ISSN 1392-0340
E-ISSN 2029-0551

Pedagogika / Pedagogy
2015, t. 119, Nr. 3, p. 116–125 / Vol. 119, No. 3, pp. 116–125, 2015

LIETUVOS
EDUKOLOGIJOS
UNIVERSITETAS

Analogies in Science Education

Lolita Jonāne

Daugavpils University, Faculty of Natural Sciences and Mathematics, Department of Physics, Parades St. 1,
LV-5400 Daugavpils, Latvia, lolitaj@inbox.lv

Abstract. Scientific literacy as a goal of education for sustainable development focuses attention to development of learning, inquiry, and "transfer" skills to enable young people to be able to use the aquired knowledge an skills in everyday and professional activities. This means that student must apply knowledge and skills from some to the new situation, from one area to another, not directly, but generalised, seeing similarity or analogy between them. Analogical reasoning is a central cognitive ability that is used in our everyday lives, in research, teaching and learning.

The study analized usage of analogies in physics textbooks for Basic and High School in Latvia. Seven physics textbooks are examined by using the descriptive analysis method. The usage of analogies were analysed to discuss on their effectiveness for a deeper acquisition of science concepts and phenomena, for developing students' reasoning, meaning making, and transfer skills during teaching physics.

Keywords: *analogy, physics textbook, analogical reasoning.*

Introduction

Regardless the great competition of more recent and sophisticated sources of information, textbooks are primary sources from which students obtain kmowledge. Traditionally textbook has been a medium of educational content and performed an organizational function of an education process. According to a contemporary goal of education one of the features of qualitatively shaped textbooks refer to the tasks for developing deeper learning and transfer skills. Deeper learning is defined as the process through which an individual becomes capable of taking what was learned in one situation and apply it to new situations (i.e., transfer). The product of deeper learning is transferable knowledge,

DOI: http://dx.doi.org/10.15823/p.2015.027

including content knowledge in a domain and knowledge of how, why, and when to apply this knowledge to answer questions and solve problems (Pellegrino & Hilton, 2012).

One of the possibilities to develop transfer skills is to use analogies during science, and, particularly, physics education. In order to use analogies effectively, it is important to understand exactly what an analogy is, how it can help learning and form transfer skills. A key question for science education researchers and science teachers is to investigate whether students can economically and repeatedly employ these same analogical reasoning skills to understand a new concept or phenomenon.

What is an analogy? What is their role in science in general and in physics education?

An analogy is a comparision which an idea, a thing or a process is compared to another that is quite different from it. It aims at explaining that idea, thing or process by comparing it to something that is familiar. On the basis of certain similarities, a principle or characteristic of the one term is applied to other term and asserted as true in that case as well.

Reasoning by similarities is one of the greatest sources for the development of physical theories. Analogies and analogical models have always played an important role in scientific explanation, and discovery from the eighteenth century and help scientists understand, present, and communicate about phenomenas and structure of a natural world (Harrison & Treagust, 2006; Glynn, 2008). The essential role of analogies in science can be highlighted by several historical examples: Boyle imagined elastic gas particles as moving coiled springs, Huygens used water waves to theorise that light was wavelike, Carnot compared of heat engines with waterfalls, Coulomb's law is similar with Newton's law of gravitation, and many others. In formulating a theory of electrical phenomena, James Clerk Maxwell claimed, "*Instead of using the analogy of heat, a fluid, the properties of which are entirely at our disposal, is assumed as the vehicle of mathematical reasoning... The mathematical ideas obtained from the fluid are then applied to various parts of electrical science*" (Podolefsky & Finkelstein, 2006). In its essence, analogy is a similarity on a more conceptual level, since it is strictly dependent on the intentions of the thinker (Polya, 1954). According to Gentner (2002), *the basic intuition behind analogical reasoning is that when there are substantial parallels across different situations, there are likely to be further parallels* (106). In this sense, analogical arguments can be used to generalize concepts, theories and methods so that they become applicable to classes of objects which are not of the same kind as those to which they originally apply (Tzanakis, 1998).

Some analogies can serve both to communicate ideas and to generate new scientific knowledge. For example, Ernest Rutherford produced an atom model that explained experimental results which accomplished better than competing analogies, such as the

ISSN 1392-0340
E-ISSN 2029-0551

"plum pudding" model. This analogy is often used to communicate an introductory atomic model to students. A key question for science education researchers to investigate is whether students can economically and repeatedly employ these same analogical skills to understand a new phenomenon (Treagust, 1993). In a traditional use of analogy in instruction, the analogy is presented to the students through a lecture or textbook passage. Science teachers, like scientists, frequently use analogies to explain concepts to students (James & Scharmann, 2007).

School physics is a subject which is rather complex and represents the foundation for the development of great deal of student's knowledge, abilities and skills significant for life. The analogies serve as initial models, or simple representations, of science concepts. Analogy provides the bridge from the material world to the abstract physics domain. Podolefsky & Finkelstein (2007) concluded, than the analogy leads to conceptual change more readily than the abstraction and students may develop the skill of abstraction by building upon lower level analogical thinking skills. The analogies used in classrooms, textbooks should be designed to promote elaboration, the cognitive process of constructing relations between what is already known and what is new (Glynn & Duit, 1995).

Analogies can foster understanding, but they can also lead to misconceptions. As Duit, Roth, Komorek, and Wilbers (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).

Effective analogy use fosters understanding and avoids misconceptions (Duit & Glynn, 1995). In order to use analogies effectively, it is important to understand exactly what an analogy is and how it can help learning.

An analogy in physics is not just a comparison between different domains: it is a special kind of comparision that is defined by its purpose and by the type of information it relates. According to Gentner (1989) „*an analogy is a mapping of knowledge from one domain (the base) into another (target), which conveys that a system of relations that holds among the base objekts also holds among the target objects*" (p.201). The purpose of analogy is the tranfer relational structure from a known, or familiar, domain to a less known domain. Both the analog and the target have *features*. Thus, the strenght of an analogy lies less in a number of features the analog and target domains and the system of connected information that it conveys (Gentner, 1983; Orgill, 2013). A systematic comparison, verbally or visually, between the features of the analog 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 as *structure mapping:* A→T, where A is the base domain or analog (e.g., the solar system) and T is the target domain (e.g. atom). Therefore, there are interesting questions how this strategy is implemented in physics textbooks.

ISSN 1392-0340
E-ISSN 2029-0551

What is the content foci of analogies and relationship between analog and target in physics' textbooks?

Based on a systematic analysis of science textbooks, Curtis and Reigeluth (1984) suggested that analogies are most effective for concepts that cannot be directly expierenced. Duit (1991) noted that in physics textbooks analogies are used to explain abstract or challenging information. 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. Aubusson, Treagust, & Harrison (2009) argued, that analogies to help student learning by providing visualisation of an abstract concept, by helping to compare similarities of students' real world with new concepts, and by increasing students' motivation.

To differentiate analogies Gentner (1983) breaks domain comparisons into three categories:

- literal similarity – a large number of both attributes and relations are mapped (e.g. the microphone is like or ear);
- analogy – a large number of relations, but few attributes, are mapped (e.g. the hydrogen atom is like our solar system);
- abstraction – the base domain is an abstract relational structure (e.g. the hydrogen atom is a central force system).

The notion that analogies usually cover target material that is difficult or abstract also support the relative levels of abstraction of analog and target concept. Analogs are generally used to make relational structure of the features of abstract target concepts more clearly to students than they would have been after a direct explanation of the target concept.

Research methodology

The aim of this study is:

1) to explore how often analogies are used in basic and high school physics textbooks;
2) to categorized analogies that are included in physics textbooks for basic and high school;
3) to analyze the level of abstraction and level of enrichment and evaluate their effectiveness for deeper acquisition of science concepts and phenomena.

Methods and procedure. Seven physics textbooks were read and examined by the use of a descriptive analysis method. The authors, title of these books, and publishing house are mentioned in Latvian as follows:

1) Vilks I. (2007). Fizika 8 klasei, Zvaigzne ABC.
2) Vilks I. (2008). Fizika 9 klasei, Zvaigzne ABC.

3) Šilters E., Reguts V., Cābelis A. (2013). Fizika 10 klasei, Lielvārds.
4) Šilters E., Reguts V., Cābelis A. (2006). Fizika 11 klasei, Lielvārds.
5) Šilters E., Reguts V., Cābelis A. (2008). Fizika 12 klasei, Lielvārds.

All of them are recommended for the use in basic high schools by the Ministry of Education of Latvia. Each textbook was read from start to the end, the analogies were identified, and marked The identified analogies were analized and divided into categories according to the classification system developed by Thiele and Treagust (1994) and systematized by Yener (2012). The analogies in each book are classified according to the following six categories:

The analogical relationship between analogue and a target:

- structural: the analogue and target concepts in the analogy share attributes of shape and size;
- functional: the analogue and target concepts in the analogy share attributes of function, behaviour, etc;
- structural-functional: the analogue and target concepts in the analogy share both structural and functional attributes.

The presentational format:

- verbal: the analogy is presented in the text in a verbal format only;
- pictorial-verbal: the analogy is presented in a verbal format along with a picture, drawing or visual model of the analogue.

The level of abstraction of the analogue and target concepts:

- concrete-concrete: both the analogue and the target concepts are of a concrete nature;
- concrete-abstract: the analogue concept is of a concrete nature but the target concept is an abstract;
- abstract-abstract: Both the analogue and the target concepts are of an abstract nature.

The position of the analogue relative to the target:

- advance the organizer: the analogue concept is presented before the target concept in the text;
- embedded activator: the analogue concept is presented with the target concept in the text;
- post-synthesizer: the analogue concept is presented after the target concept in the text.

The level of enrichment:

- simple: in this type of analogy, only one similarity is underlined between the analogue and the target concepts. The analogy is formed of a simple sentence with no details.
- enriched: it tells the student that the analogy is about processes, about dynamic functions and not limited to superficial structures. Indeed, the difference between

ISSN 1392-0340
E-ISSN 2029-0551

a simple structural analogy and an enriched functional analogy is the addition of some form of causation; that is, a simple analogy is descriptive whereas an enriched analogy is more explanatory;

- extended: two or more similarity dimensions between the analogue and target concepts are underlined. Extended analogies contain a mix of simple and enriched mappings or all the mappings are enriched analogies. The "eye is like a camera" analogy is an extended analogy. The grounds on which an "eye is like a camera" are stated in each case and there are multiple shared attributes in the analogy (and some limitations or unshared attributes) (Harrison & Treagust, 2006).

Pre-topic orientation:

- analogue explanation: introducing the analogue concept related to the target concept in the analogy through at least point;
- strategy identification: underlining that the text presented as an analogy is an assimilation;
- both analogue explanation and strategy identification: underlining both the explanation of the analogue and the strategy identification.
- none: underlining neither the analogue explanation nor the strategy identification.

The limitations of the analogy: underlining the situation that there breaking points in analogies at which misunderstandings may possibly arise.

Results

As a result (see table1) of the exploration, it was found that analogies are quite often presented in physics textbooks both for basic and high school students. A total of 52 analogies were detected in five physics textbooks. The majority of analogies in basic and high school physics textbooks are included in topics about electricity, magnetism and electromagnetic waves which which included many unfamiliar abstract concepts. These topics are learned in form 9 (in basic school) and form 11 and 12 (in high school).

According to previous studies, there is an average of 8.3 analogies in elementary and high school science textbooks in the United States (Curtis & Reigeluth, 1984), an average of 9 analogies in high school chemistry textbooks in Australia (Thiele & Treagust, 1994), and an average of 12.5 analogies in school physics textbooks in Turkey (Yener, 2012).

ISSN 1392-0340
E-ISSN 2029-0551

Table 1. **Categorization and number of analogies in school physics textbooks**

	Textbook number	3.	4.	5.	6.	7.	Total	
Category	Number of analogies	**8**	**10**	**2**	**17**	**15**	**52**	**%**
Analogical relationship	Structural	1	3	1	5	7	17	33
	Functional	3	5	–	8	7	23	44
	Structural-functional	4	2	1	4	1	12	23
Presentational format	Verbal	6	3	–	7	7	23	44
	Pictorial-verbal	2	7	2	10	8	29	56
Condition of subject matter	Concrete-concrete	6	2	1	7	5	21	40
	Concrete-abstract	2	8	–	8	7	25	48
	Abstract-abstract	–	–	1	2	3	6	12
Position in the text	Advance - organizer	2	2	–	6	8	18	34
	Embedded activator	6	6	1	10	6	29	56
	Post synthesizer	-	2	1	1	1	5	5
Level of enrichment	Simple	4	4	1	9	10	28	54
	Enriched	3	4	–	6	3	16	30
	Extended	1	2	1	2	2	8	15
Pre-topic orientation	Analogue explanation	2	2		7	6	17	33
	Strategy identification	3	4	1	1	2	11	21
	Both	3	2	–	4	3	12	23
	None	–	2	1	5	4	12	23
Limitations	Existing	1	–	–	1	–	2	4
	None	7	10	2	16	15	50	96

It was determined that analogies in Latvian physics textbooks were mostly considered as functional and presentation form is pictorial-verbal. Functional analogies are often used to understand abstract physics concepts and they are also of an engaging nature. Pictorial-verbal analogies are easier to remember and increase the permanence of knowledge. It is known that pictures are more memorable than sentences. Bean et al. (1990) reached the conclusion that an analogy presented in a pictorial-verbal format is more effective in understanding the structure and functions of a cell than an analogy presented in verbal format. In physics textbooks do not emphasize the physics formula (law) analogy. For example, storing energy in a capacitor is like stretching a spring Coulomb's law is like Newton's law of gravitation. Emphasize structural similarities and differences between the physical quantity included in formula is left to the teachers' responsibility.

In terms of the condition of the subject matter it was found that to present the analogue and target concepts, the concrete - abstract analogy type was used more often (48 %), than concrete-concrete (40 %) and on very rare occasions abstract- abstract (12 %) analogies.

ISSN 1392-0340
E-ISSN 2029-0551

The majority of analogies in the textbook for form 12 are formed as a simple sentence with no details. For example, in the textbook designed for form 12 included information that laser optical resonator can be compared with taut violin string, in which it formed and reinforced sound waves. The analogy makes it possible to see similarities between the occurrence of standing waves in string and in laser core. Much more detailed the new concept and the analogy explanation is found in physics textbook for form 9. For example, for the explanation of the concept electric voltage the analogy to the barrages over which falls towards the water stream is used.

In terms of the position of the analogue relative to the target, the embedded activator analogy is most common in physics textbooks (56 %), then respectively (34 %) advance organiser and (5 %) post synthesiser analogies have been used. Embedded activator types of analogies are more intuitive for students. Advance organiser or post synthesiser types of analogies require more experience and prior knowledge for the student.

In terms of the level of enrichment, simple (54 %), and then respectively, enriched (30 %) and extended (15 %) analogies are used in the physics textbooks.

In terms of pre-topic orientation, majority of analogies used in physics textbooks used as analogue explanation, strategy definition or both. Authors often used such form of expression like "Similarly…", "Likewise…", "In comparison to…" Analogy is identified as an "analogy" in one case and it is insufficient.

It is important to explain the basic properties of the analogue used in an analogy to enable an analogical transfer to be correctly established between the analogue and a target. Description of the analogue and definition of the strategy both help to direct students to focus on suitable features for the analogical transfer (Thiele & Treagust, 1994). Must be held that the little attention has been paid to the limitations of analogies. Brown & Clement (1989) stressed the it is necessary to specify the breaking points that may cause misunderstandings in the analogies used in books or unshared features between the analogue and target to prevent false concepts arising from the analogies.

Summary, conclusions

Textbooks commonly use a limited number of analogies (e.g. electrical current – water flow in pipes, atoms – small balls). Evaluation of analogies after the criteria above are subjective but the overall the presentation of analogies in science textbooks is fairly consistent, regardless of the grade level or content focus of the book. Abstract concepts, in which analogies are used most frequently, include the physics concepts that are difficult for students to understand. The main function of analogies is to make the concepts that are difficult to understand comprehensible. Well selected analogies are a powerful pedagogical tool that can help students to visualize and to comprehend unfamiliar abstract concepts and to develop the transfer skills and dispositions to generate their own analogies.

Overall analysis of analogies included in textbooks enables a deeper understanding of their role in the comprehension process, and especially for a young teachers to improve methodological competences for transfer skills advancement.

References

Aubusson, P., Treagust D., & Harrison A. (2009). Learning and teaching science with analogies and metaphors. In *The World of Science Education: Handbook of Research in Australasia*. Sense Publishers.

Bean, T. W., Searles, D., Singer, H., & Cowen, S. (1990). Learning concepts from biology text through pictorial analogies and an analogical study guide. *The Journal of Educational Research*, *83* (4), 233–237.

Brown, E., & Clement, J. (1989). Overcoming Misconceptions via Analogical Reasoning: Abstract Transfer Versus Explanatory Model Construction. *Instructional Science*, *18*, 237–261.

Curtis, R., & Reigeluth, C. (1984). The use of analogies in written text. *Instructional Science*, *13*, 99–117.

Duit, R., Roth, W. M., Komorek M., & Wilbers J. (2001). Fostering conceptual change by analogies – between Scylla and Carybdis. *Learning and Instruction*, *11* (4), 283–303.

Gentner, D. (1983). Structure-Mapping: A Theoretical Framework for Analogy. *Cognitive Science*, 7, 155–170.

Gentner, D. (1989). The mechanisms of analogical learning. In Vosniadou& Ortony (Eds.). *Similarity and analogical reasoning.* London. Cambrige University Press, 199–241.

Gentner, D. (2002). *Analogical reasoning, psychology of Encyclopedia of Cognitive Science*. London: Nature Publishing Group.

Glynn, S. M. (2008). *Making science concepts meaningful to students: teaching with analogies*. Four decades of research in science education: books.google.com.

Glynn, S. M., & Duit, R. (1995). Learning science meaningfully: Constructing conceptual models. In S. M. Glynn & R. Duit (Eds.) *Learning science in the schools: Research reforming practice* (pp. 3–33). Mahwah, NJ: Erlbaum.

Harrison, A. G., Treagust, D. F. (2006), Teaching and learning with analogies. In Aubusson et al. (Eds.). *Metaphor and Analogy in Science Education* (pp. 11–24). 11 Springer.

James, M. C., & Scharmann, L. C. (2007). Using analogies to improve the teaching performance of preservice teachers. *Journal of Research in Science Teaching*, *44* (4), 565–585.

Orgill, M. K. (2013). How Effective Ia the Use of Analogies in Science Textbook. In M. S. Khine (Ed.). *Critical Analysis of Science Textbooks: Evaluating instructional effectiveness*. Springer.

Pellegrino, J. W., & Hilton, M. L. (2012). *Education for Life and Work*. National Academy of Sciences, Washington.

Podolefsky, N. S., & Finkelstein, N. D. (2006). Use of analogy in learning physics: The role of representations. *Physics Education Research 2*.

ISSN 1392-0340
E-ISSN 2029-0551

Podolefsky, N. S., & Finkelstein, N. D. (2007). Analogical scaffolding and the learning of abstract ideas in physics: Empirical studies. *Physics Education Research 3.*

Polya, G. (1954). Mathematics and plausible reasoning. In *Vol. 1*: *Induction and Analogy in Mathematics*. Princeton: Princeton University Press.

Thiele, R. B., & Treagust, D. F. (1994). The nature and extend of analogies in secondary chemistry textbooks. *Instructional Science*, *22* (1), 61–74.

Tzanakis, C. (1998). Discovering by analogy: the case of Schrödinger's equation. European. *Journal of. Physics, 19,* 69–75.

Treagust, D. F. (1993). The evalution of an appproach of using analogies in teaching and learning science. *Research in Science Education, 23,* 293–301.

Yener, D. (2012). A study on analogies presented in high school physics textbooks. *Asia-Pacific Forum on Science Lerarning and Teaching, 13*, Issue 1, Article 5.

Analogijos gamtamoksliniame švietime

Lolita Jonāne

Daugpilio universitetas, Gamtos mokslų ir matematikos fakultetas, Fizikos katedra, Parades g. 1,
LV-5400 Daugpilis, Latvija, lolitaj@inbox.lv

Santrauka

Paprastai vadovėliuose sutinkame gana ribotą analogijų skaičių (pvz.: elektros srovė – vandens srovė vamzdžiuose, atomai – maži kamuoliukai). Analogijų vertinimas pagal pateiktus kriterijus yra subjektyvus, tačiau dažnai analogijos vadovėliuose pateikiamos gana nuosekliai, neatsižvelgiant į turinį ir klasę, kuriai jis (vadovėlis) skirtas. Dažniausiai randama abstrakčių, taip pat ir fizikos, sąvokų analogijų, kurias mokiniams sunku suprasti. Pagrindinė analogijų funkcija – padėti suprasti sudėtingas sąvokas. Gerai parinktos analogijos yra veiksminga pedagoginė priemonė, kuri padeda mokiniams vizualizuoti ir suprasti nežinomas abstrakčias sąvokas, plėtoti perkeliamuosius gebėjimus ir kurti savo analogijas.

Bendra vadovėliuose sutinkamų analogijų analizė padeda geriau suvokti jų vaidmenį supratimo procese, o mokytojams, ypač jauniems, pagerinti metodines kompetencijas perkeliamiesiems gebėjimams plėtoti.

Esminiai žodžiai: *analogija, fizikos vadovėliai, analoginis priežastingumas.*

Įteikta / Received 2015-03-21
Priimta / Accepted 2015-06-19