. *The International Journal of Early Childhood Learning*, *20*(2), 37-50. https://doi.org/10.18848/2327-7939/CGP/v20i02/58951

Taber, K. S. (2015). Prior knowledge. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 785–786). Berlin-Heidelberg: Springer-Verlag.

van Riesen, S. A. N., Gijlers, H., Anjewierden, A. A., & de Jong, T. (2018). Supporting learners' experiment design. *Educational Technology Research and Development*, 66, 475–491. https://doi.org/10.1007/s11423-017-9568-4

Windschitl, M. (2017). Planning and carrying out investigations. In C. V. Schwarz, C. Passmore, & B. J. Reiser (Eds.), *Helping students make sense of the world using next generation science and engineering practices* (pp. 135– 158). Arlington, VA: National Science Teachers Associations Press.

Zacharia, Z. C., Manoli, C., Xenofontos, N., de Jong, T., Pedaste, M., van Riesen, S. A. N., et al. (2015). Identifying potential types of guidance for supporting student inquiry when using virtual and remote labs in science: A literature review. *Educational Technology Research and Development*, 63, 257–302. https://doi.org/10.1007/s11423-015-9370-0

Zion, M., Michalsky, T., & Mevarech, Z. R. (2005). The effects of metacognitive instruction embedded within an asynchronous learning network on scientific inquiry skills. *International Journal of Science Education*, *27*(8), 957-983. https://doi.org/10.1080/09500690500068626

Zuljan, D., Valenčić Z. M., & Pejić P. P. (2021). Cognitive constructivist way of teaching scientific and technical contents, *International Journal of Cognitive Research in Science, Engineering and Education*, *9*(1), 23-36. https://doi.org/10.23947/2334-8496-2021-9-1-23-36

Author Information

Evdokia Andrikopoulou

https://orcid.org/0000-0002-8507-381X

Department of Primary Education

University of the Aegean

1 Dimokratias Ave., 85132 Rhodes

Greece

Contact e-mail: *evie_andrikopoulou@yahoo.gr*

Michael Skoumios

https://orcid.org/0000-0001-7234-9832

Department of Primary Education

University of the Aegean

1 Dimokratias Ave., 85132 Rhodes

Greece

Appendix. Questionnaire (Part B)

Aris and Giota made an electromagnet. Aris claims that they can make it stronger, so that it can pull more pins, using more batteries. But Giota believes that this cannot happen because she believes that it is not possible for an electromagnet to become stronger using more batteries.

After this disagreement, the children decided to do a science investigation.

Question 4: What is the question that children have to investigate?

Question 5: What could be a possible answer to this question?

Question 6: What will they change in their investigation?

Question 7: What will they measure in their investigation?

Question 8: What will not change in their investigation?

Question 9: What would you suggest the children should do to find out who is right? (Answer in as much detail as you can).