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Using Analogies in Teaching Physics: A Study on Latvian Teachers' Views and Experience

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Abstract

The role of analogies as tools for teaching difficult science concepts has been widely discussed in science education. The application of analogies in the context of sustainable education involves richer potential. The purposeful use of appropriate analogies can facilitate analogical thinking and transfer skills, as well as develop abilities which are required for life and lifelong learning, including successful integration into modern society and facility within our technology saturated world. Analogical thinking supports development of students' higher order thinking skills. The aim of this study was to identify Latvian physics teachers' views on the importance of analogies and the methodology of their usage in physics education, as well as to discover innovative examples of analogies. The study involves both quantitative and qualitative methodology: survey of 35 secondary school physics teachers and group interviews with 18 experienced physics teachers. The findings reveal that, in general, now and then Latvian physics teachers use analogies in their pedagogical practice, although they are mostly simplistic and with illustrative character. Some teachers use analogies in order to help students build new knowledge through activating, transferring, and applying existing knowledge and skills in unfamiliar situations.

Keywords: analogy, analogical thinking, transfer skills, teaching physics, teachers' views

Context of the Study

Education is a key agent for change towards sustainable development (UNECE, 2011). The relationship between education in general, science education and sustainable development is complex. Education for sustainable development (ESD) requires new ways of conceiving goals, tasks, organization of learning processes, and teacher training. Although the specifics of curriculum and didactics, or the specifics of any subject and its associated teaching methods, have been empirically studied in relation to different aspects of ESD (e.g., Gerretson, Howes, Campbell, & Thompson, 2008; Jonāne, 2008; Soobik, 2014), there are still many opportunities both for general education and teacher education to discover innovative approaches based on the principles of sustainability.

According to research carried out by a group of experts from the European Commission (2007), the interest of youth in science subjects, including physics, has decreased.

The European Commission points to the complex reasons for this decline, further stating that "there is firm evidence that indicates a connection between attitudes towards science and the way science is taught" (p. 8). Experts stress the idea that teachers are the key players in the revitalization of science education. Specialists of the Community Research and Development Information Service (CORDIS) (EC, 2013) project emphasize that "conceptual change is a core feature of learning science. It reflects the knowledge transformation and development that occurs during the learning process… Analogical reasoning plays a central role in the process of conceptual change" (p. 1).

The interest in physics among Latvian school-aged youth is low, notwithstanding diverse activities in the field of science education. Starting in 2005, new curricula content were designed by the EU/ESF project *Production of Educational Content and Promotion of Teacher's Qualification in Science, Mathematics and Technology* and has been introduced into Latvia's schools since 2008. This new physics curriculum and support materials for teachers were designed by drawing on the basic principles of contemporary science education. They envisaged (1) the understanding of processes, regularities in nature, and use of mathematical models; (2) acquiring research and information processing skills including the use of information technologies; (3) learning physics with a connection to real life by learning the interconnections between science, technologies, society, and environment in the context of individual needs.

This article focuses on aspects of physics teacher education in promoting students' deeper learning and transfer dexterity through use of analogies. These are aspects of physics education that have not received sufficient attention from either university teachers or researchers. Because of the range and interconnectedness of physics knowledge, deeper learning is particularly relevant in the context of education for sustainability (Warburton, 2003). Students acquire such knowledge during their secondary education, including exposure to social, environmental, and economic issues, as well as the importance of interdisciplinary thinking and holistic insight. Therefore, during pre-service and in-service teacher education, physics teachers should comprehend strategies and develop professional competences to help support their students' deeper learning approaches and transfer skills, as well as cognitive and meta-cognitive strategies that can be applied to solve students' personally important problems.

Deeper learning is a key strategy by which students extract meaning and understanding from course materials and experiences (Warburton, 2003). According to Pellegrino and Hilton (2012), deeper learning is the process through which an individual becomes capable of taking what was learnt in one situation and applying it to a novel situation. The product of deeper learning is transferable knowledge, including content literacy in a domain, as well as understanding how, why and when to apply this knowledge in real-life situations.

As defined by the Hewlett Foundation (Huberman, Bitter, Anthony, & O'Day, 2014), deeper learning competencies focus on the development of knowledge and cognitive skills, particularly mastering core academic content knowledge and developing critical thinking skills. This definition characterizes students' mastery of core academic content as the ability to "develop and draw from a baseline understanding of knowledge in an academic discipline and … to transfer knowledge to other situations" (p. 9). In other words, students are able to process and transfer information in meaningful ways within new contexts to address new problems; furthermore, they are able to apply and transfer core knowledge to tasks in other subjects and in real-world situations, as well as in non-routine ways.

The identification, analysis and adjustment of global experience delineate important steps in the improvement of teacher education for the implementation of contemporary educational goals in each and every country. Although deeper learning is not directly emphasised in the *Sustainable Development Strategy of Latvia until 2030* (Saeima of the Republic of Latvia, 2010), it appeals to the features of deeper learning focusing on the development of creative thinking: "[The] general education system should develop a creative personality in each learner. By including problem-solving in the study process, independence and transition from practical skills to conceptual knowledge would be promoted" (p. 38). These suggestions are in strong conformity with deeper learning competencies. Ability of creative thinking has a powerful connection to the development of meaningful learning and transfer skills.

Teachers' understanding of strategies to promote deeper learning affects the quality of education. One of the strategies that contributes to deeper learning and development of transfer skills is a purposeful use of analogies in teaching science, including physics. It is, therefore, essential to identify the usage of analogies in teaching science as well as articulate the opinions and experience of teachers regarding this issue.

Analogies and Analogical Reasoning from a Constructivist Perspective

Analogies and analogical models have always been a key part of scientific reasoning from the eighteenth century onwards and have helped scientists understand, present and communicate about the phenomena and structure of the natural world (Glynn, 2008; Harrison & Treagust, 2006). Yet, learning by analogies occurs not only in scientific contexts. For instance, transformation of economic development towards sustainable development is accomplished through analogical reasoning from the source context of ecological systems to the target contexts of economic outcomes (Sriram, Ganesh, & Mathumathi, 2013).

Analogical reasoning is a cognitive skill that underpins many 21st century competencies (Richland & Simms, 2015). It is the process of representing information and objects in our world as systems of relationships, such that these systems of relationships can be compared, contrasted, and combined in novel ways depending on contextual goals. Analogical reasoning requires a type of scrutiny involving memories and prior experiences in an effort to solve problems or critique solutions, and to explain or interpret situations (Gentner, 1983; Richland & Simms, 2015). It is a key feature of the learning process as framed within a constructivist perspective: every learning process includes a search for similarities between what is already known and the new, as well as the familiar and the unfamiliar (Wittrock & Alesandrini, 1990). Analogy pervades our thinking, from our everyday speech and our trivial conclusions to artistic ways of expression and formulating our highest scientific achievements (Polya, 1954). Analogy is a mechanism which has been recognised by scientists, philosophers and psychologists alike as having the potential of bringing prior knowledge to bear on the acquisition of, sometimes, radically new information (Vosniadou, 1988). It can play a central role in the restructuring of students' conceptual frameworks (Duit, Roth, Komorek, & Wilbers, 2001). Politicians and other public figures often use analogies in their public performances and discussions.

The term 'analogy' refers to a cognitive process of transferring information or meaning from a particular object (the analogue or source) to another particular object (the target). Analogy is an inductive mechanism based on structured comparisons of mental representations (Holyoak, 2012). An analogy is a comparison through which an idea, a thing or a process is contrasted to another that is quite different from its counterpart. The aim is explaining that idea, thing or process by comparing it to something that is familiar. The use of analogy is often viewed as one of the primary means of drawing on students' prior knowledge. By activating relevant prior knowledge which is already understood by the learners, the analogy serves as a vehicle to bring meaning to incoming information (Brown & Clement, 1989).

In many analogies, the similarity of the objects is at a purely relational level. An example is the analogy that led to Kekule's theory about the molecular structure of benzene (see Holyoak & Thagard, 1995). In a dream, Kekule had a visual image of a snake biting its own tail which gave him the idea that the carbon atoms in benzene could be arranged in a ring. The similarity between the snake and the carbon atoms was at the purely relational level of a circular arrangement. The fact that the objects being compared in an analogy should be linked by the same relationships is widely accepted to be the hallmark of analogical reasoning. On the basis of certain similarities, a principle or characteristic of one term is applied to another term and asserted as true in that case as well.

According to Holyoak (2012), analogical reasoning is a complex process involving retrieval of structured knowledge from long-term memory, representing and manipulating role-filler bindings in working memory, identifying elements that play corresponding roles, and generating new inferences and learning abstract schemas. Human analogical reasoning is heavily dependent on working memory and other executive functions supported by the prefrontal cortex, being selectively activated when multiple relations must be integrated to solve a problem.

Analogical reasoning is a key feature of the learning processes within a constructivist perspective; every learning process includes a search for similarities between what is already known and the new, as well as the familiar and the unfamiliar, to actively apply prior knowledge in a new situation (Wittrock & Alesandrini, 1990). Constructivist models of learning emphasise that connecting the new knowledge to be acquired with the existing knowledge is essential in order to promote meaningful learning (Limon, 2001). Meaningful learning occurs when students are not only able to remember knowledge, but also to transfer it to new situations. According to Duit and his colleagues (2001), new conceptual frames are developed when transferring structures from familiar to new domains by establishing an analogy between the familiar and the unfamiliar.

Analogies in Physics Teaching and Learning: Some Didactic Explanations

Physics has played a crucial role in understanding the fundamental laws of nature; its concepts and techniques underpin the progress of all other branches of science and technology, as well as in transforming humanity to the present-day. Physics is essentially a science of abstractions that are not easy to understand unless related to everyday experiences. Reasoning by similarities is one of the greatest sources for the development of physical theories; moreover, it is an important tool in physics education both at school and higher-level education. Science teachers, in a same way as scientists, frequently use analogies to explain concepts to students (James & Scharmann, 2007). These concepts often represent complex, hard-to-visualize systems with interacting parts: including atoms, electric current, voltage, and electromagnetic waves. Much of the research (Aubusson, Treagust, & Harrison, 2009; Duit, 1991; Gentner, 1983; Gentner, 1989; Glynn, 2008; Treagust, Harrison, & Venville, 1998, etc.) has focused on how teachers understand and use analogies in science education. These theoretical findings apply to physics teaching as a school science subject. Therefore, it is important both to aggregate the theoretical insights from pertinent studies and to recognize physics teachers' experiences related to the use of analogies.

Scientists conceptualize analogy differently. According to Poincaré, analogies can be classified by level: from "primitive analogies", about immediate sense impressions, to "mathematical analogies" which maintain a structure's relations beyond the simplistic relation dependent on appearance. For Poincaré, primitive analogies are usually just a brief comparison, which utilizes the imagination but lacks critical thought (Cruz-Hastenreiter, 2015). Besides, analogies can be represented in different formats: verbal, pictorial (Thiele & Treagust, 1994), real-object modelling and animation (Kim & Ryu, 2001).

An analogy in physics is not just a comparison between different domains: it is a special type of comparison that is defined by its purpose and by the information it elicits. Nevertheless, analogies in a more elaborate sense, particularly mathematical analogies, are a form of reasoning that involves representative thinking (Cruz-Hastenreiter, 2015). Analogies can boost student learning by providing visualization of abstract concepts, by helping to find similarities of the students' real world with the new concepts, and by increasing students' motivation (Aubusson et al., 2009; Duit, 1991; Harrison & Coll, 2008; Treagust, Harrison, Venville, & Dagher, 1996). Analogy draws a bridge from the concrete material world to the abstract physics domain (Dilber & Duzgun, 2008; Duit, 1991). Analogies allow new material, especially abstract concepts, to be more easily assimilated with students' prior knowledge, enabling them to develop a more scientific understanding of the concept. When students explore new concepts, meaningful learning proceeds when they find and visualize connections between a newly taught construct and what they already know.

Familiar analogies, such as mechanical fluctuations or mechanical waves, often serve as initial mental models that students can use to form limited, yet meaningful, understanding of complex target concepts such as electromagnetic fluctuations or electromagnetic waves. As Duit and his colleagues (2001) explain:

> A growing body of research shows that analogies may be powerful tools for guiding students from their pre-instructional conceptions towards science concepts. But it has also become apparent that analogies may deeply mislead students' learning processes. Conceptual change, to put it into other words, may be both supported and hampered by the same analogy. (p. 283)

If the analogies are appropriate, they promote concept learning that can encourage students to build links between past familiar knowledge or prior experiences and new contexts or novel problems (Harrison & Treagust, 2006). According to Vosniadou (1988), productive use of an analogy involves analogical reasoning to produce a new understanding of the explanatory structure of a target system. Gentner (2002) notes that the "basic intuition behind analogical reasoning is that when there are substantial parallels across different situations, there are likely to be further parallels" (p. 106). In this sense, analogical arguments can be used to generalize concepts, theories and methods. Furthermore, analogies can be motivational in that, as the teacher uses ideas from the students' real world experiences, a sense of intrinsic interest can potentially be generated (Aubusson et al., 2009; Venville & Treagust, 1996).

Educational researchers argue that analogies can guide students towards conceptual change (Brown & Clement, 1989; Duit et al., 2001). Podolefsky and Finkelstein (2007) conclude that analogies lead to conceptual change more readily than the abstraction and students may develop the skill of abstraction by building upon lower-level analogical thinking skills. Holyoak and Thagard (1995) posit that the very act of forming an analogy requires a kind of mental leap: it necessitates visualizing one thing as if it were another, such as the flow of automobiles in roadways gives possibility to imagine an electric current in circuitry.

Famous analogies in science frequently reveal an ability to make mental leaps. For example, the idea of envisaging heat as a fluid that can be contained in warm objects with the ability to flow from one object to another has been a powerful image throughout history and is still used today. James Clerk Maxwell developed the theory of electromagnetism by drawing physical analogies between fluid dynamics and electromagnetic phenomena. Albert Einstein, possibly the greatest metaphorical thinker ever, conducted thought experiments that helped to lead him towards his rebel view of light as particles rather than waves (Hofstadter & Sander, 2013). As well as being an important cognitive mechanism in creative thinking, an analogical approach is a basis for problem solving and forms a core component of everyday mental processing.

Despite their advantages and usefulness, analogies can also cause incorrect or impaired learning depending on the analogue/target relationship. If the teacher uses an analogy that is unfamiliar to the learner, development of understanding through use of that particular analogy is constrained. Although analogies may be more useful to students who primarily function at the concrete operational level, analogical reasoning may be limited if the students struggle to compare the similarities between the ideas. In contrast, students already functioning at a formal operational level may have an adequate understanding of the target and the inclusion of an analogy adds unnecessary information (Treagust et al., 1998). Some authors (Aubusson et al., 2009; Dilber & Duzgun, 2008) warn that the use of analogies in science, including physics teaching, does not always produce the intended effects; this is especially true when students take an analogy too far and are unable to distinguish it from the content being learned. Duit and his colleges (2001) stress that

> the analogical relations have a clear and fixed meaning from the perspective of the analogy provider. These meanings are often not shared with the students. Students are in a different position than teachers and textbook authors. [The] analogy may be viewed differently by learners and teachers, that is, bring about different observations. Students, therefore, may not *see* the analogy at all. (p. 286)

An essential aspect of the physics teaching methodology is an effective use of analogies. The purpose of analogy is the transfer of a relational structure from a known or familiar domain to a less known domain. Richland and Simms (2015) claim that analogy can be understood as a powerful learning tool; analogy and analogical reasoning can produce learning in a variety of instructional contexts; teaching should lead students to view knowledge as something to be refined, manipulated, connected to other information, and otherwise used across contexts to serve one's goals.

Analogical reasoning has been defined as a goal-oriented process of representing information and objects in the world as systems of relationships and drawing connections across these systems of relationships (Gentner, 1983). According to Gentner's (1983) structure mapping theory, "an analogy is a mapping of knowledge from one domain (the base) into another (the target) which conveys that a system of relations that holds among the base objects also holds among the target objects" (p. 201). Both the analogue and the target have features. Thus, the strength of an analogy lies less in the number of features of the analogue and target domains than in the system of connected information that it conveys (Gentner, 1983; Orgill, 2013). A systematic comparison, verbally or visually, between the features of the analogue and target is called a mapping. To use the analogy is to complete a mapping from one structure to another.

Gentner (1983) calls this theoretical framework structure mapping: fit to the target domain from the analogue domain; for example, electric current is analogous to water flow. Aubusson and his colleagues (2009) agree that the mapping of like and unlike attributes is essential to any effective pedagogy that uses analogy for science learning. According to Richland and Simms (2015), understanding the key steps of structure mapping is important in order to develop cognitively grounded insights for supporting higher order thinking:

> It is the process of representing information as systems of relationships, aligning and comparing/contrasting these systems to develop higher order relationships (such as same, different, or causal), and then drawing inferences, problem solving, and reasoning on the basis of those higher order relationships. (p. 180)

Based on an extensive body of research with many schools, teachers and lessons, Treagust and his colleagues (1998) proposed the ***Focus—Action—Reflection*** (FAR) guide. The FAR guide has three stages for the systematic presentation of analogies and resembles the planning phases of expert teaching and the action research model. At first, teachers recognise what difficult or abstract concept they want to teach and what analogy could be appropriate. ***Focus*** refers to the decision about using the analogy when teachers initially consider the different aspects of the concept to be taught, whether or not the students already know something about the target concept: Is it difficult, unfamiliar or abstract? What ideas or prior knowledge do the students already have about the concept? Is it something analogue or familiar?

Action refers to the class presentation when the teacher pays careful attention to the students' familiarity with the analogue and identifies the common and uncommon features of the analogue and target science concept or process. To achieve this, the features of the analogue and target are negotiated with students. Similarities and differences are drawn between them and ways that the analogue and the target are not alike are explicitly identified. Is the analogy clear and effective rather than confusing? The action phase usually involves at least three cognitive steps: familiarity with the analogue, mapping of the shared attributes and, then, negotiating with the students where the analogy breaks down. For example, knowledge about Newton's law of gravitation helps to understand and remember Coulomb's law of electrical interaction force. Both are inverse-square laws and both have constants. However, although the laws are similar, it is important to emphasize differences between them. In Newton's law, gravitational interaction force depends on the mass of an object; in comparison, the electrical interaction force in Coulomb's law depends on the electrical charge of a particle or an object. Furthermore, although both laws have constants, in Newton's law it is a very small number whereas in Coulomb's law it is a very large number. Yet another distinction is that gravitational force only attracts, while electrical force attracts when charges are different but repels when they are similar.

Reflection takes place after the analogy has been used in class when the teacher discusses the clarity and usefulness of the analogy and draws conclusions. Reflection is characteristic of all good teaching and competent teachers implement this step in their pedagogical work. In summary, the FAR guide supports teachers to maximise the benefits and minimise the constraints of analogies when they arise in classroom discourse or in textbooks.

Accordingly, it can be assumed that the teacher's ability to implement the FAR guide when teaching physics promotes deeper learning. In particular, this pedagogy supports development of awareness toward an appreciation of environmental, social and economic issues, which are essential for ESD. The teacher's ability to include a wide range of problems within the context of sustainable development promotes students' comprehension and mindfulness of the consequences of human activities such as climate change, resource depletion, and adverse environmental factors on human health. As well, use of analogy during the learning process develops students' higher order thinking skills, which are essential for the development of responsible citizenship. This idea is highlighted in the book *Analogy is as the Fuel and Fire of Thinking* (Hofstadter & Sander, 2013) which describes analogies as a main process of thinking. Therefore, it is of great interest whether physics teachers use analogies, and the FAR model in particular, in their teaching.

Purpose of the Study and Research Questions

The purpose of this study was twofold: 1) to identify Latvian physics teachers' views on the use of analogies in teaching physics, including the context and main aspects of their usage, and 2) to evaluate teachers' comprehension and beliefs about the role of analogies in the promotion of transfer skills and deeper learning. The present study is linked with teachers' reflection-during-action, as well as after the event where teachers consciously review, describe, analyse and evaluate their past practice with a view toward gaining insight to improve their future practice (Finlay, 2008).

This study focuses on four main research questions: 1) What are the views of physics teachers on the use of analogies? 2) What types of analogies do they use? 3) How do physics teachers evaluate their students' achievement in relation to analogical problem solving? and 4) What are the main aspects of the usage of analogies during physics instruction?

Method

Research Tools and Data Analysis

In this research, both qualitative and quantitative methods were combined (Creswell, 2003); that is, a questionnaire was administered and group interviews were applied. To gather useful and relevant information about the teachers' views, the questionnaire was prepared and piloted with Master programme students enrolled as emerging physics teachers. After the piloting process, some items in Part 2 of the questionnaire were clarified and Part 4 was added to the questionnaire to ask about the personal views or experiences regarding the usage of analogies during the physics teaching/learning process. The revised questionnaire was distributed to physics teachers via e-mail.

The questionnaire consists of four parts. The Part 1 collects the information on the respondents' demographic data such as gender, age, qualification, teaching experience, and school type. Part 2, titled "Views on using analogies in teaching physics", contains 12 items to be assessed by a five-point Likert scale that ranges from agree to disagree (see Table 1). The first three items inquire whether the teachers use analogies in general and whether they use them consciously. Other items were formulated according to the findings of Aubusson et al. (2009), Podolefsky and Finkelstein (2007), Holyoak and Thagard (1995), Duit (1991), and Vosniadou (1988) regarding the different aspects of usage of analogies in science and particularly during the physics teaching/learning process described above. This section of the questionnaire presents an opportunity to detect the teachers' views related to analogical reasoning and transfer skills development. Part 3 of the questionnaire relates to the teachers' experience in regard to a specific example of analogy usage. The prompt was taken from Latvian National Sample of the Physics Programme (Izglītības satura un eksaminācijas centrs [Curriculum Development and Examination Center], 2008) concerning a visual aid comparing the gravitational and electric fields. Teachers are asked to comment and describe their views regarding the abilities, success, and failure of their students in terms of this prompt. This task enables detection of successes and difficulties affecting the development of analogical reasoning. In the last section of the questionnaire, respondents are invited to submit some examples of useful analogies and describe their views and experience in terms of the usage of analogies in their work.

In addition to the questionnaire, a group interview protocol was developed based on the phenomenological approach within a paradigm of critical constructivism (Goodman, 2008). A qualitative research interview seeks to cover both a factual and a meaning level, though it is usually more difficult to interview on a meaning level (Kvale, 1996). The interview protocol includes five open-ended questions reflecting the research objectives that were generated following a review of the relevant literature. The main areas of the interview plan address aspects of the usage of analogies, experience about the successful usage of analogies, suggestions for the efficient implementation of analogies in class, beliefs and attitudes towards analogies as a tool for development of transfer skills, the context of contemporary physics education, and self-evaluation. The interview plan was piloted with Master programme students enrolled as emerging physics teachers; no major edits were deemed necessary.

The analysis for the data from the questionnaire and the interview transcripts was based on the principles of quantitative and qualitative methodology. Quantitative data from Part 2 of the questionnaire was processed by polling the answers and calculating their percentage. Content analysis was utilized for the qualitative data from Parts 3 and 4, as well as the interview transcripts. Appropriate textual units (phrases, sentences, or entire text of written answer) conveying a theme or idea were identified for coding. Similar cases were clustered in groups and appropriate language was chosen to describe the emergent categories. The interview data was triangulated with the data from the teachers' questionnaire.

Sample and Procedures

The sample can be divided in two segments. Physics teachers (N = 35; 21% male, 79% female) from Latvian schools were surveyed. The age of participants ranged from 27 to 64 years, their pedagogical experience span from 4 to 40 years with a mean average of 23 years. The participants represented three of the four historical and cultural regions in Latvia: Latgale, Vidzeme and Zemgale. During the data collection from this first segment of sample, the questionnaire data were obtained in electronic form. Participation was voluntary; the teachers were informed about the aim of the study and assured as to the confidentiality and anonymity of their responses prior to administration of the questionnaire.

Independent of the questionnaire, three group interviews with six physics teachers each (N = 18; 33% male, 67% female) were undertaken. The second segment of sample, 18 teachers, was involved in the study as part of an in-service teacher training course facilitated by the author. Participants gained information about analogies in general, the role of analogical thinking in scientific investigations, prior research about the use of analogies in scientific investigation and science education, and the methodology of the FAR model. After the lecturer's presentation, the teachers gathered in small groups to share their experience, to illicit examples of analogies and the methods associated with their usage. Participants discussed advantages and disadvantages of this approach. Teachers were informed about the aim of the group discussion and demographic data was collected, as well as some examples of analogies. Later, according to the interview plan, teachers were asked about their views, experiences, beliefs and attitudes towards analogies as a tool for development of transfer skills. The interview with each small group lasted approximately 40 minutes. All the interviews were audiotaped and transcribed to facilitate coding. Depending on the nature of data, appropriate quantitative and qualitative data analysis methods were applied.

Collaboration between the researcher and the teachers during the interview fosters self-reflection on the teachers' personal and professional development. This alliance allows for creative organisation and navigation of the processes where the interviewees can independently construct a unique critical discourse on personal and societal levels. For the researcher, it only remains to evaluate how close these reflections are to the essential principles of sustainability and formalised requirements for ESD competences (Pipere & Mičule, 2014).

Results and Discussion

The results of the study will be presented in four sections according to the research questions and, where possible, compared with the results of prior research. The study investigates: 1) What are the views of physics teachers on the use of analogies? 2) What types of analogies do they use? 3) How do physics teachers evaluate their students' achievement in relation to analogical problem solving? and 4) What are the main aspects of the usage of analogies during physics instruction? We begin with a summary and analysis of the empirical data presenting the teachers' views on using analogies. Next, we highlight the types of analogies collected; then summarize the evaluation of the students' analogical problem solving skills. Finally, aspects of the usage of analogies as compiled are presented.

Teachers' Views on Using Analogies

The data show that the majority of the participants sometimes use analogies in class as evidenced by the responses to the questionnaire's items as well as by the teachers' statements during the interviews. Table 1 summarises the empirical data from Part 2 of the questionnaire. Since the study engaged a small number of teachers, the results can be considered representative solely for the given group of teachers.

Table 1
Physics Teachers' Views on the Use of Analogies in Physics Teaching (N = 35)

Item		A	RA	N	RD	D
1. During physics lessons, I sometimes use analogies consciously	Count %	8 23	14 40	2 6	6 17	5 14
2. More frequently I use analogies consciously rather than when they arise spontaneously	Count %	9 26	9 26	2 6	11 31	4 11
3. I encourage students to analyse analogies contained in textbooks	Count %	3 9	14 40	4 11	14 40	0 0
4. I think that analogies help students to imagine and understand directly perceived objects or processes	Count %	22 63	13 37	0 0	0 0	0 0
5. I think that analogy contributes to the development of imagination	Count %	7 20	25 71	2 6	1 3	0 0
6. I think that analogy contributes to understanding of abstract concepts or indirectly perceptible processes	Count %	22 63	10 28	1 3	2 6	0 0
7. Analogy sometimes diverts attention from the main concept or misleads students	Count %	3 8	12 34	6 18	9 26	5 14
8. Visualisation of analogy is more effective than just the process of negotiating	Count %	15 43	18 51	0 0	2 6	0 0
9. If the teacher uses analogy in an explanation, the students reiterate it in their answers or discussions	Count %	2 6	4 11	0 0	16 46	13 37
10. Purposeful use of analogies develops the ability to apply knowledge to new situations, develops transfer skills	Count %	19 54	16 46	0 0	0 0	0 0
11. Learning with analogies requires a mental "leap", because it involves imagining one thing as another	Count %	2 6	31 88	2 6	0 0	0 0
12. At the end of secondary education, most students have insufficiently developed analogical reasoning	Count %	0 0	2 6	7 20	22 63	4 11

Note. A – agree, RA – rather agree, N – neutral or no answer, RD – rather disagree, D – disagree

The results reveal that approximately half of respondents use analogies consciously rather than they arise spontaneously. This is consistent with the conclusion by Cruz-Hastenreiter (2015) that during teaching activities the use of analogies is deliberate and can be planned to promote analogical reasoning development. Some respondents encourage their students to analyse analogies contained in textbooks and, in their explanations to students, some teachers use analogies both consciously and spontaneously. Nevertheless, approximately half of the sample (51%) does not draw students' attention to analogies that are contained in textbooks. Overall, analysis of analogies included in textbooks can enable a deeper understanding of their role in the comprehension process and, especially for young teachers, to improve analogical reasoning and transfer skills for their students.

Responses from the questionnaire are consistent with the interview responses on this issue and this coherence confirms the validity of answers, providing data triangulation. During the interviews, the teachers expressed both positive and negative opinions in relation to the use of analogies which, in general, correspond to the data presented in Table 1. The interviewed teachers recognized that the main factors to consider while preparing a lesson include: where an analogy will be used, students' familiarity with analogy, students' background knowledge and the ability to compare and transfer features from one object to other. Treagust and colleagues (1998) point to similar factors: the degree of difficulty of the topics, the degree of novelty, prior knowledge of students, and familiarity with the analogy.

Furthermore, the respondents agree (63%) or rather agree (37%) that analogies can help students to imagine and understand indirectly perceptible objects and processes. Several other studies highlight the potential of analogy in the teaching and learning of science, primarily of concepts with a higher degree of complexity (e.g., Duit, 1991; Glynn, 2008; Harrison & Treagust, 2006). For example, Glynn (2008) notes that science teachers at all grade levels frequently use analogies when explaining fundamentally important concepts.

The large share of those responding "rather agree" or "rather disagree," as well as missing answers, suggest that these teachers have little experience with analogies or they are not completely confident about this pedagogy. Such answers were obtained for the statements: "More frequently I use analogies consciously rather than when they arise spontaneously", "I encourage students to analyse analogies contained in textbooks", "Analogy sometimes diverts attention from the main concept or misleads students".

It should be noted that the use of analogy does not always yield a positive effect. Several teachers indicated that analogy sometimes diverts students' attention from the main concept or misleads students. This is also mentioned in other studies (Aubusson et al., 2009; Dilber & Duzgun, 2008; Duit et al., 2001). Some students only remember the analogy and not the content under study; other students focus upon extraneous aspects of the analogy and draw spurious conclusions about the target concept. In these cases, understanding of the new concept would be more successful without the use of analogies. At the same time, according to Cruz-Hastenreiter (2015), analogies allow for insights and highlight students' misconceptions. One teacher mentioned that after watching video "Nanotechnology" where atoms were shown as the small yellow balls, some students perceived this analogy directly; consequently, in the test situation, they characterized the atom as a small yellow tennis ball.

Respondents agree (54%) or rather agree (46%) that the purposeful use of analogy develops students' ability to apply knowledge to new situations and assists development of transfer skills. Similar conclusions can be found in various publications. When analogies are effective, they readily engage students' interest and clarify difficult abstract ideas (Harrison & Coll, 2008). Concrete analogies facilitate understanding of abstract concepts by pointing to similarities between objects or events in the students' world and the phenomenon under discussion (Aubusson et al., 2009). Cruz-Hastenreiter (2015) emphasizes that analogies lead to the activation of analogical reasoning, organize perception, develop cognitive skills such as creativity and decision making. Analogies make scientific knowledge more intelligible and plausible, facilitating the understanding and visualization of abstract concepts and, moreover, they can promote student interest. Use of analogies is a powerful and effective tool in order to contribute to the process of conceptual change. In general, the majority of the teachers recognized that purposeful use of analogy is a good method in teaching abstract science topics.

Types of Analogies

Approximately 85% of the surveyed teachers have mentioned at least one analogy; 27% – two or three analogies. The majority of the analogies were presented in verbal form; in four cases, the teachers listed their analogies as physical formulae. Overall, the teachers provided a total of 22 examples of analogy. Most of the teachers proposed analogies using physical objects, for instance, to illustrate the similarity between the atom model and the solar system, the Earth and an egg, a power source and a pump, electrical current and the water flow in pipes, mechanical pendulums and oscillation circuits, sound and electromagnetic waves. Teachers also named analogies using physical processes, such as free-electron movement in metals compared to a hurdling athlete, an electric current and the flow of a crowd of people, electrical oscillations and mechanical fluctuations. Brown and Clement (1989) emphasize that teachers more frequently use bridging analogies, analogies between well-known structures, objects or processes and novel scientific phenomena, such as the latter examples. These bridging analogies provide students with a platform from which to develop inferences and to prompt conceptual change, moving from one's original ideas about a target phenomenon to reformulate them based on comparison with the source.

A majority of analogies (70%) mentioned by the teachers can be found in physics textbooks used in Latvian schools, such as the similarity between an electric current and the flow of automobile traffic. However, few of these analogies are innovative; for example, the effect of radioactive emission on cell membranes can be pictured as a stone thrown against the window. Alternatively, a teacher could encourage students to analyze and evaluate the impact of radiation in varied situations, including human body cells, health, workability, well-being. Another creative analogy involves the comparison of two processes: tapping by a hammer on the stone can cause sparks and, similarly, solar wind particles striking on atmospheric particles result in a fixed wavelength radiation which may occur as a gorgeous nature phenomenon known as the northern lights. This phenomenon is distinctly illustrated in Einstein's conclusion on the association of mass and energy as well as cause-and-effect relationships.

Studies (Dilber & Duzgun, 2008; Glynn, 2008; Kim & Ryu, 2001) have found that electric current is very difficult for students to understand and that it is very hard to change the students' alternative ideas about electric current into scientific ones. Consequently, electric current is taught mostly through the use of analogies to elementary and secondary school students. Furthermore, the studied teachers included a large number of analogies related to electricity. During the group interview, the experienced teachers shared their experience with teaching the concept of electrical resistance. One teacher offered the analogy where the power cord is imagined as a long corridor with chairs located in some placement; each layout of chairs may be different, just as the atomic arrangement of metal crystal lattice varies. In addition, the experienced teachers pointed out that it is important to rethink the strategy to create a "bridge" between the known and the new concept, sometimes by including real models and by involving students in role-play. Based of the popularity of informational technologies, approximately half of the interviewed physics teachers use a variety of animation analogies that are easy to create or user-friendly. Kim and Ryu (2001) infer that animation analogy is more effective than pictorial or verbal analogy for developing students' understanding of rather difficult concepts, particularly those associated with electricity.

Some of the teachers admitted that, in their practice, they intuitively use the Focus–Action–Reflection approach (Treagust et al., 1998) when they teach concepts such as electric and gravitational phenomena, similarity and differences between electric current and water flow, mechanical and electromagnetic waves and their properties. Brown and Clement (1989) stress that it is necessary to engage the student in the process of analogical reasoning in an interactive teaching process rather than simply present the analogy in text or a lecture.

Several teachers acknowledged the formal analogy associated with the similarity of physical equations or laws, although the physics textbooks do not emphasise this analogy. For instance, storing energy in a capacitor is like stretching a spring and Coulomb's law is like Newton's law of gravitation. Furthermore, Dilber and Duzgun (2008) have indicated that Coulomb's law is often taught in introductory courses as analogous to Newton's law of gravitation. Electric current is often likened to water flowing through a pipe. These authors conclude that analogies were helpful for learning abstract and complex concepts of electricity. Emphasising structural similarities and differences between the physical quantities included in a formula is, consequently, left to the decision of teachers. According to some teachers, emphasising the similarities of the formulae facilitates their memorisation.

The view of several teachers was that the majority of students do not want to devote time and effort to understand the essence of a new topic; these students would rather rely on the fact that, in case of need, they will be able to find the required information. Some teachers emphasized that the majority of students are not motivated to learn physics; some mentioned that the students' lack of background knowledge is problematic. Consequently, the interviewed teachers acknowledged that they cannot pay sufficient attention to the development of analogical reasoning or take time to develop the necessary background knowledge.

Evaluation of Students' Analogical Problem Solving

In a National Sample of Physics Programme (Izglītības satura un eksaminācijas centrs [Curriculum Development and Examination Center], 2008) one of the deliverables for students was to establish a visual aid comparing the gravitational and electric field by analyzing and evaluating given information (p. 21). The main focus of this task was to observe similarities between two physics laws, as well as to consider some concepts, formulas and models. In Part 3 of the questionnaire the teachers were asked whether the execution of this exercise, requiring analogical thinking and problem solving, provides an opportunity to evaluate students' transfer skills. Content analysis of the teachers' comments reveals three main aspects of this issue: 1) organisation of students' training in terms of this task, 2) procedural and transfer skills of students and 3) students' understanding of the basic concepts corresponding to the theme.

Several comments emphasise the organisational aspect of the learning activity; for example, one teacher shared that *if students receive a worksheet with a clear formulation of the task and key words and have access to the relevant literature, majority of students can complete this exercise or execute at least the part of it.* Such comments indirectly suggest that there are students who are hesitant to tackle broader-scale tasks independently. Other teachers indicate that if the teacher guides the students in their work step-by-step, by asking questions or by giving directions, then this task for the student becomes feasible. Some teachers indicated that only a few students are able to perform this task independently; this fact points to the usefulness of the FAR model. The importance of motivation and organisation of the learning process to achieve results was also mentioned during the group interviews.

In assessing the procedural skills of their students, the teachers highlighted several issues and commented that:

- Students have difficulties to compare, discerning the similarities and differences, to analyse and to draw conclusions (n = 11);
- Students have problems with performing comparisons (n = 9);
- Students do not know how to begin solving the task (n = 1);
- Students are unable to think by analogy (n = 1);
- Students do not know how to think "globally" (n = 1).

These comments clearly display the recognition of the lack of students' procedural skills, including analogical reasoning and transfer skills. This suggests that a large proportion of teachers do not pay sufficient attention to the development of analogical reasoning while teaching physics. Teachers also indicated shortcomings with regard to prior physics content knowledge:

- *Only a few students remember the law of gravity and are able to see the similarity with the Coulomb's Law;*
- *Students quickly forget what was previously learnt, so before tackling this task it is necessary to revisit about the gravitational field and its related concepts.*

Furthermore, some teachers concluded that the majority of secondary school students are unable to identify deeper similarities between two different phenomena, gravitational and electrostatic interaction, probably because the tasks with such content are performed rarely.

It may be presumed that sufficient attention is not given to a comparison of physical phenomena. In this context, Dilber and Duzgun (2008) highlight that while using analogical instruction, analogies should address the correspondence of its attributes and relationships between the target concepts in order to make the connections more explicit. Moreover, a science teacher should become familiar with their students' difficulties in understanding scientific concepts. A majority of the respondents (74%) recognised that at the end of secondary education, most students have insufficiently developed analogical reasoning. The fact that the Latvian secondary school students' analogical reasoning and transfer skills are not cultivated on a sufficient level is evidenced by the results of the centralised examinations in physics, chemistry and biology.

Students have difficulties with tasks where creative application of the acquired knowledge and skills in a novel situation is required, for instance, transferring the principles of natural systems to technological constructions. Similar results are displayed in OECD research (Geske, Grīnfelds, Kangro, Kiseļova, & Mihno, 2013) where a relatively small number of 15-year-old students have high achievement in reading, mathematics and science; only 0.1% of the students were able to perform tasks of the highest level of difficulty. On average, across OECD countries, the highest level of competence was attained by 0.8% of students. Therefore, it is important to determine the reasons for such results. This study revealed some potential sources of acknowledged shortcomings.

For instance, when asked about the main features of physics teaching/learning in secondary school, teachers admitted that in recent years, since the new physics curriculum was implemented in 2008, there are other priorities, including laboratory research, development of students' research skills and teaching to use IT for extraction of information, data storage and processing, as well as for acquisition of the fundamental physics concepts and understanding of physical phenomena. Besides, as their primary task, teachers often focus on preparing those students who opt to take state examinations. The teachers also acknowledge their students' lack of motivation to fully understand the essence of ideas and are frustrated by the majority's unwillingness to struggle to reach high educational achievements.

Is it necessary to promote the development of analogical reasoning in the physics teaching/learning process? The teachers gave an affirmative answer to this question. There were two viewpoints: some teachers expressed the idea that, in the practice of choosing the tasks, teachers more often have to focus on mid-level students so they do not always have time to cultivate analogical reasoning and other high-order thinking skills. In contrast, some teachers emphasised the importance of using analogy for the development of reasoning; when their students identify an analogy, they show satisfaction with their ability to perceive it and to easily understand the associated new construct. A similar conclusion was reached by Richland and Simms (2015): when participants identify that they should be making an analogy, they often appear competent and are able to draw and benefit from key higher order structural mappings.

One teacher noted that *physics by its nature is an analysis of real-life situations and experimentation, creation of models and analogies and their interpretation on the grounds of previously discovered laws of nature. Physics has to be learnt if only just because it teaches people to think. ... And everyone needs to think, judge and analyse in their lives.*

Dimensions of the Usage of Analogies

When analysing the group interview transcripts, attention was paid to the dimensions of the usage of analogies. Four themes were distinguished and summarised in Table 2. The variety of examples mentioned by the teachers suggests that teachers are familiar with the aims for the usage of analogies.

Table 2
Dimensions of the Usage of Analogy: Physics Teachers' Views

Dimensions	Specific aims
Development of an initial understanding of a concept, idea or process	To generate momentum for acquisition of the topic by activating students' experience To build on prior knowledge and understanding of a target concept To organise students' thoughts about a concept
Visualisation of an abstract concept	To develop a picture or models of abstract substances To visualise indirectly perceived objects or processes
Information for switching "thinking"	To provoke thought triggering memories To promote thinking when students get into a deadlock To refresh students' minds with information from real life
Memorization or rephrasing of terms or operations	To determine the meanings of physics terms (such as capacitor, transformer, convection, etc.) To stimulate certain operations

During the discussion, the teachers came to the recognition that analogies should be taught by methods that evoke students' intuition and spur them to apply their prior knowledge and reasoning skills to solve unfamiliar problems. With regard to the methods of analogy use, three main insights from the teachers' interviews indicate that:

1) Analogy should be correct and accurately phrased: *Analogy must be correct in order to prevent misconceptions of not directly perceived processes, and not too primitive, because a primitive analogy does not catch students' attention;*
2) Objects or physical processes must be confronted with real life objects or processes or prior knowledge or skills: *For students it is easier to learn something new if it is compared with their prior knowledge. Analogies from life are sometimes very helpful in inspiring imagination. They create associations and it becomes easier for students to understand a new concept.*
3) There is a need to compare the analogue and target object or process: *The fact which we take as clear and understandable, for instance, when analysing the operation of pump and power source in electric circuit, is far from clear and understandable for students. So, step-by-step, we need to analyse what is similar and what is not, because students often take only part of the idea – "pull" it out of the context and thus develop their misperceptions.*

Therefore, to promote secondary school students' analogical reasoning, it is important to explain the basic properties of the analogue to enable an analogical transfer that is correctly established between the analogue and a target. Description of the analogue and the discussion of the strategy help to direct students toward focusing on suitable features for the analogical transfer.

When describing their own analogical reasoning, several teachers recognised that their ability to facilitate analogical thinking has developed in the course of their teaching career. In particular, physics as a subject is appropriate for demonstrating a way and means to arrive at new conclusions on the grounds of prior knowledge and experience in order to promote analogical reasoning and transfer skills development. Richland and Simms (2015) conclude that analogies are regularly used in both textbooks and classroom discourse, though there is converging evidence that acquisition of complex, integrated relational systems of knowledge within science cannot happen without explicit instructional support. This may take many forms, including direct instruction, scripted analogy activities, or carefully designed technologies for promoting knowledge integration.

Conclusion

In this study, the methodological tool for the development of transfer and analogical reasoning in physics teaching/learning was analysed from theoretical and empirical points of view and in different contexts. There is a consensus that, in the context of sustainable development, 21st century education should prioritize students' skills for higher order thinking, analogical transfer and flexible reasoning over memorization of facts. Analogy as a learning tool provides analogical reasoning, which can be seen as an important learning outcome. Such pedagogy raises new challenges for researchers, curriculum developers, teachers, teacher educators and authors of teaching aids; effective implementation asks for a more systemic approach, as well as more extensive studies to inform instruction and support in-service teacher training.

The teacher and his/her competence have a significant impact on the quality of ESD. A physics teacher should be able to contribute to their students' analogical thinking. According to this study, teachers' repertoire of analogies is primarily derived from textbooks; therefore, authors of textbooks should be careful to include appropriate information and tasks that promote analogical thinking.

A majority of the teachers believe that purposeful use of analogy is a good method for teaching abstract science topics. But there is little empirical evidence to demonstrate that drawing students' attention to the development of analogical reasoning and transfer skills can contribute to their awareness regarding the interconnectedness of physics knowledge with social, environmental, and economic issues. With regard to the methods of analogy use, three major insights indicate that: 1) analogy should be correct and accurately phrased; 2) target objects or physical processes must be compared with real life objects or processes or prior knowledge or skills; and 3) there is a need to explicitly compare the analogue and target object or process. Teachers' professional competences in terms of these recommendations can be improved only by continuous and systematic professional development, as well as by engagement in reflective activity.

Further research is required to understand how analogies can facilitate the comprehension of complex physics concepts, how to develop analogical reasoning and how to embrace the relationships between physics, laws, environmental, economical and social issues. The analysis of insights and views collected from educational researchers and experienced teachers is an important step toward the improvement of methodology of physics teaching and teacher education in the context of sustainable development.

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