A study on analogies presented in high school physics textbooks

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Contents

Abstract

This is an important study of analogies of textbooks in high schools. It is important for teaching based on analogies to determine how analogies are structured in physics textbooks. The aim of this study is to scrutinise the types of analogies used in physics textbooks in High Schools, and to study how these analogies are structured and presented. In this study, four physics textbooks are examined using the descriptive analysis method. Analogies detected in textbooks are classified according to criteria such as the Analogical Relationship, Presentational Format, Condition of Subject Matter, Position in Text, Level of Enrichment, Pre-Topic Orientation and Limitations. As a result of the analysis, a total of 50 analogies were detected in four physics textbooks. It was determined that these were mostly configured as functional, verbal, concrete-abstract, embedded activator, and simple analogies. The results are compared with science teaching literature and recommendations are developed.

Keywords: Analogy, physics, textbooks, teaching.

Introduction

Nowadays, despite the improvements observed in technology and communication, textbooks retain their importance for students and teachers in classroom environments. Throughout the education process, science and technology textbooks are one of the most commonly used effective teaching materials. It is a well-known fact that students and teachers trust and are highly dependent on textbooks (Lumpe & Scharmann, 1991). Therefore, analysis in a variety of ways of the textbooks used by students and teachers will contribute to the literature on science education. One of the issues that should be analysed in science and technology textbooks is the way that analogies are configured by the author(s).

When educational analogies are used in texts, some of them may not be suitable for all learners. Therefore, teachers and authors of books need to have and develop an available and useful analogy repertoire (Shulman, 1986; Thiele & Treagust, 1994). At present, analogies are frequently found in science textbooks (Iding, 1997). It is especially difficult for learners to understand and explain most science concepts, which they are not able to test directly and observe clearly (Thiele & Treagust, 1995). Analogies help theoretical concepts of this kind to be stimulated in the mind and make them clear (Lawson, 1993).

Analogy is mostly used for understanding abstract concepts and complicated issues. An analogy is an explanation that compares a fact that is unknown and unfamiliar with another known and familiar one. The unknown fact is the target while the known fact is the analogue. The analogy compares the similar characteristics of the target and analogue and then a transition from the known information area to the unknown information area is made (Duit, 1991; Harrison & Treagust, 1994). The analogue is known information while the target is a less known or unknown information. An analogy is an application of features in the analogue to the target concept (Figure 1). The more closely the analogue matches the target, the more effective and powerful the analogy is (Glynn, 1991; Harrison & Treagust, 1994).

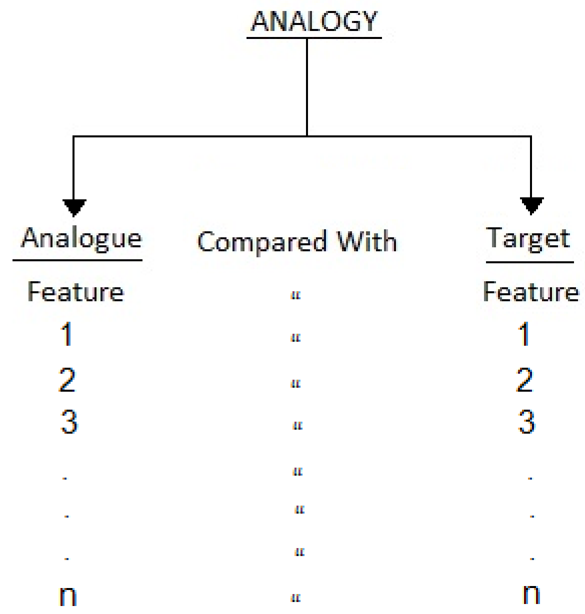

Figure 1. The relationship between analogue and target domains in an analogy (Glynn, 1991).

Analogies are effective teaching tools, helping the students convey new information to the available information structure, providing meaninful learning motivation and giving a new point of view on the subject (Glynn & Takahashi, 1998; Heywood, 2002). Analogies help to remove misconceptions and play an important role in conceptual exchange (Stavy, 1991; Venville & Treagust, 1996). Analogies make abstract concepts concrete (Thiele & Treagust, 1994). There are some disadvantages when they are not used well (Duit, 1991). Not all analogies are good analogies, and neither are all good analogies useful for all students (Orgill & Bodner, 2004). In an analogy, if the analogue and target concepts do not fully overlap with each other, they can lead students to form erroneous concepts and make mistakes (Clement, 1993; Geban et al., 1999; Duit et al., 2001). Analogies in textbooks are usually used randomly and are inadequate for students (Gilbert, 1989), which causes them to make mistakes (Thiele & Treagust, 1994). This teaching method makes complicated issues easier to understand with the help of analogy. While using analogy, it makes associations with real life, thus, it helps students visualize them by turning abstract concepts into more concrete ones. Analogies should therefore be chosen carefully and used in accordance with certain rules. Some teaching models aiming to use analogies effectively in science education have been developed.

Of these, the one which is used most is the Teaching with Analogies Model (TWA). The TWA model explains the rules that teachers need to follow during analogy-based teaching. These rules comprise the following six steps (Glynn, 1991):

1. Introduce the target concept
2. Cue retrieval of the analogue concept
3. Identify relevant features of the target and analogue
4. Map similarities
5. Indicate where the analogy breaks down
6. Draw conclusions

Analogies serve as initial models to promote scientific concepts and are used frequently in science textbooks (Iding, 1997). When they looked at the international science education literature, Curtis and Reigeluth (1984) found an average of 8.3 analogies for each science textbook in the United States. Thiele and Treagust (1994) expanded Curtis and Reigeluth's (1984) classifying system and categorized analogies in high school chemistry textbooks in Australia in a systematic way and found a total of 93 analogies in 10 books. Thiele, Venville and Treagust (1995) compared high school chemistry and biology textbooks for their use of analogies and found that analogies were used more in biology textbooks. Newton (2003) compared elementary school science textbooks with high school science textbooks in terms of their use of analogies.

Where national science education literature is concerned, it is seen that more studies focus on analogies in biology textbooks (Dikmenli, 2010) than in science and technology (Dikmenli & Kıray, 2007) and chemistry (Şendur et al., 2011) textbooks. For example, Dikmenli (2010), analyzing the types of analogies used in high school biology textbooks in Turkey, scrutinised how these analogies are configured and presented. In this study, a total of 119 analogies were identified in seven biology textbooks. It was found that most of the analogies used in biology textbooks are configured and presented in the form of structural, verbal, concrete-abstract, embedded activator and simple analogies. In that study, it was revealed also that most of the analogies in the books are not configured according to the analogy-based teaching guides as analogies based on the teaching model are.

In the literature of science education, there has been no study so far about analogies used in physics textbooks in high schools in Turkey. In developing countries, due to a lack of technology and laboratory facilities and to teacher-centred teaching strategies, textbooks stand out even more. Physics textbooks are important and have a central role in the process of the teaching of science. For example, Chiappetta et al. (2006) report that more than 90% of high school science teachers trust textbooks. It is intended that the analysis of the analogies used in physics textbooks in Turkey will therefore benefit students, teachers, writers and programmers. The issues difficult to understand become simpler to acquire thanks to using analogies in physics textbooks. It is aimed to give information to other physics teachers about how and to what extent the analogies in this textbook which is taught in each state school and some private schools are being used.

Purpose

The purpose of this study is to scrutinise the types and scopes of analogies that are prepared in accordance with the curriculum for physics education and used in the physics textbooks of the 9th, 10th, 11th, and 12th classes. In parallel with this goal, we have sought answers to these questions:

a) How often are analogies used in high school physics textbooks?

b) What types of analogies are used in the books?

c) Is a description given of the analogue in the analogies used, with a definition of the strategy and its limitations?

Method

Textbooks

In this study, four physics textbooks recommended for use in high schools by the Ministry of National Education in Turkey were examined (MEB Journal Papers, 2010). The details of these books are as follows:

Book A: Kalyoncu, C., Tütüncü, A., Değirmenci, A., Çakmak, Y., & Pektaş, E. (2008). Ortaöğretim fizik 9 ders kitabı (Secondary school physics textbook 9). MEB Yayınları, İstanbul.

Book B: Kalyoncu, C., Pektaş, E., Değirmenci, A., Kurnaz, M.A., Tütüncü, A., Çakmak, Y., & Bayraktar, G. (2010). Ortaöğretim fizik 10 ders kitabı (Secondary school physics textbook 10). MEB Yayınları, İstanbul.

Book C: Kurnaz, M.A., Değirmenci, A., Kalyoncu, C., Pektaş, E., Bayraktar, G., Aydın, U., & Moradoğlu, Y. (2010). Ortaöğretim fizik 11 ders kitabı (Secondary school physics textbook 11). MEB Yayınları, Ankara.

Book D: Karaaslan, İ., Ceran, M., Altuntaş, A., Öksüzoğlu, H., Tütüncü, A., İmamoğlu, K., Zengin, F., & Turdoğlu, A. (2009). Ortaöğretim fizik 12 ders kitabı (Secondary school physics textbook 12). MEB Yayınları, İstanbul.

These books are published in line with the national high school curriculum in Turkey, and are the physics textbooks still in use in classrooms of 1st, 2nd, 3rd, and 4th classes with the approval of the Ministry of National Education. These four textbooks have been used in state schools in all cities by the Ministry of National Education.

Data Collection and Analysis

The study is a descriptive research (Çepni, 2005) and uses a screening model. The study is descriptive study about physics textbooks. It is not a study about teachers. Each book that is discussed in the document analysis was read twice from start to finish. All figures or comparison types considered to be an analogy were marked and photocopied. These were re-read using the photocopies and the analogies were identified. The identified analogies were divided into categories according to the classification system developed by Thiele and Treagust (1994). The analogies in each book are classified according to the following categories.

The analogical relationship between analogue and target

Structural: The analogue and target concepts in the analogy share attributes of shape, size, colour, etc.

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 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.

Abstract-Abstract: Both the analogue and the target concepts are of an abstract nature.

Concrete-Abstract: The analogue concept is of a concrete nature but the target concept is abstract.

The position of the analogue relative to the target

Advance 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 target concepts. The analogy is formed of a simple sentence with no details.

Enriched: Two similarity dimensions between the analogue and target concepts are underlined. The analogical statement is formed of sentences which are basic for the analogy.

Extended: Two or more similarity dimensions between the analogue and target concepts are underlined. The analogical statement is formed of basic sentences including details. Analogies in which many sources have been used while explaining a target concept are also considered as extended analogies.

Pre-topic orientation

Analogue explanation: Introducing the analogue concept related to the target concept in the analogy through at least one 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 are breaking points in analogies at which misunderstandings may possibly arise.

Results and Discussion

As a result of the analysis, a total of 50 analogies were identified in high school physics textbooks. Each analogy was examined independently by two faculty members who are researchers and experts on physics education. In the process of analogy classification, the rate of 94.9% consensus was achieved for 350 classifications (7 criteria x 50 analogies). As a result of discussion, a consensus was achieved for the remaining 18 classifications (5.1% of 350 classifications). An average of 12.5 analogies was found in each book. It was seen that the fewest analogies (8) were in book A, and the most (16) were in book C (Table 1). 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 9.3 analogies in high school chemistry textbooks in Australia (Thiele & Treagust, 1994), an average of 43.5 analogies in high school biology textbooks in Australia (Thiele et al., 1995), an average of 2.6 analogies in elementary school science textbooks in the UK (Newton, 2003), an average 19.75 analogies in college bio-chemistry textbooks (Orgill & Bodner, 2006), and an average of 17 analogies in biology textbooks in Turkey (Dikmenli, 2010).

In terms of the analogical relationship between the analogue and target concepts, it was identified that functional (48%) and then structural-functional (30%) and structural (22%) analogies were most commonly used in physics textbooks (Table 1). Functional analogies are often used to understand difficult and abstract physics concepts and they are also of an engaging nature. For example, “as soon as the tap is opened in the compound containers the water flows right through from the container where the water level is high to the one with less water. This flow will continue until the water levels in the two containers are equalized. The reason for the water flow is due to the difference in the water level of the containers. If the level of water is synchronized there is no water flow… So must there be a difference between the water levels that is similar to the one between the poles of the battery? Can the difference in water levels be likenend to the potential difference between the poles of the battery, causing the movement of electrons to start in electrical circuits? This difference between the poles of the battery is defined as potential (voltage). The current will continue to pass through the circuit until this difference is reset. If there is no potential difference between the poles of the battery the current does not go through from the circuit the battery it is connected to" (Book A, p. 185).

An example of a structural-functional analogy used in textbooks is: "Reflection and transmission of light waves is similar to the movement of spring waves. That is, a thin spring in a soft breaker environment acts like a thick spring in a very hard breaker atmosphere" Book D, p. 95). An example of a structural analogy used in textbooks is: "... the atom radius is about 10-10 meters. Positive loads are distributed evenly into the sphere. Negative loads are sorted to make the atom neutral and their locations are fixed. This model is also called a 'raisin cake model' as it looks like raisin cakes" (Book D, p.122). This is explained in the structural analogy by comparing the structure of an atom to a raisin cake. According to previous research, multi-functional analogies have mostly been used in chemistry textbooks (Thiele & Treagust, 1994), biology textbooks (Thiele et al., 1995) and college bio-chemistry textbooks (Orgill & Bodner, 2006). When considering whether functional or structural-functional analogies are more effective in education (Duit, 1991; Thiele & Treagust, 1994), understanding is required of the circumstances in which such analogies are frequently encountered in physics textbooks. In a structural analogy, students are supposed to know that the analogue and target concepts only share structural features. Otherwise, students may transfer the function and behavioural features from the analogue towards the target (Orgill & Bodner, 2006).

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

	Books	A	B	C	D	Total number of analogies	
Category	**Number of analogies**	**8**	**13**	**16**	**13**	**50**	**%**
Analogical Relationship	Structural	1	2	6	2	11	22
	Functional	4	7	7	6	24	48
	Structural-Functional	3	4	3	5	15	30
Presentational Format	Verbal	4	7	13	11	35	70
	Pictorial-Verbal	4	6	3	2	15	30
Condition of Subject Matter	Concrete- Concrete	1	1	1	3	6	12
	Abstract-Abstract	3	5	2	1	11	22
	Concrete-Abstract	4	7	13	9	33	66
Position in Text	Advance Organiser	1	1	-	1	3	6
	Embedded Activator	7	12	14	12	45	90
	Post Synthesiser	-	-	2	-	2	4
Level of Enrichment	Simple	5	5	12	7	29	58
	Enriched	3	4	4	3	14	28
	Extended	-	4	-	3	7	14
Pre-Topic Orientation	Analogue Explanation	2	1	-	1	4	8
	Strategy Identification	3	3	5	5	16	32
	Both	1	2	1	3	7	14
	None	2	7	10	4	23	46
Limitations	Existing	-	1	2	-	3	6
	None	8	12	14	13	47	94

In terms of the presentational format of analogies in the book, it has been discovered that the analogies presented were 70% verbal and 30% pictorial-verbal (Table 1). One of the analogies presented in pictorial-verbal format established similarities between atoms and the solar system. "In the atomic model developed by Rutherford, the positive charge in the atom forms most of the mass and has a centre named the nucleus. Electrons in the spaces outside the core revolve around the nucleus like the planets in the solar system" (Figure 2) (Book C, pp. 221-222).

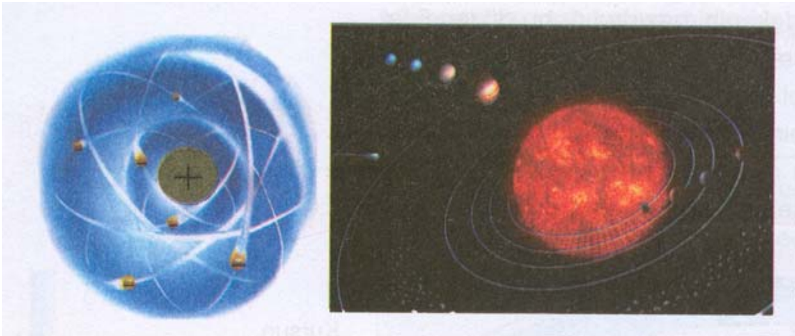

Figure 2. Image of an analogue in a pictorial-verbal analogy (Book C, p. 222).

In this analogy, the text is supported by a picture of the analogue (solar system) and thus the structure of the atom is made attractive and permanent to students. Another example of pictorial-verbal analogies used in textbooks is: "Expansion of the universe after the big bang can be compared to the inflation of a balloon" (Figure 3) (Book C, p. 342).

Pictorial-verbal analogies are found in the books examined in previous studies (Dikmenli & Kıray 2007; Orgill & Bodner, 2006; Thiele et al., 1995). Thiele et al. (1995) reported that only 6 of 174 analogies in four high school biology textbooks were presented using a pictorial-verbal format. It is important to support analogical texts with pictures to make the analogies interesting for students because pictures are always interesting. However, this is particularly important for elementary and high school students. 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.

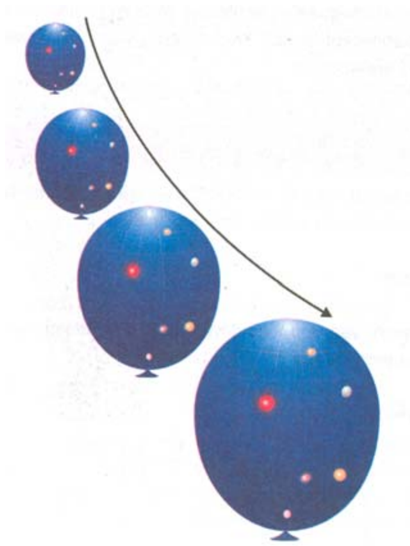

Figure 3. Image of an analogue in a pictorial-verbal analogy (Book C, p. 342).

In terms of the condition of the subject matter it was found that to present the analogue and target concepts, 66% of the analogies in books are concrete-abstract, 22% concrete-abstract and 12% abstract-concrete (Table 1). The use of more concrete-abstract analogies in physics textbooks in Turkey is natural and desirable because the most important role of analogies in teaching is to make the target concepts in abstract properties concrete for the learner. The best style of teaching goes from concrete to abstract. An example of the concrete-abstract analogy type in the textbooks used is as follows: "... collision of photons with electrons is similar to the collision of two billiard balls" (Book D, p. 107). These findings are similar to the findings of previous studies (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele et al., 1995). However, Newton (2003) in his study, stated that the concrete-concrete analogy type was used more often (59.8%) in science textbooks written for the 7-11 age-group students of elementary schools. The researcher reported that this case is connected with the cognitive level of younger age-group children.

In terms of the position of the analogue relative to the target, the embedded activator analogy is most common in physics textbooks (90%), then respectively (6%) advance organiser and (4%) post synthesiser analogies have been used (Table 1). Similar results were revealed in previous studies (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1994). Newton (2003) noted that all the analogies in science textbooks prepared for 7-11 age-group students in the UK were presented as embedded activators. 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 (58%), and then respectively, enriched (28%) and extended (14%) analogies are used in physics textbooks (Table 1). Roughly similar rates have been revealed in other studies (Dikmenli & Kıray, 2007; Dikmenli, 2010, Thiele and Treagust, 1994; Thiele et al., 1995). However, detailed analogies will help students transfer new information to old information (Paris & Glynn, 2004). Studies indicate some dangers with simple analogies. In simple analogies, students must establish the relationship between the analogue and target on their own. Therefore, the use of simple analogies may also often cause students to develop wrong concepts (Thiele et al., 1995). Glynn and Takahashi (1998) stated that analogies must be explained clearly or enriched for the purpose. It has been found that detailed analogies make students learn the target concept and increase their interest (Paris & Glynn, 2004).

In terms of pre-topic orientation, just 8% of analogies used in physics textbooks used analogue description only, 32% strategy definition only, and 14% used both strategy definition and description of the analogue. In 46% of analogies neither a description of the analogue nor any definition of the strategy was found (Table 1). 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 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).

In terms of limitations of analogies, limitations were pointed out in 6% of the analogies used in physics textbooks, while there was no emphasis on the limitations in 94% of the analogies (Table 1). An example that points to the limitations of analogies used in textbooks is as follows: "... naming the movement of electrons as electric current, we have compared the electron movement to the water flow that occurred when we opened the tap which tied the containers with different water levels to each other. In this case, it is the level differences that make the water move. This level difference is explained as potential difference. We have compared the water molecules to electrons. <u>In this figuring, we need to note that the movement of electrons cannot simulate exactly the movement of water molecules... "</u> (Book B, p.141). 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 (Brown & Clement, 1989; Clement, 1993; Coll & Treagust, 2001).

Conclusions and Recommendations

As a result of the examination, it was found that analogies are often used in physics textbooks. It is seen that these analogies are used more for abstract target concepts (Table 1). Abstract concepts, in which analogies are used most frequently, include the physics concepts that are difficult for students to understand. One of the important functions of analogies is to make the concepts that are difficult to understand comprehensible. In this regard, most of the analogies used in physics textbooks are very reasonable in terms of the content of the target concept. It is seen that analogies can be configured as a functional analogy, verbal analogy, concrete-abstract analogy, embedded activator type analogy or simple analogy.

Figure 2 may cause a lot of misconceptions. It shouldn't be used like that. Moreover, sufficient explanations on the analogy and issue should be certainly provided in order to prevent misunderstandings and misconceptions. The following suggestions may be offered to students to provide them with better benefits from analogy-based learning in physics textbooks: enriched or expanded and advance organiser analogies in books can be highlighted more. Overlapping features in generated analogies between the analogue and target can also be presented to the attention of students. The analogies generated should be presented in a systematic manner with the limitations clearly described if they are to be effective educational tools. The presentation method mediates the effectiveness of analogies as well. When analogies provide a greater conceptual understanding and are taught in a systematic way, there is less risk of misinterpretation. One way to achieve this is to use educational models. A number of educational models have been detailed in the literature including the FAR book (Harrison, 1995) and Instructional Model in Analogies (Glynn, 1991).

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