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Scientific Vocabulary in Argumentative Elements: A Case Study from Physics Teacher Education

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Abstract

A central part of learning science is learning to use its language fluently. However, teachers' awareness of the language of science varies greatly. In this study, we have analysed coherence of argumentation by inspecting how pre-service teachers use physics vocabulary in argumentative elements in written reports (N = 36). We found out that the use of physics vocabulary in argumentative elements was coherent in some reports, while most of the reports ignored either relevant argumentative elements or physics vocabulary. Still, most pre-service teachers made progression in their argumentation. The results suggest that pre-service teachers have implicit knowledge of the language of science, but more explicit teaching is needed. We conclude that along with the language awareness it is important that future teachers are competent to support their students learning the language of science along with content knowledge.

Keywords

The language of science, argumentation, vocabulary, pre-service teachers

Introduction

Thinking and communication are intertwined with language and thus language is a prerequisite to conceptualization and thinking (Bratkovich, 2018). People form and convey information through language. Reading, writing, and talking are forms of expressing and communicating ideas and thoughts. Communication requires mutual understanding of the meaning and use of concepts, and it becomes challenging if concepts are not used normatively right way (Lemke, 1990; see Mercer, 2009). Therefore, language is a central perspective to education because teaching and learning happen through language (Mercer, 2009). Learning to use the language of science intertwines with the central learning goals in science education, which is highlighted by the remark that difficulties in learning the language of science are linked with difficulties in learning science (Wellington & Osborne, 2001). Besides school science, students are expected to be able to take part in discussions of science topics in real life and some of them will pursue a science career, all this demanding understanding of scientific content knowledge and how this knowledge is formed and presented (Bratkovich, 2018).

Students' ability to communicate knowledge in their own words is widely used to measure their understanding and learning (see Bratkovich, 2018; Glynn & Muth, 1994) even though teachers and students rarely notice the role of language in assessment (see Wellington & Osborne, 2001). Students need to learn content knowledge and how to read, write and talk about it (Bratkovich, 2018). Students are asked to show their understanding of a concept by using it correctly in relevant contexts and still, assessment criteria seldom pay attention to the disciplinary specific language of this communication (Bratkovich, 2018; Stenhouse, 1986). The hidden role of the language of science continues in teaching as science classes often focus on more non-verbal aspects of science communication – equations, graphs, laboratory activities – than learning how to read, write and discuss science (Bratkovich, 2018; Wellington & Osborne, 2001). Bratkovich and Paulsen (2020) describe a situation where a mathematics teacher's students "'understand the math' yet struggle to craft arguments". This highlights the teacher's implicit notion of the role of argumentation and thereby language in learning. In this study, we approach argumentation as the way to communicate and justify complex ideas by using the language of science.

Teachers should be aware of the importance of the language of science as they have corresponding demands on their own language skills: teachers' own competence has value in teaching only if they can communicate ideas to students in an understandable way. Teachers represent their own discipline and scientific community in school and act as language teachers of their subject (Wellington & Osborne, 2001). The language of science is a significant part of science content knowledge and pedagogical content knowledge (see Bratkovich, 2018; Francisco, 2022) and thus, teacher education plays a central role in building teachers' competence to support this aspect of the content area teaching. In such manner also teachers' language awareness develops since they are better equipped to formulate their teaching for different learners.

The language of science, its vocabulary and argumentation

Science has its own language with its own vocabulary and ways to use it (see e.g., Lemke, 1990). Scientific disciplines include language that needs to be learned to understand their topics (Bratkovich, 2018; Hufferd-Ackles et al., 2004). Science is done through language in the sense that the language of science, the knowledge that is described in the language and research activities to obtain new knowledge are intertwined inseparably (Bratkovich, 2018; Lemke, 1990; Stenhouse, 1986). Presenting knowledge, passing it on and discussing it are key activities in research (Stenhouse, 1986) and the language of science and normative ways of using it in this communication, argumentation and justifying complex ideas have developed over time as part of science (Bratkovich & Paulsen, 2020; Bratkovich, 2018). Understanding of different kinds of scientific arguments, their structure and criteria for validity is a part of a discipline's content knowledge and way of thinking (Francisco, 2022; see also Ayalon & Even, 2014). However, this does not mean that any scientist knows all there is to learn about argumentation. Rather, scientific discussion in its many forms is also a tool to develop one's thinking and argumentation skills throughout the career. Learning to use the language of science better is a part of not only learning science but doing it, too.

The concept language of science carries different meanings in the literature. In this study, we pay special attention to the structural complexity in which the language of science is used and analysed, and as a synthesis based on literature, we suggest four different levels of it. The levels are 1) scientific terms that build scientific vocabulary, 2) scientific facts and claims, 3) more complex scientific arguments, and 4) scientific debate and comparison of arguments. In the following, we unfold the four levels to some extent.

Level 1: vocabulary. A simple and straightforward way of looking at the language of science is to pay attention to its vocabulary: what words are used to communicate relevant scientific concepts and if they are special terms of the field of science or commonly used terms with a more precise discipline-specific definition (e.g., see Vuola & Nousiainen, 2020; Vuola, Nousiainen & Koponen 2023; Wellington & Osborne, 2001; Yun, 2020).

Level 2: sentences. On the second level, the language of science can be seen as using scientific vocabulary to construct straightforward thoughts–sentences that describe, for example, scientific facts or claims. This level finds support from the idea that learning scientific vocabulary includes learning the meaning and use of terms in different contexts (Wellington & Osborne, 2001).

Level 3: arguments. Correct lists of facts are not enough to convey scientific communication. In the third level to use the language of science argumentation is used to construct, communicate and justfy more complex ideas (see Bratkovich & Paulsen, 2020; Schwarz, 2009). At this level, reasoning includes also vocabulary from everyday language because it is needed to turn detached facts into a coherent argument (see Bratkovich & Paulsen, 2020). Many researchers (e.g., see Sampson & Clark, 2008; Toulmin, 2003) have studied the argumentation structure from the perspective of general to field-specific criteria.

Level 4: discussion. The fourth structural level of the language of science is the level of scientific discussion and debate where arguments are weighed and compared (e.g., see Bratkovich & Paulsen, 2020; Hufferd-Ackles et al., 2004). This viewing of arguments at the metalevel requires advanced understanding of science and its language.

Studies reducing the language of science to just its vocabulary have been criticized to naively dismiss the more comprehensive understanding of the language of science (Bratkovich, 2018). Still, this four-level structure of the language of science can be seen as steps of progression and analysing the use of language at different levels can give us fruitful insights into it.

Teaching and learning the language of science

Students need to learn the language of science to be able to describe their own understanding, gain insight into others' ideas and take part in meaningful discussion. In physics education, many assignments require language skills at the vocabulary and sentence level – they demand facts and mathematical derivations but not further verbal explanations (see also Kosko et al., 2014). However, teaching happens at the discussion level as teacher and students seek mutual understanding of new knowledge. This requires far more complex language skills than memorizing new vocabulary or presenting single facts (Bratkovich, 2018; see Bratkovich & Paulsen, 2020; Schwarz, 2009). Teachers challenge students to use language starting from simpler tasks and developing towards more complex argument construction and discussion. The opposite order of learning activities is also used as classroom argumentation supported by the teacher develops students' own language skills at every level (Kosko et al., 2014; Mercer, 2009; see Francisco, 2022; Ayalon & Even, 2014). This highlights that knowing the language of science and its vocabulary is a crucial part of teachers' knowledge base.

Teachers' awareness of the language of science differs, and this also affects their teaching the language of science which might emerge as more implicit than explicit. Teachers' views on teaching the language of science can be anything from versatile to non-existent (Ayalon & Hershkowitz, 2018). Regardless of teachers' views, they act as examples for their students and show how the language of science is used – what kind of vocabulary is needed in the science classroom, how scientific ideas or questions can be verbalized, which claims need to be justified and how precisely, and how to seek mutual understanding (Hufferd-Ackles et al., 2004; see also Ayalon & Even, 2014).

For many teachers, it is unclear what language and argumentation skills exactly mean in their subject (Bratkovich & Paulsen, 2020). This uncertainty may lead to limited possibilities for both students and teachers to practice the use of the language of science. Goldman et al. (2016) and Hufferd-Ackles et al. (2004)

stress the importance of tangible learning goals which reflect the epistemic aspect of scientific knowledge (see also Schwarz, 2009). Established disciplinary practices frame the ways that knowledge is formulated. These practices serve as frames for argumentation, while leaving room and requiring individuals' own thinking and emphases in presenting the content (see also Bratkovich & Paulsen, 2020). Students' and teachers' challenges share similar features and range from the level of scientific vocabulary to scientific discussion and knowledge formation. Teachers have challenges in forming coherent arguments which reflect the discipline's conventional ways of presenting knowledge justifying and tying it to relevant contexts (Nousiainen & Vuola, 2023). Such insufficiently coherent examples used by teachers and the lack of explicit criteria for sound argumentation leave students guessing what teachers mean when they ask for explanations (see Ayalon & Even, 2014; Bratkovich & Paulsen, 2020).

Thus, students and teachers need support in their use of the language of science. The need can be there to some measure even after long-term practice (Hufferd-Ackles et al., 2004) even though teachers may erroneously assume that students learn the language of science passively or without the teachers' support (Kosko et al., 2014; see also Ayalon & Even, 2014). The need for support is not necessarily a sign of incompetence. Even in communicating new scientific ideas, scientists use peer support (peer review) in building up coherent argumentation in different forms of scientific discussion.

For teachers, the goals for mastering the language of science are high. Although increasing awareness of the importance of language in teaching and supporting subject teachers' language skills is challenging (Bratkovich, 2018), it also offers opportunities in the form of new perspectives. The language of science offers tools to reflect one's own content knowledge, its formation and how to support students' learning. Understanding the role of language in science can broaden teachers' image of their own expertise (Bratkovich & Paulsen, 2020; see Francisco, 2022; Hufferd-Ackles et al., 2004).

The context of the study

The first step towards understanding pre-service physics teachers' knowledge of physics and how they communicate it, previous research has focused on their use of scientific vocabulary (Vuola et al., 2023) and argumentative elements (Nousiainen & Vuola, 2023) in explaining introductory quantum physics phenomena. Quantum physics is a fruitful context for studying the use of the language of science because explaining the phenomena thoroughly requires rich vocabulary and choosing between different interpretations (see Ayene et al., 2019; Cheong & Song, 2014).

As part of their science education, pre-service physics teachers study classical physics several years before quantum physics. Both classical physics and modern quantum physics study the nature of light and matter, but their results and interpretations are contradictory. When describing quantum phenomena, it is necessary to use modern physics vocabulary that has been developed in quantum physics research. Due to mutual fundamental research interests and historical background, it is common and useful to use vocabulary that is coming partly from classical physics. Also, vocabulary related to experimental set-ups and supplementary, more general physics vocabulary can be relevant. Pre-service physics teachers have difficulties in using physics vocabulary consistently: their use of modern physics vocabulary is not comprehensive enough to cover enough different perspectives needed for sound reasoning, and some pre-service physics teachers rely heavily on vocabulary of classical physics or concrete experimentation instead (Vuola et al., 2023). The physics contents are reviewed more broadly in Vuola et al. (2023) and knowing them more specifically is not needed to understand this study.

Previous research has shown that some pre-service physics teachers can construct structurally sound arguments, but many have challenges in using necessary argumentative elements and combining them in a logical manner (Nousiainen & Vuola, 2023). To analyse physics argumentation, Nousiainen and Vuola (2023) have introduced four key argumentative elements: background for the argument including motivation and consensus knowledge (A1 in what follows, see Table 1), assertion substantiation that can be based on experimental or theoretical reasoning (A2), inferences from the assertion substantiation and their meaning (A3), and broader conclusions (A4). These steps highlight the need for arguing both the core idea of the argument (elements 2 and 3) and its context (elements 1 and 4). The core of physics argument is presenting the central claim and justifying it explicitly through experimental or theoretical reasoning. Without the core, there is really no physics argument. How broadly the context of an argument is described can be more flexible. The context is still needed to underline why the core of an argument matters and what it means for the bigger picture. Many pre-service teachers' arguments feature background consensus knowledge in the form of long fact lists at the expense of describing justification and inferences, which are the core part of sound physics argumentation (Nousiainen & Vuola, 2023; Vuola & Nousiainen, 2020; see Bratkovich & Paulsen, 2020).

A good argumentative structure and relevant use of physics vocabulary are necessary but not sufficient preconditions for a good explanation. Thus, in this study, we combine these perspectives and look at how the presented physics vocabulary and argumentative structure relate to each other in pre-service physics teachers' explanations.

Research design and sample

The participants of the study were nine pre-service physics teachers in their third or fourth year of university studies in a large university in Finland. They had all passed the basic level physics studies, including quantum physics. The data was collected as a part of a seven-week long, intermediate level physics teacher preparation course, which focused on physics content knowledge organization for teaching purposes at upper secondary school level. Our sample consists of 36 written reports, which the nine pre-service teachers wrote on four well-known experiments on introductory quantum physics: the photoelectric effect (report 1), the Compton effect (report 2), the double-slit experiment with single photons (report 3) and the double-slit effect with single electrons (report 4).

During the course, the pre-service teachers first read a research article on the experiment as their base material and analyzed its scientific argumentation. The argumentation analysis task was scaffolded by utilising a graphical tool (called knowledge justification scheme, Nousiainen, 2017) which guided the pre-service teachers to find out the most relevant argumentative elements: what is the purpose of the study, what are the main findings, how the experiment is carried out, what assumptions or idealisation are needed, what are the main conclusions etc. In the written reports, the pre-service teachers were asked to describe how the phenomena could be introduced in teaching and they were asked to include the most central concepts, phenomena, experiments, models, and theories regarding the task and to offer detailed explanations and justification for the presented physics knowledge. During the course, pre-service teachers' got feedback on their argumentation analysis and on their written reports. This teaching sequence (reading article, analysis of the article and writing the report) was repeated with all four topics.

Research questions

In this study, we aimed to describe what kind of physics vocabulary pre-service teachers use in different argumentative elements. Our research questions are

1. How do the use of physics vocabulary and argumentative elements relate to each other in pre-service teachers' written reports?
2. What progress can be found in physics argumentation in pre-service teachers' reports?

In an ideal case, the reports are expected to use classical physics vocabulary (VC) especially in background of the argument (A1). Classical physics vocabulary is necessary in the first task in particular, since the task assumes only classical physics as background knowledge, and it can also be relevant in latter tasks and other argumentative elements. Modern physics vocabulary (VM) is needed at least in A3 (inferences) and A4 (conclusions), since the tasks are about explaining phenomena in modern physics. The latter tasks can include modern vocabulary in A1 (background) or A2 (assertion) when modern physics is already presented in the previous tasks. Vocabulary on the main experiment (VE) is necessary in A2 as all reports involve empirical evidence; it can be presented also in A3 if inferences are explicitly argued. Supplementary physics vocabulary (VS) can be found in the reports, although it may not be necessary: besides general physics terms, vocabulary concerning other phenomena can be found mainly in A1 or A4 as broader context for the task.

Table 1 summarizes the role of different subcategories in an ideal case. A comprehensive justification in a report should contain all argumentative elements. The four most relevant subcategories in these reports are experimental vocabulary in assertion (A2VE) and modern physics in inferences (A3VM) forming the core of the argument. Classical physics in background (A1VC) and modern physics in conclusions (A4VM) describe the relevant context of the argument. There are many ways of explaining the phenomena, so in addition to these four most relevant subcategories, different combinations of physics vocabulary in argumentative elements are possible for sufficient and effective explanations.

Table 1. The use of physics vocabulary in argumentative elements: predictions in an ideal report.

	VC. Classical physics vocabulary	*VM. Modern physics vocabulary*	*VE. Experimental vocabulary*	*VS. Supplementary physics vocabulary*
A1. Background for the argument	***Relevant: classical physics background***	*Can be relevant after quantum theory is introduced in the first task*	*Describing the key experiment is not needed in background knowledge*	*Can be used throughout argumentation but should not be the focus*
A2. Assertion	*Can be relevant: reflecting the phenomenon against the classical physics background*	*Can be relevant: using quantum theory in assertion substantiation*	***Relevant: experimental assertion substantiation***	
A3. Inferences		***Relevant: quantum physical interpretation of the phenomenon***	*Can be relevant: tying inferences implicitly to evidence*	
A4. Conclusions		***Relevant: broader implications in quantum theory***	*Describing the key experiment is not needed in broader conclusions*	

Based on our previous studies, we assume that pre-service teachers face challenges in delivering coherent physics argumentation structure (Nousiainen & Vuola, 2023) or in using relevant physics vocabulary (Vuola et al., 2023). Since the teaching sequences were developed to scaffold pre-service teachers' physics related argumentation, we expect that the argumentation in the reports will develop in a more coherent direction and we could see progression in the pre-service teachers' reports.

Data analysis

The data analysis used mixed methods: most of the analysis was qualitative classification but we also calculated the number of the vocabulary classes in order to better compare the cases. First, we did the argumentation analysis. Each reports' argumentative elements A1–A4 were identified by sentence. The argumentative elements and examples of them in the reports are shown in table 2. Here we give a short overview of the method (for details, see Nousiainen & Vuola, 2023).

Table 2. Argumentative elements and their identification in the reports.

Argumentative elements	*Description*	*Example sentences*
A1. Background for argument	Motivation, consensus knowledge	Classical physics cannot explain this. Millikan wanted to test Einstein's equation. All bodies emit thermal radiation.
A2. Assertion	Empirical or theoretical assertion substantiation	Rüeckner and Titcomb performed the double-slit experiment with single photons. According to de Broglie, matter particles have wave nature, and their wavelength can be calculated using de Broglie's wavelength law.
A3. Inferences	Inferences derived from experiments or through theory, and their meaning	Millikan was able to determine the constant h that appeared in Einstein's theory, which he confirmed to be the same as Planck's constant previously determined by Planck. The results are an indication of the wave nature of the electron
A4. Conclusions	The broader meaning and implications of the results	The wave model of light must be corrected to a model of the wave-particle dualism of light. It has properties of both classical fields and particles, but it is not both at the same time, but a completely new kind of entity.

Second, we analysed physics vocabularies. Physics terms in each sentence were identified and then divided into four vocabulary categories described in table 3. Since the reports were written about four different physics phenomena, the categorization was task dependent. For example, the term "Millikan's experiment [on photoelectric effect]" was identified as VE in the report on photoelectric effect, but as VS in the subsequent reports.

Table 3. Vocabulary categories and their identification in the reports.

Vocabulary category	*Description*	*Example terms*
VC. Classical physics	Terms used in classical physics describing field, radiation, energy, wave model and particle model –the key perspectives to the topics of the report	Classical field, electromagnetic radiation, light, the conservation of energy, wavelength, diffraction, spectrum, particle, mass, charge
VM. Modern physics	Quantum mechanics, stochastics, duality, localization and identification – the key perspectives to the topics of the report	Wave function, quantum of energy, photon, probability, random, wave-particle duality, particle nature, local, individual
VE. Experimental	Experimental set-ups related to the topics of the report	Double-slit, electroscope, reflector, detector, voltage, laser, screen
VS. Supplementary physics vocbulary	Physics vocabulary beyond the core topics of the report: general physics terms, the topics of previous assignments, further applications	Time, discrete, prediction, hypothesis, ideal, phenomenon, distribution, law, model

After this, we counted how many times terms from different vocabulary categories appeared in sentences representing each argumentative element. Each report was described by a 4x4 matrix: the number of physics terms by argumentative element (A1–A4) and by physics vocabulary (VC, VM, VE, VS), a total of 16 subcategories. We compared how different subcategories emerged in pre-service teachers' reports. The subcategories A3VM and A2VE form the core of the argument, as well as A1VC and A4VM offering relevant context as discussed earlier, as they should be included in all reports as key components forming a comprehensible argument. To ensure the credibility of the analysis, 20 % of the data was double scored by another expert on physics education. The interrated agreement between the scorers was 89.2 %, indicating high degree of agreement.

Results

The data consisted of 36 reports written by nine pre-service physics teachers, four reports each. In individual reports, the number of physics terms were between 53 and 333, an average 134. Seven out of nine pre-service teachers used the most words in their first report.

Each report was described by a 4x4 matrix showing how many physics terms each vocabulary category (VC, VM, VE, VS) included in different argumentative elements (A1–A4) (see Figure 1). In the whole sample, the minimum number of physics terms in a subcategory was zero, maximum 69, average eight and median five. There were seven reports with terms in every subcategory, but it was far more common to have one or more subcategories with no terms. All reports had distinctly emphasized subcategories and 2–14 subcategories that were median or under. In most reports, the most emphasized subcategory had multiple terms compared to the median. Based on this, we decided to use median 5 to make a distinction between emphasized subcategories (above the median) and those that were ignored or used very sparingly (zero to median).

Vocabulary categories

First, we focus on the vocabulary categories. The use of a vocabulary category is seen as consistent if it is found at least in the corresponding relevant subcategory: classical physics vocabulary (VC) in the background of the argument A1, modern physics vocabulary VM in inferences A3 and conclusions (in latter reports possibly in the background A1), and experimental vocabulary in assertion substantiation A2.

Classical physics' vocabulary VC can be found in every report over median in one or more subcategories. In 29 reports the use of classical physics vocabulary (VC) seems consistent: it is featured in the background of the argument A1 and possibly in broader conclusions A4 connected with the context of the argument. Some reports use classical vocabulary also in the core of the argument (A2 and A3) so that a classical physics' perspective continues throughout the argument (e.g., see report a1 in Figure 1). In seven reports, mainly from the fourth task, the use of classical vocabulary seems more inconsistent: classical vocabulary is either not used in A1 but is brought up in latter argumentative elements (e.g., see g4 in Figure 1), or it is missing from A2 but can be found in other argumentative elements.

a1	VC	VM	VE	VS
A1	**34**	1	4	34
A2	39	21	**20**	41
A3	43	**15**	31	31
A4	8	**5**	2	4

a2	VC	VM	VE	VS
A1	**21**	5	0	16
A2	35	7	**0**	12
A3	37	**6**	8	20
A4	8	**11**	7	8

a3	VC	VM	VE	VS
A1	**28**	9	11	12
A2	12	29	**16**	3
A3	7	**21**	14	7
A4	10	**22**	1	8

a4	VC	VM	VE	VS
A1	**9**	7	6	6
A2	13	37	**19**	4
A3	9	**42**	15	9
A4	7	**16**	0	5

b1	VC	VM	VE	VS
A1	**15**	3	5	16
A2	8	1	**10**	5
A3	45	**12**	15	20
A4	8	**5**	2	5

b2	VC	VM	VE	VS
A1	**23**	1	1	17
A2	9	1	**1**	2
A3	25	**4**	5	13
A4	6	**2**	4	4

b3	VC	VM	VE	VS
A1	**69**	24	2	66
A2	1	6	**5**	3
A3	2	**16**	11	1
A4	2	**3**	0	3

b4	VC	VM	VE	VS
A1	**11**	3	2	7
A2	1	1	**7**	0
A3	11	**22**	21	13
A4	3	**10**	0	4

c1	VC	VM	VE	VS
A1	**26**	3	3	26
A2	40	13	**25**	30
A3	5	**3**	6	19
A4	4	**5**	2	3

c2	VC	VM	VE	VS
A1	**12**	4	2	5
A2	9	0	**7**	2
A3	41	**3**	3	6
A4	24	**4**	0	21

c3	VC	VM	VE	VS
A1	**7**	5	6	0
A2	4	6	**20**	0
A3	10	**16**	13	8
A4	12	**16**	10	11

c4	VC	VM	VE	VS
A1	**4**	9	4	3
A2	2	7	**9**	10
A3	15	**36**	16	24
A4	12	**16**	0	9

d1	VC	VM	VE	VS
A1	**25**	10	6	14
A2	16	11	**9**	12
A3	2	**1**	0	5
A4	4	**4**	1	0

d2	VC	VM	VE	VS
A1	**20**	7	1	9
A2	8	6	**4**	4
A3	17	**6**	3	4
A4	1	**1**	0	0

d3	VC	VM	VE	VS
A1	**8**	3	3	2
A2	6	3	**9**	0
A3	8	**16**	8	5
A4	3	**1**	1	2

d4	VC	VM	VE	VS
A1	**0**	0	0	0
A2	9	25	**11**	12
A3	6	**31**	21	5
A4	2	**2**	0	1

e1	VC	VM	VE	VS
A1	**39**	6	11	36
A2	19	9	**21**	12
A3	13	**3**	12	11
A4	0	**6**	0	2

e2	VC	VM	VE	VS
A1	**45**	11	7	31
A2	31	2	**5**	15
A3	12	**9**	2	10
A4	0	**0**	0	0

e3	VC	VM	VE	VS
A1	**36**	9	6	35
A2	2	1	**3**	1
A3	2	**8**	4	3
A4	8	**23**	8	10

e4	VC	VM	VE	VS
A1	**17**	15	0	22
A2	0	0	**0**	0
A3	0	**0**	0	0
A4	0	**5**	0	1

f1	VC	VM	VE	VS
A1	**35**	5	0	20
A2	8	2	**8**	15
A3	29	**11**	9	20
A4	3	**2**	0	2

f2	VC	VM	VE	VS
A1	**7**	1	3	7
A2	16	0	**12**	6
A3	6	**3**	3	7
A4	0	**0**	0	0

f3	VC	VM	VE	VS
A1	**9**	1	1	10
A2	4	3	**13**	2
A3	0	**4**	9	2
A4	3	**6**	1	2

f4	VC	VM	VE	VS
A1	**19**	10	2	9
A2	3	1	**0**	3
A3	5	**10**	12	6
A4	3	**5**	2	4

g1	VC	VM	VE	VS
A1	**20**	5	6	25
A2	20	6	**32**	28
A3	26	**3**	22	24
A4	1	**2**	0	1

g2	VC	VM	VE	VS
A1	**9**	3	3	8
A2	18	5	**2**	9
A3	21	**6**	4	7
A4	7	**9**	0	4

g3	VC	VM	VE	VS
A1	**7**	9	5	4
A2	3	3	**4**	1
A3	5	**9**	2	7
A4	4	**5**	0	7

g4	VC	VM	VE	VS
A1	**4**	9	1	0
A2	5	7	**5**	3
A3	8	**12**	2	6
A4	5	**7**	2	6

h1	VC	VM	VE	VS
A1	**21**	18	8	53
A2	0	0	**0**	0
A3	0	**0**	0	0
A4	3	**3**	0	2

h2	VC	VM	VE	VS
A1	**21**	14	2	27
A2	7	1	**0**	8
A3	11	**6**	0	4
A4	0	**0**	0	0

h3	VC	VM	VE	VS
A1	**15**	9	1	12
A2	3	1	**4**	0
A3	2	**4**	3	1
A4	0	**0**	0	0

h4	VC	VM	VE	VS
A1	**1**	6	4	1
A2	8	7	**3**	11
A3	9	**10**	2	6
A4	4	**1**	1	1

i1	VC	VM	VE	VS
A1	**29**	1	7	27
A2	9	3	**12**	5
A3	0	**0**	0	0
A4	1	**2**	0	2

i2	VC	VM	VE	VS
A1	**29**	3	3	18
A2	0	0	**0**	0
A3	0	**0**	0	0
A4	0	**0**	0	0

i3	VC	VM	VE	VS
A1	**19**	8	0	14
A2	0	0	**0**	0
A3	5	**8**	7	0
A4	1	**3**	0	1

i4	VC	VM	VE	VS
A1	**4**	2	0	5
A2	7	8	**3**	5
A3	9	**16**	5	7
A4	9	**8**	3	4

Figure 1. The number of physics terms in different argumentative elements in pre-service teachers' reports. The top left corner refers to the pre-service teacher (a–i) and the assignment (1–4). Argumentative elements A1–A4 are described in table 2, physics vocabulary categories VC, VM, VE and VS in table 3. Each number refers to physics terms in the respective subcategory. Subcategories median (5) or under are marked with lighter grey. The most relevant subcategories for the argument (described in table 1) are bolded.

Modern physics' vocabulary VM is used consistently in 10 reports: it is used (over median) at least in inferences A3 and conclusions A4, possibly also in background A1 or assertions substantiation A2 (e.g., see g4 in Figure 1). In 15 reports, modern vocabulary VM is well-featured either in A3 or A4, but not in both. In five reports, modern physics' vocabulary is not emphasized in any argumentative element and in six reports it was found only in A1 or A2 (e.g., see i2 in Figure 1).

Experimental vocabulary VE is used consistently in 18 reports: It can be found playing a significant role at least in assertion substantiation A2, where it is necessary, and possibly in background A1 or inferences A3, in some cases following throughout to conclusions A4 (e.g., see c3 in Figure 1). In 11 reports, experimental vocabulary VE is not emphasized at all (e.g., see e4 in Figure 1) and in seven reports, experimental vocabulary was used in some other argumentative element than A2.

The use of physics supplementary vocabulary VS is more ambiguous to analyse because general physics terms such as "phenomenon" or "time" can be needed in any argumentative element, and describing for example previous tasks in background A1 or further applications in conclusions A4 can offer the argument fruitful context and meaning. Still, to follow the assignment, supplementary physics vocabulary VS should not take the lead. In 24 reports, supplementary physics vocabulary VS was featured in one–two argumentative elements, in 10 of them only in A1 or A4 (e.g., see b3 in Figure 1). In 11 reports, supplementary physics' vocabulary VS was featured in three–four argumentative elements (e.g., see a1 in Figure 1). However, we found that the reports featuring VS in two–four argumentative elements also featured vocabulary categories VC, VM and VE more than reports where VS was featured only in zero–one argumentative element.

Argumentative elements

Second, we focus on the pre-service physics teachers' use of the four argumentative elements. The use of an argumentative element is seen consistent if it is found at least in the corresponding relevant vocabulary subcategory: the background of the argument A1 with classical physics vocabulary VC, in latter reports possibly with modern physics vocabulary VM, assertion substantiation A2 with experimental vocabulary VE, and inferences A3 and conclusions A4 with modern physics vocabulary VM.

In the category A1 (background), we expected to find classical physics vocabulary VC, particularly from the first reports, and maybe more of modern physics vocabulary VM from the latter reports. VC played a central role in 31 reports, often together with other vocabulary categories (e.g., see report e3 in Figure 1). VM was central in three reports of the last task (and VC was not). In two reports, neither VC, VM, nor VE was central in describing background A1 (e.g., see d4 in Figure 1).

In the assertion substantiation A2, we expected to find experimental vocabulary VE in particular, and it was greatly present in 18 reports with various combinations of the other vocabulary categories. Assertion substantiation played a central role in 10 reports in their A2 VC (four reports), VM (two reports) or both VC and VM (four reports), half of the time combined with emphasis on VS. In eight reports, neither VC, VM, nor VE was central in describing assertion substantiation A2.

In the inferences A3, we expected to find at least modern physics VM, which was central in 23 reports with combinations of the other vocabulary categories (e.g., see b1 in Figure 1). Seven reports paid more attention to VC, VE, and VS (e.g., see c2 in Figure 1) and six reports used hardly any physics' vocabulary including VS to discuss the inferences A3 (e.g., see i1 in Figure 1).

In the broader implications A4 we expected modern physics' vocabulary VM due to the task, possibly with classical physics VC to reflect the implications in contrast to the background, or supplementary physics VS in the form of further applications. 12 reports met this initial expectation (e.g., see h3 in Figure 1). Five reports had emphasis in other than modern physics' vocabulary (e.g., see b2 in Figure 1) and 19 reports did not use any physics vocabulary to discuss the broader implications A4 (e.g., see d2 in Figure 1).

The core and the context of the argument

As described in the Table 1, we identified four relevant vocabulary subcategories which are necessary for sound physics argumentation in these tasks. The four argumentative elements, and thus the four relevant subcategories in them, play different roles in the argument. The core of the argument – the claim, its empirical or theoretical justification and inferences – is communicated through at least subcategories A2VE and A3VM. The context of the argument – the motivation, background knowledge and broader conclusions – is communicated through at least subcategories A1VC and A4VM. Next, our analysis focused on whether these, the core and the context of the argument, were present in the reports.

Five reports had all four relevant vocabulary subcategories over median. The core subcategories were present in five reports, but they had relevant context subcategories lacking. Six reports used their terms the other way around: they had emphasis on the context subcategories as the core subcategories were lacking. In 15 reports both core and context subcategories were partly median or under. The context subcategories and relevant core subcategories were partly lacking in five reports.

Pre-service teachers' progress between the tasks

Second, we studied each pre-service teacher's four reports and how the use of the subcategories changed between tasks 1–4. Our analysis reveals that six out of nine pre-service teachers made progress in their reports. They all had their most comprehensive vocabulary use in either of the last two reports. We first discuss the best six cases (a to i in Figure 1). Interestingly, these six cases split into two very different groups. On one hand, four cases (a to d) succeeded best in using the relevant four subcategories (see Table 1). They all had two to three reports where at least the core of the argumentation was over median and in most of them also the context. On the other hand, two cases (h and i) expressed only very limited argumentation. They managed to use one or two relevant subcategories in each report, usually A1VC writing about the classical physics in the background of the argument. Experimental vocabulary played a significant role only in one report. Still, their last reports were noticeably different from their previous reports: all argumentative elements A1–A4 had some physics vocabulary (in contrast to ignoring one to three of them altogether). Although they did not necessarily use more physics terms than before, the use of vocabulary was more consistent. The remaining three pre-service teachers (cases e, f, and g in Figure 1) prepared alternately limited and more comprehensive reports. Every other of their reports were lacking in both core and context subcategories. Their other reports mainly described the context and only one of their reports had its core subcategories above median.

Discussion and conclusions

In science education, the perspective of language is central to both content knowledge and teaching science (see Bratkovich, 2018; Mercer, 2009; Stenhouse, 1986). In this study, we focused on how pre-service physics teachers use the language of science at vocabulary and argument structure levels. We analysed nine pre-service physics teachers' use of vocabulary and argumentative elements in their four reports on introductory quantum mechanics, a total of 36 reports. We identified four relevant intersections of physics vocabulary and argumentative elements (referred to here as relevant subcategories) that are needed for coherent argumentation in the reports: classical physics vocabulary in the background of the argument, experimental vocabulary in the experimental assertion substantiation, and modern physics vocabulary both in the inferences and the broader conclusions.

In research question 1 we asked how the use of physics vocabulary and argumentative elements relate to each other in pre-service teachers' argumentative reports. As expected, pre-service teachers used various combinations of physics vocabulary categories in the argumentative elements, which supports the idea that the same point can be argued in many ways (Bratkovich & Paulsen, 2020). From the perspective of the four relevant subcategories, the use of physics vocabulary in argumentative elements was coherent in some reports, while most reports ignored relevant argumentative elements or relevant physics vocabulary.

Every report featured at least one of the relevant vocabulary subcategories and all four of them were featured in five reports. These reports used relevant physics terms and argumentative elements so that both the core argument and its context can be well described. The writers of these reports also were among the ones who made significant progress moving forward in the tasks.

We expected to also see reports that express very few argumentative elements (Nousiainen & Vuola, 2023) and use classical and experimental vocabulary at the expense of modern physics vocabulary (Vuola et al., 2023). This was seen as most reports ignored some of the relevant subcategories and thus, these reports failed to coherently present the core and/or the context of the argument. Classical physics' vocabulary was consistently used in most reports, whereas under a third of the reports used modern physics' vocabulary consistently. Half of the reports used experimental vocabulary consistently, while the other half did not explicitly describe the central experiment, its results, or inferences to justify the conclusions and thus, failing in argumentation typical of physics.

In research question 2 we asked what progress can be found in physics argumentation in pre-service physics teachers' reports. Based on our results, most pre-service teachers made progress in their physics argumentation during the study and the rest maintained their level. The pre-service teachers' longest report was typically the first one. This means that as the reports became shorter, their argumentation became stronger or remained at the same level.

Four pre-service teachers' argumentation clearly developed during the tasks: The most successful pre-service teacher presented the core of the argument well in their first report, the context in the second and both in the last two reports. The next two pre-service teachers were also able to present both core and context in their last reports. The fourth pre-service teacher was able to express the core of the argument in the final two reports. These pre-service teachers showing the most progress also presented the most comprehensive content in their reports. This is what we expected to see: pre-service teachers succeeding better in their physics argumentation as the tasks became more familiar and they received and made use of feedback from the previous tasks.

Three pre-service teachers did not make clear progress: their reports were alternately lacking in both the core and context of the argument or had emphasis only on one of the aspects, typically the context. Here we see the difficulties we were expecting based on previous research: these pre-service teachers seemed to consistently struggle to pay attention to the core of the argument. The last two pre-service teachers made progress, but all their reports were still lacking in both the core and context of the argument. We are glad to monitor at least some pre-service teachers did progress in their argumentation and vocabularies. However, we also noticed that pre-service teachers have challenges in delivering coherent argumentation with relevant vocabularies as we expected based on our previous research (Nousiainen & Vuola, 2023; Vuola et al., 2023). The result of this study supports the idea that, for pre-service teachers, the need for argumentation or means to explicate reasoning may stay unclear even when explanations are directly requested (cf. Ayalon & Even, 2014).

Based on this and previous studies (Nousiainen & Vuola, 2023; Vuola et al., 2023), pre-service physics teachers have very different ways of using the language of science both due to many possible ways of emphasizing content knowledge in an argument and challenges in constructing scientific justifications that are relevant in physics. However, this case study gives us a promising interpretation of pre-service teachers' use of the language of science, especially its vocabulary, and their development than the previous studies where the perspectives on the language of science were narrower (Nousiainen & Vuola, 2023; Vuola et al., 2023).

It is highly possible that the pre-service teachers practiced scientific argumentation explicitly for the first time in the physics teacher preparation courses where the data was collected. Even though they had already studied science for several years including university physics courses, learning the language of science at this complex level had not happened automatically. Though short single interventions can raise teachers' awareness of the language of science and serve as an initial impetus for its development, we call for long-term practice of language skills in physics education and clearly set learning goals for it to support both teaching and learning the language of science. In the courses related to our study, pre-service teachers were scaffolded by being presented with a general structure of physics argument including the relevant argumentative elements and their connections to each other. Practicing how the general argumentation structure can be used in different relevant contexts, receiving feedback on the tasks, discussing, and comparing different ways of arguing the same phenomena had a clear effect on pre-service teachers' language skills. In the future, it could be fruitful to scale down these argumentation tasks to a form that could be utilized in physics education as another perspective for presenting and justifying physics content knowledge. Teachers' challenges in scientific argumentation and teaching it can stem from the lack of practice in argumentation, taking part in scientific discussions or even organizing them (see Kosko et al., 2014). In addition to increasing pre-service teachers' opportunities to actively use the language of science and get scaffolding for it, teachers and pre-service teachers could benefit from peer-support and easily accessible opportunities to discuss challenges and brainstorm ideas about scientific argumentation and the use of language in their own subject.

Regardless of teachers' language awareness, they give students examples of using the language of science all the time in the classroom. Our case study results show that pre-service teachers have implicit knowledge of the language of science and can develop their language skills when given the opportunity and support for it. Language awareness is important in supporting students learning science content knowledge and the language of science as an intertwined part of it. This study was carried out in a very specific context (introductory quantum physics), but the ideas are so general that they are transformable to other subjects as well. Teaching and learning the language of science is relevant for cross-curricular education since there are multiple ways to embed these learning goals to different multidisciplinary contexts.

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