ANALYSING ARGUMENTATION EPISODES: A CASE STUDY FROM PHYSICS TEACHER EDUCATION

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ABSTRACT

We discuss here how domain-specific argumentation and skills related to it can form part of learning science in higher education. In this study, we analyse pre-service physics teachers written reports (N=36). We introduce here four argumentative elements and propose how they can be used to analyse physics knowledge argumentation. The analysis allows us to detect how pre-service teachers combine argumentative elements in their explanations and consider what is the logical order of the appearance of argumentation episodes. Results show that the analysis method based on argumentative episodes reveal relevant differences in pre-service physics teachers' argumentation and its structure. We conclude by discussing how explicit teaching of argument construction may help pre-service teachers to improve their abilities to construct logical arguments.

INTRODUCTION

Learning argumentation and skills of constructing a coherent argument have been noticed as central goals for science education (Fischer et al., 2014; Rapanta, et al., 2013; Tiruneh, et al., 2016), but research field regarding argumentation is wide and the views are somewhat contradictory. Researchers do not share a similar view on the basic structure of argumentation or what are the objectives, conditions, and possibilities of argumentation (Wohlrapp, 2014). Many researchers have suggested that paying attention to argumentation in teaching have several potential benefits in science education. For example, learning argumentation can support students' cognitive and metacognitive processes, develop their critical thinking and scientific literacy skills, and develop students' ability of evaluating the epistemic criteria for knowledge (see, for example, Jiminéz-Aleixandre & Erduran, 2008). Even though the importance of argumentation as a general skill has been widely accepted, the aims of science education rarely concentrate on how argumentation can help to improve learning the targeted contents knowledge.

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Learning content knowledge is essential in science education but equally important, for successful learning and teaching, is to consider the pedagogical and didactical solutions approach for teaching of content knowledge. For example, in Finland goals of science teaching have recently increasingly put weight on such wide-ranged themes as scientific literacy (Kokkonen & Laherto, 2018) and sustainability. In both cases, one solution for educational challenges, posed by the wide-ranged themes, is emphasising argumentation skills as part of teaching and learning science at schools (Cavagnetto, 2015). Development of argumentation skills can be supported at all levels of education (von Aufschnaiter, et al., 2007; Fischer et al., 2014), and the most promising results can be achieved when argumentation skills are learned together with content knowledge (Mercer, 2009, Rapanta et al., 2013; see also Nousiainen 2017; Vuola & Nousiainen, 2020) or if teaching scientific argumentation is combined with constructivist epistemic beliefs (Nussbaum et al., 2008). However, often students are expected to learn argumentation quietly without teaching it explicitly. There is an abundance of different definitions for argumentation. We define here argumentation as the form of reasoning which aims to support or weaken a claim (Nussbaum, 2008) or a way to convince that something is true (Brigandt, 2016).

One of the central aims of physics teacher education is that pre-service teachers, learn, besides physics content knowledge, an overall picture of physics as science, understand the nature of physics knowledge and learn scientifically acceptable ways to justify physics knowledge formation. Teaching and learning physics should thus pay attention to logical, coherent, analytical, and critical thinking, and in addition, to argumentation because all these are indisputable features of physics as science (Sandoval & Millwood, 2007). The ability to construct good explanations is a crucial skill for a teacher because teaching can be seen as didactical argumentation (Wolhrapp, 2014). Consequently, argumentation as a part of explanation construction, is also an important part of constructing good explanations. Argumentation can thus be seen as a powerful didactical tool to construct good explanations, and conversely, many aspects of good explanation can be analysed by paying attention to quality of argumentation and its structure. However, research has shown that pre-service physics teachers seem to have problems in coherent mastering of large knowledge structures of content knowledge (i.e., too often knowledge remains fragmented) as well as in formulating coherent argumentation even in advanced-level university studies (see e.g., Mäntylä & Nousiainen, 2014; Nousiainen, 2017; Nousiainen, 2013; Vuola & Nousiainen, 2020) and their subject matter-related vocabularies are insufficient (Vuola et al., 2023).

Good command on SMK is not always connected to good argumentation skills in the same area, and thus, learning argumentation and SMK needs to be practiced together. Argumentation models that are useful must identify argument parts, how arguments are construed, what criteria are needed to characterize arguments and how those criteria are used to evaluate the quality of arguments. To reach argumentation successfully in the context of learning physics in higher education, we need criteria to teach and evaluate physics-specific argumentation to support practical didactical solutions to implement argumentation as part of physics education in higher level. Especially teacher education programs need suitable scaffoldings to teach argumentation and its practices as an integral part with subject-matter knowledge.

THEORETICAL BACKGROUND: FROM DOMAIN-GENERAL ARGUMENTATION TO PHYSICS-SPECIFIC ARGUMENTATION

The research on learning scientific argumentation usually concentrates on domain-general approach, the argumentation process and rational argumentation (for a review, see Osborne, et al., 2004). Even though the importance of argumentation as a general skill is commonly accepted, less attention is paid to how learning domain-specific argumentation and skills related to it can form part of learning science in higher education (cf. Engelmann, et al., 2018). Learning argumentation and argumentation skills need thus to be contextualised, i.e., practiced in some specific domain. In such a way, we can teach and learn domain-specific argumentation that proceeds from (empirical) evidence and pays attention to formation and evaluation of justified claims based on evidence. Domain-specific argumentation naturally share the general features describing argumentation, but focusing on one subject, or even more specially on one of its contexts, allows us to determine the specific criteria of what counts as acceptable argumentation in that field.

However, argumentation frameworks that clearly focus on physics or which are suitable for analysing physics knowledge are rare, but there have been attempts towards that direction. For example, Böttcher and Meisert (2010) propose a framework that emphasizes the role of models and modelling in physics knowledge formation. This very detailed framework is capable to discern differences in the way students construct and use models in constructing explanations but as a practical research tool, the framework is very heavy to use. Sampson and others present an argumentation model for school science experiments (Sampson, Grooms & Walker, 2011; Sampson & Blanchard, 2012). This argumentation model describes the relationships between argument components (claim, evidence, and justification) and criteria (empirical, theoretical, and analytical) to evaluate the argument components. This framework summarizes many important aspects to evaluate argumentation in school science, but it leaves many unanswered questions considering practical use of frameworks, for example, what counts as adequate or relevant evidence, what is appropriate way to handle data etc.

Toulmin's account (despite its known shortcomings) has been used to analyze various domains and it has impacted widely on argumentation research (Toulmin 1957/2003). For being such an overarching framework, Toulmin's model has its benefits and disbenefits: when focusing into some subject domain, it always calls for transformation to domain-specific criteria, but on the other hand, Toulmin's model has identified some very general structural features that apply to all argumentation: starting point (data), warrant (justification) and conclusion. Toulmin's model has been criticized because it only deals with part of argumentation, namely supporting claims and knowledge justification (Wolhrapp, 2014), Toulmin's model is not suitable to analyse long argument structures (Böttcher & Meisert, 2010) and Toulmin's argument structure analysis does not consider the rationality of the knowledge claim (Sandoval & Millwood, 2007). However, Toulmin's model is useful in identifying the logical order in which an argument should proceed. This is the aspect we consider in what follows.

In addition to Toulmin's structural argument analysis, Sandoval and others suggests that attention needs also to be paid to conceptual and epistemic quality of arguments (Sandoval, 2003; Sandoval & Millwood, 2007). This viewpoint is rarely considered in argumentation analysis frameworks and is thus a needed addition to existing analysis frameworks. Backman and others have recently taken a step towards that direction in suggesting that argument analysis could be carried out by utilising so called Rational force model (RFM) that combines acceptability and relevance of a knowledge claim (Backman, et al., under review). Even though the idea is very general, it lends itself very easily to analysing physics knowledge claims as well.

IDENTIFYING THE ARGUMENTATIVE EPISODES FROM SENTENCE ANALYSIS

In learning scientific ideas and theories, pre-service physics teachers need to build their understanding on investigation of data and elaborating arguments. To evaluate evidence, students need to understand the criteria for science and based on evidence-based scientific arguments one can decide which proposed explanation is correct (Brigandt, 2016). For physics knowledge formation, the interplay between inductive and deductive knowledge is essential. In context of science education, inductive form of logic appears quite often as part of experiments and empirical evidence, while deductive logic finds it uses dominantly in rational reasoning, use of theoretical knowledge and in modelling and model-based interpretation the empirical results. Therefore, experiments and models certainly deserve a special attention as part of argument construction.

We introduce here four structural argumentative elements that can be used to analyse physics knowledge argumentation. The viewpoint on argumentation adopted here borrows inspiration and motivation mainly from two sources: from Wohlrapp's view (2014) and Nussbaum's view (2008). According to Wohlrapp's very general account, a good argument has a certain structure: it should include a question, an assertion, and a conclusion. According to Nussbaum and others have (2008), a so-called CER model (claim-evidence-reasoning) is central in identifying argumentative sequences.

In physics knowledge formation, the assertion substantiation or justifying the claim includes the use of empirical evidence and theoretical knowledge, and their interpretations (Koponen & Mäntylä, 2006; Vuola & Nousiainen, 2020).

Therefore, we propose the following argumentative elements to analyse physics knowledge argumentation:

1. Background for argument. Motivation and starting point for argumentation, including consensus knowledge, for example facts without clear justification.

2. Assertion. Assertion substantiation in the form of either a) empirical evidence from experimental setup, measurements or the direct results or b) theoretical knowledge to explain the phenomenon.

3. Inferences. Relationships found from experiments and/or through theory, and their meaning. Inferences derived from experiments and/or through theory.

4. Conclusions. The broader meaning of the results and their further implications.

We also propose that this is the order (1 background – 2 assertion – 3 inference – 4 conclusion) how coherent and sound argumentation proceeds. Therefore, we seek for argumentative episodes where argumentative elements appear in 1-2-3-4 order, and we call this coherent argumentation. Argumentative element 2 is vital to justify physics knowledge. Leaving that out, we can say that argumentation is missing. Therefore, subsets 2-3-4, 1-2-3 and 2-3 are also interesting because they are the key element combinations to express physics knowledge argumentation.

RESEARCH PROBLEM AND RESEARCH QUESTIONS

We investigate pre-service teachers' argumentation and pay special attention to how pre-service teachers' use of empirical evidence and deduction in building up their explanations. We use the introduced argumentation elements to analyse the written explanations. The specific research questions are:

1. What combinations of argumentative elements are found in pre-service teachers' explanations?

2. What is the amount of coherent argumentation episodes?

Our aim is to show how the suggested argumentative elements can be used to analyse the coherence of argumentation in pre-service teachers' explanations. The analysis gives us an opportunity to compare the number of argumentative elements found in data.

RESEARCH DESIGN AND METHODS

Our sample consists of written reports on course assignments in a physics teacher preparation course that focused on organizing physics knowledge, in a way that is useful for teaching purposes. In the written reports (N=36, each report consisted of approximately 25 argumentative elements), pre-service teachers explain four well-known experiments on quantum physics (the photoelectric effect, the Compton effect, the double-slit experiment for single photons and the double-slit experiment for single electrons, referred as tasks A-D in what follows). During the course, pre-service teachers first read a research article on the phenomenon and analysed its argumentation. Second, pre-service teachers wrote explanations of how the phenomenon could be presented in teaching. The tasks are designed so that they implicitly enhance pre-service teachers to use the desired argumentative structure (background, assertion, inferences, and conclusion) but the exact analysis method was created after data collection. We analyse here these reports in the level of sentences.

Here are some examples (translated from Finnish) showing how sentences are classified into argumentative elements 1–4:

Example 1. background for argument: "Classical theory could not explain the photoelectron's kinetic energy's dependence of the radiation frequency instead of its intensity."

Example 2. assertion substantiation: "In the experiment, a voltage is created between plate electrodes in a vacuum."

Example 3. inference: "With this experiment we can define a threshold frequency, characteristic to each metal, $f = E_0/h$ (where E_0 is the minimum energy required to detach electrons), which is equal to the minimum frequency of electromagnetic radiation that can detach electrons from metal."

Example 4. conclusion: "We can conclude that energy is quantized, and light-quanta are real."

First, we categorise each sentence into one argumentative element category 1–4. Then we compress the information by paying attention only to the order of the argumentative elements (not the amount of similar argumentative elements). This means that even though the analysis is carried out sentence by sentence, in the results we fade out the length of the analysed reports and express only the order of argumentative elements (see Figure 1).

To ensure the credibility of scoring, 20% of the data was double scored by another expert on physics education. The inter-rater agreement between the scorers was 89.2 %, indicating that researchers had a high degree of agreement, and the dimensions were scored similarly between the scorers.

RESULTS

We illustrated the argumentative elements of each report in the form of heat maps (see Figure 1). From the heat maps, we can identify the different ways the pre-service teachers combine the argumentative elements. The analysis is carried out for all four tasks and the results are condensed in Table 1.

Table 1. The number of different argumentative element combinations found from the pre-service physics teachers reports (named as cases 1-9). Note that one report can contain more than one argument element combination.

	Task A	Task B	Task C	Task D
combination 1-2-3 and 23	8	7	2	7
combination 2-3-4	2	1	0	4
combination 1-2-3-4	1	2	5	0
other combinations	3	3	3	3

We could find at least one argumentative element combination of interest (1-2-3, 2-3, 2-3-4 or 1-2-3-4) from six cases in all tasks. In most cases, the number of combinations 1-2-3-4 and 2-3-4 that reflect coherent argumentation, gradually increases from task A to task D.

A closer analysis shows that the cases are different from each other. The best argumentation structure can be found in case 6 who has presented a coherent argumentation structure (1-2-3-4) in tasks A–C, and a 2-3-4 structure in task D. Next best case is case 1 who has a 1-2-3-4 structure in task C and a 2-3-4 structure in tasks A and D. Case 3 shows gradual change towards more coherent argumentation structure: from having one 1-2-3 structure in task A, to 2-3-4 structure in tasks (B and D) and a 1-2-3-4 structure in task C. Similar kind of notions can be made for task 4 as well. Case 8 has made a significant improvement since she/he does not have any coherent argument structure in three first tasks (A-C) but manages to present a 2-3-4 structure in the last task (D).

But at the same time, there are cases that do not have any argumentative element combination that might reflect coherence. For example, the argumentation element analysis shows that case 7 presents argumentation that proceeds in arbitrary order in all tasks. Unfortunately, there are many similar cases (e.g., task A 4 and 8, task B cases 5 and 8, task C cases 2 and 8, task D cases 2, 5 and 9).

Figure 1. Argumentative elements identified from all reports of all tasks. Each coloured bar presents one pre-service teacher report (cases 1–9) in form of a heat map. The coloured numbers in the heat map refer to the argumentative elements 1–4: green block (1) express background for argumentation, yellow block (2) express assertion substantiation, orange block (3) express justification and green block (4) express conclusion.

DISCUSSION AND CONCLUSIONS

The results presented in this study indicate there is a need to enhance pre-service teachers' skills to explicate scientific argumentation. We are especially concerned about two features we take as unwarranted. First, pre-service teachers' arguments are too often dominated by background knowledge, which after all is not much needed for the rest of the argument. In the best scenario, the high use of background knowledge can mean that pre-service teachers find it important to explicitly connect the explanation to previous knowledge and motivate the task well. Still, many times this is done at the expense of focusing on the more vital parts of the argument. Second, although at least partially working argumentative structures can be found in most reports, the structure of arguments too often appears incoherent lacking rational ordering how inductive and deductive steps or steps containing experimental and theoretical knowledge are combined structure of one third of the reports. Clearly pre-service teachers are not getting enough support to develop their argumentation skills throughout their studies. Science educators trust too much in students learning scientific argumentation by themselves, implicitly along their education. As good argumentation skills are a central learning goal for pre-service teachers, science educators need tools to teach argumentation systematically and explicitly so that also future teachers get practical tools to help them organize and consider their own knowledge.

We have here paid attention only to the argument structure in form of argumentative element combinations. The analysis itself is domain-specific but as such it is incapable to assess the quality of argumentation. However, coherent argument structure is a necessary but not sufficient prerequisite for content coherence. Therefore, the next step of research is finding out what kind of connection there is between pre-service teachers' argument structure and content knowledge.

Argumentation and explanation are ways to communicate coherent and well-ordered subject matter knowledge in teaching and they need to be explicitly taught (cf. Fischer et al., 2014). Increasing attention is paid to how argumentation can form part of science teaching in schools, aiming at scientific literacy. Schools and teachers play a central role in teaching and practicing students' argumentation skills. In that way education can guide future citizens towards sustainable decision-making. We suggest that the presented argumentation elements can be used to direct and further scaffold pre-service physics teachers' explanations to more argumentative direction.

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