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IMPROVING THE STRUCTURE OF STUDENTS' ARGUMENTS THROUGH A TEACHING-LEARNING SEQUENCE ON NEWTON'S SECOND LAW

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Abstract:
The present paper intends to investigate the contribution of a teaching-learning sequence on Newton's Second Law to the structure of high school students' written arguments. Instructional material on Newton's Second Law, based on the constructivist approach towards learning with the use of science practices and the exploitation of the educational software "Interactive Physics", was developed and was finally implemented to 39 high school students (15 years old). The research data included students' answers to questionnaires both before and after the teaching-learning sequence. Students' written arguments were analyzed with the use of a framework for evaluating the presence and the sufficiency of the components of the arguments. The data analysis showed that the teaching-learning sequence significantly contributed to improving the structure of students' arguments.

Keywords: teaching-learning sequence, science practices, structure of arguments, science learning

1. Introduction

In science teaching, it is important that the students, apart from learning science ideas and concepts, develop science practices and become familiar with their use (NRC, 2012). Science practices have to do with the way in which scientists explore natural phenomena and construct models and theories in order to interpret them. One of these practices is the construction of arguments based on evidence (NGSS Lead States, 2013), where the students should evaluate the available data in order to select sufficient and adequate evidence and develop their own arguments or assess the arguments they are presented with (NRC, 2012). The construction of arguments by the students is necessary because it can contribute to them both understanding the conceptual content of science

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(Bell & Linn, 2000; McNeill & Krajcik, 2007) and adopting a positive attitude towards science (McNeill & Krajcik, 2006).

Despite the importance attributed to the construction of arguments, the research on the quality of students' arguments and the possibility for its improvement is particularly limited. The present paper studies the contribution of a teaching-learning sequence to the structure of students' written arguments.

2. Theoretical Framework

According to McNeill and Krajcik (2012), an argument is made up of four components: the claim, the evidence, the reasoning and the rebuttal (Figure 1). In particular, 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 is considered evidence supporting the claim with the use of science principles; the rebuttal explains why or how an alternative claim is false.

The criteria for the quality of an argument are the structure and the content of the argument (McNeill, Lizotte, Krajcik & Marx, 2006; Sandoval & Millwood, 2005). The structure of an argument is related to the presence and the sufficiency of its components. An argument is considered sufficient when it includes a claim, the evidence supporting the claim, the reasoning that involves science principles through which the evidence is connected with the claim as well as a rebuttal that includes another claim, which is supported by evidence and reasoning. The content of an argument is related to the adequacy of its components when the latter are evaluated with regard to school knowledge.

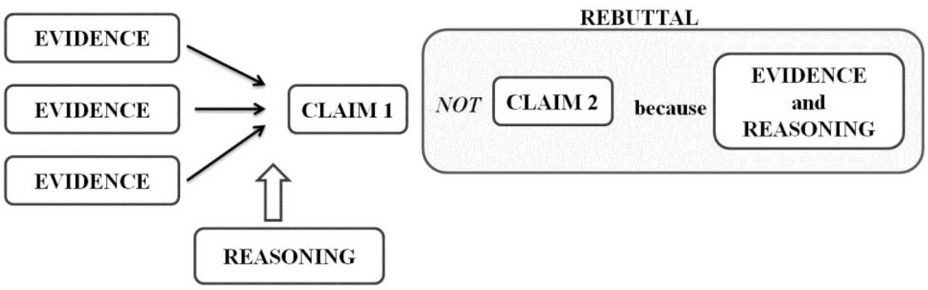

Figure 1: Framework for Constructing Scientific Argumentations
(Adapted from McNeill & Krajcik, (2012))

3. Literature Review

The research data demonstrate the difficulties of the students in constructing evidence-based arguments. In particular, the students suggest claims without justifying them (Jiménez-Aleixandre, Rodríguez & Duschl, 2000; Sadler, 2004) or suggest insufficient and inadequate evidence 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, the students hardly ever use reasoning in the arguments they construct (Lizotte, Harris, McNeill, Marx, & Krajcik, 2003; McNeill & Krajcik, 2007, 2012; Moje et al., 2004; Sadler, 2004; Songer & Gotwals, 2012; Zeidler, 1997), while their ability to evaluate arguments and construct rebuttals is particularly limited (McNeill & Krajcik, 2012; Zeidler, 1997).

Although the importance of students' involvement in the practice of argumentation has been recognized (Driver et al., 2000; Duschl & Osborne, 2002; McNeill et al., 2006; Sandoval, 2003), there is limited research on the contribution of teaching interventions to the improvement of the quality of students' written arguments (Chen, Wang, Lu, Lin, & Hong, 2016; McNeill et al., 2006; Sampson, Enderle, Grooms, & Witte, 2013; Sampson & Walker, 2012; Sandoval, 2003). More specifically, there is no research on the contribution of teaching interventions focused on the practice of argumentation to the conceptual area of forces and motions. In addition, there is no research focusing on the discrete evaluation of the structure and the content of students' written arguments.

4. Purpose and Research Questions

The present paper aims to study the contribution of a teaching-learning sequence on Newton's Second Law, which is based on the constructivist approach towards learning with the use of science practices and the educational software "Interactive Physics", to the structure of high school students' (15 years old) written arguments.

In particular, the following research questions are intended to be answered:

a) What is the contribution of the proposed teaching-learning sequence on Newton's Second Law to the sufficiency of the claims of students' written arguments?
b) What is the contribution of the proposed teaching-learning sequence on Newton's Second Law to the sufficiency of the evidence of students' written arguments?
c) What is the contribution of the proposed teaching-learning sequence on Newton's Second Law to the sufficiency of the reasoning of students' written arguments?
d) What is the contribution of the proposed teaching-learning sequence on Newton's Second Law to the sufficiency of the rebuttals of students' written arguments?

5. Methodology

5.1 Research Process and Sample

The research was conducted in two phases. The first phase (pilot research) included the compilation of the questionnaire and the instructional material (on Newton's Second Law). The second phase (main research) included the implementation of the instructional material compiled after the educational software "Interactive Physics" had been exploited and the answering of the questionnaire by all the students before and after the implementation of the teaching-learning sequence. Thirty-nine students of high school (15 years old) participated in the research process.

5.2 Instructional Material

Instructional material on Newton's Second Law was compiled, based on the constructivist approach towards science learning with the use of science practices on the side of the students (see Table 1) and the exploitation of the interactive instructional software "Interactive Physics".

The development of the instructional material involved the 5E instructional model of Bybee et al. (2006), which includes the following phases: engagement, exploration, explanation, elaboration and evaluation.

Table 1: Phases and Respective Science Practices

Phases	Science Practices
Engagement	Asking questions.
	Obtaining, evaluating, and communicating information.
Exploration	Planning and carrying out investigations.
	Analyzing and interpreting data.
	Using mathematics and computational thinking.
	Obtaining, evaluating and communicating information.
Explanation	Constructing explanations.
	Obtaining, evaluating, and communicating information.
	Using mathematics and computational thinking.
	Analyzing and interpreting data.
Elaboration	Obtaining, evaluating, and communicating information.
	Using mathematics and computational thinking.
	Constructing explanations.
	Engaging in argument from evidence.
Evaluation	Engaging in argument from evidence.
	Obtaining, evaluating and communicating information.

In the phase of engagement, the students, initially on a personal level, recorded their predictions about problems they were given so that their alternative perceptions could be revealed. Through discussions on a group level and negotiations on a class level they selected the questions they were to explore.

In the phase of exploration, the students became familiar with designing and conducting research, i.e. submitting research questions and suppositions, identifying variables (independent variables, dependent variables and control variables), describing experimental processes, implementing processes with the use of software and collecting data.

In the phase of explanation, the students processed the data and identified different tendencies. It was intended that the students should construct arguments (based on the evidence they had collected through research). The students were presented with the components of an argument (claim, evidence, reasoning, rebuttal), which were also explained to them, the necessity for the construction of arguments was discussed, and the students constructed and evaluated arguments under the guidance of the teacher.

In the phase of elaboration, the students processed problems different from those they had initially negotiated so that they could examine to what extent they systematically activate the new knowledge in new problems. The students became familiar with activities through which they identified the components of the argument and elaborated and evaluated their own arguments with the help of evaluation frameworks (self-evaluation of arguments).

In the phase of evaluation, the students compared the new knowledge with their original conceptions in order to attain self-control and realize their cognitive progress.

5.3 Data Collection and Analysis

The data collection tool was the questionnaire that was initially (pilot research) handed to a small number of students (5 students) so that they could clarify some obscure points. The questionnaire was also given to two science teaching researchers so that they could verify the internal validity and make corrections.

The final form of the questionnaire included six questions in which the students were asked to predict and justify issues related to Newton's Second Law. Table 2 shows the issues researched and the questions of the questionnaire related to each case.

Table 2: The issues of Newton's Second Law and the respective questions of the questionnaire

Issues	**Questions**
Relationship between the resultant force and the acceleration in a body of constant mass.	1 and 6
Relationship between mass and acceleration when the resultant force is constant.	2 and 3
Relationship between the applied force and the change in the kinetic state of the body.	4
Relationship between the resultant force and the kind of motion of the body.	5

The research data included students' written answers (arguments) to the questions of the questionnaire. The evaluation of the written arguments' structure involved a scale of graduated criteria on the basis of which the presence and sufficiency of the components of the arguments were evaluated regardless of the validity of their conceptual content (Skoumios & Hatzinikita, 2014) (see Table 3).

Table 3: Rubric of graduated (at levels) evaluation criteria of the structure of students' written arguments

Components	**Levels**		
	Level 0	**Level 1**	**Level 2**
Claim	Does not suggest a claim	Suggests an insufficient claim	Suggests a sufficient claim
Evidence	Does not suggest evidence	Suggests insufficient evidence	Suggests sufficient evidence
Reasoning	Does not suggest reasoning	Suggests insufficient reasoning	Suggests sufficient reasoning
Rebuttal	Does not suggest	Suggests an insufficient	Suggests a sufficient

	a rebuttal	rebuttal	rebuttal

The following is an example of the evaluation of an argument a girl student developed (answer to Question 1) after the implementation of the teaching-learning sequence (post-test).

Argument:
"*In bodies of equal masses, acceleration is affected by the resultant force* (suggestion 1). *The measurements in the table show that when force increases, acceleration increases too* (suggestion 2). *According to Newton's Second Law, acceleration is proportional to the resultant force and since the bodies of the table are of equal masses, their acceleration is affected by the resultant force* (suggestion 3). *Velocity does not affect acceleration because its values are random* (suggestion 4)."

Evaluation of the Argument's Structure:
As for its structure, this argument includes:

- Claim (suggestion 1), which is considered sufficient (level 2).
- One piece of evidence (suggestion 2) instead of all the evidence required for supporting the claim (level 1).
- Reasoning (suggestion 3) connecting the evidence with the claim and based on a science concept (Newton's Second Law); it is considered sufficient (level 2).
- Rebuttal (suggestion 4), which is considered insufficient (level 1).

After the students' arguments were evaluated, the frequencies (percentages) of occurrence of the three levels were specified with regard to each component of the students' written arguments before and after the implementation of the teaching-learning sequence. Furthermore, the median and the average value were also specified. The study on the differentiations among the levels of the components of students' arguments before and after the implementation of the teaching-learning sequence used the non-parametric criterion Wilcoxon Signed Ranks Test.

6. Results

Figure 2 shows the average values of the components of students' written arguments before and after the teaching-learning sequence.

It emerges that there is an increase in the average values of the levels of all four components of students' written arguments before and after the teaching-learning sequence. What is more, the non-parametric test Wilcoxon Signed Ranks Test showed that, both before and after the implementation of the teaching-learning sequence, the sufficiency levels of all four components of students' written arguments were significantly changed, i.e.: (a) claims ($Z = -7.446$, $p<0.001$), (b) evidence ($Z = -7.889$, $p<0.001$), (c) reasoning ($Z = -9.367$, $p<0.001$) and (d) rebuttals ($Z = -8.020$, $p<0.001$).

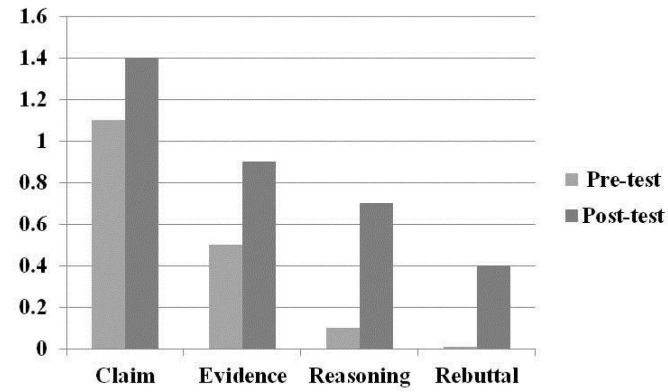

Figure 2: Average values of the levels of the components of students' written arguments before and after the teaching-learning sequence.

7. Discussion and Conclusions

Before the implementation of the teaching-learning sequence on Newton's Second Law, the structure of students' written arguments was insufficient. These conclusions are in line with the results of other research papers (McNeill & Krajcik, 2007, 2012; Moje et al., 2004; Sandoval & Millwood, 2005; Songer & Gotwals, 2012). Rarely do the students have the chance to construct arguments and the low quality of the structure of students' written arguments can be attributed to this finding (Driver et al., 2000).

The findings of the present paper demonstrate that the improvement of the structure of students' written arguments in the conceptual area of Newton's Second Law is feasible through the teaching-learning sequence implemented. After comparing the structure of written arguments before and after the implementation of the sequence, it emerged that the sufficiency of all four components of the students' written arguments (claim, evidence, reasoning and rebuttal) was significantly improved. This improvement could be attributed to the activities included in the instructional material, which gave the students the opportunity to become familiar with the components of an argument and the way in which they are connected with each other (modeling of arguments), evaluate their arguments (self-evaluation) and revise them on the basis of the evaluation they have made. Research indicates that the above processes contribute to the improvement of the quality of students' written arguments (McNeill & Krajcik, 2012; McNeill et al., 2005).

The present study was exclusively focused on the structure of students' written arguments. Further research is required for studying the content of arguments, the comparison of quality between students' verbal and written arguments as well as carry out a qualitative analysis of students' arguments throughout the instruction so that their progress can be studied and the activities significantly contributing to the improvement of the quality of their arguments can be specified.

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