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The Effects of Analogy on Students' Understanding of Direct Current Circuits and Attitudes towards Physics Lessons

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This study investigated the effects of analogy on the elimination of students' misconceptions about direct current circuits, students' achievement and the attitudes towards physics lessons. The sample of this study consisted of 51 11th grade students from two different classes. While one of the classes was the experimental group where analogy was used in the lessons, the other class was the control group where the traditional methods are employed in lessons and this selection was made randomly. When the obtained results were examined, it was seen that teaching with analogy has a significantly positive effect on the elimination of misconception and achievement although it has almost no effect on the attitudes of towards physics.

Key Words: analogy, teaching, physics education, students, achievement

Simply stated, an analogy is a process of identifying similarities between two concepts. The familiar concept is called the analog and the unfamiliar science concept is called the target (Glynn, 1991), Many models have been presented regarding analogy by Brown and Clement (1989), bridging analogies, Dupin and Joshua (1989), the analogy teaching model, Glynn (1991) Teaching-With-Analogy (TWA) and Zeitoun (1984) the general model of analogy teaching. When using an analogy in the teaching of science, teachers should select an appropriate student world analog to assist in explaining the science concept. The analog and target share attributes that allow a relationship to be identified and contribute to the concept being taught; however, there are features of the analogy that are unlike the target, and these can cause impaired learning if incorrectly matched. Consequently, the use of analogies in the teaching of science does not always produce the intended effects, especially when students take the analogy too far and are unable to separate it from the content being learned. Some students only remember the analogy and not the content under study, while others focus on extraneous aspects of the analogy and draw spurious conclusions about the target concept.

Analogies are believed to aid student learning by providing visualisation of abstract concepts, by helping compare similarities of the students' real world with the new concepts, and by increasing students' motivation (Duit, 1991). Concrete analogs facilitate understanding of the abstract concept by pointing to similarities between objects or events in the students' world and the phenomenon under discussion. Analogies can be motivational in that, as the teacher uses ideas from the students' real world experience, a sense of intrinsic interest is generated. From a teaching perspective, the use of analogies can enhance conceptual change learning of science as they open new perspectives (Thiele and Treagust, 1995; Treagust et. al., 1996; Chiu and Lin, 2002; Dilber and Düzgün, 2008)

Despite their advantages and usefulness, analogies can cause incorrect or impaired learning, depending on the analog-target relationship. For example, if the analog is unfamiliar to the learner, development of systematic understanding is precluded. Although analogies may be more useful to students who primarily function at the concrete operational level (Gabel and Sherwood, 1980), if students lack

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visual imagery analogical reasoning may be limited. Students already functioning at a formal operational level may have an adequate understanding of the target and the inclusion of an analogy might add unnecessary information or noise (Johnstone and Al-Naeme, 1991). For these reasons, some teachers choose not to use analogies at all and thereby avoid these problems while, at the same time, forsaking the advantages of analogy use.

Unshared attributes between the analog and target are often a cause of misunderstanding for learners who attempt to transfer or map unshared attributes from the analog to the target. No analog shares all its attributes with the target, or, by definition, it would become an example; therefore, every analog breaks down somewhere. For instance, when electric currents in wires are compared to water flowing in pipes, some students conclude that electricity will leak out of a switched-on power point that has no plug in it. Indeed, some students try to transfer most or all of the analog structure into the target content and then describe the target content with direct reference to analog features. Other students may only remember the analogy and not the content under study. Nevertheless, a significant body of research suggests that although analogies are commonplace in human communication, they are not as effective in the classroom as might be expected (Duit, 1991). Uncritical use of analogies may generate misconceptions, and this is especially the case when unshared attributes are treated as valid, or when learners are unfamiliar with the analogy. Indeed, in using any analogy, care needs to be taken to ensure that an impression is not conveyed that the analog is a true description of the target concept (Harrison and Treagust, 1993; Curtis and Reigeluth, 1984).

Many students do not realise that analogies operate on two levels. In simple appearance matches or descriptive analogies, one or more superficial attributes of the analog corresponds with the target, whereas true inductive analogies share both superficial and higher-order causative relations (Gentner, 1983; Harrison and Treagust, 1994). Systemic similarities between the analog and target induce functional relationships in the target, which transfer the explanatory structure from the analog to the target. Superficial attributes promote analogy recognition, accessibility and recall, but produce little growth in knowledge (Zook, 1991). The systematic mapping of true inductive analogies promotes deep understanding, but is difficult for unskilled learners to transact. Because students have difficulty in recognising the relational and explanatory power of an analogy, they often miss the real point of the analogy, and this is an excellent reason for teachers to use a systematic approach when teaching with analogies (Keane *et. al*., 1994).

Many researchers have provided different perspectives of the functions of analogies (Chiu and Lin, 2005). According to Holyoak and Thagard (1995), scientific analogies have at least four distinguishable uses: discovery, development, evaluation, and exposition. Among them, the most exciting is discovery, in which the analogy contributes to the formation of a new hypothesis. Once a hypothesis has been formed, the analogy may facilitate further theoretical or experimental development. Analogy can also serve to form arguments for or against a hypothesis' acceptance, and then the analogy can convey the new ideas to other people. For instance, Benjamin Franklin (Chiu and Lin, 2005) derived not only the idea for his experiment but also the basic hypothesis that lightning is electricity by grasping the lightning/electricity analogy. He also used that analogy to develop experiments. This implies that scientific analogies have been and can be used for more than one function for particular purposes. Wong (1993) considered that generative analogies are dynamic tools that facilitate understanding, rather than representations of the correct and static explanations or solution. Other researchers (Harrison and Treagust, 1993; Brown, (1993) consider the use of analogies to be beneficial for conceptual change in science learning. Glynn *et al*. (1989) stated that analogies serve an explanatory and creative function. Duit (1991) also agrees with Glynn that analogical reasoning can facilitate understanding and problem solving. There is substantial support for Glynn's conclusion (Black and Solomon, 1987). However, there are some studies that conclude that findings on analogical reasoning are not particularly promising because most students are unable to employ analogical reasoning to solve similar problems regarding different phenomena, and learners are not able to “see” the analogy (Glynn, 1991; Gabel and Sherwood, 1980; Gick and Holyoak, 1983; Wong, 1993).

Analogies allow new material, especially abstracts concepts, to be more easily assimilated with students’ prior knowledge, enabling them to develop a more scientific understanding of the concept. Dagher (1994) reviewed several studies and comments on the role of analogies. She argues that although several studies claim that conceptual change occurred, analogies simply served as references for initial explanations or conjectures rather than bringing forth a conceptual change. Chi (2000) argues that analogies are considered a way of assimilating new knowledge to an existing structure and, therefore, is not a conceptual change.

Various studies have been conducted where children were observed and interviewed while learning about electric circuits and current. For instance, Osborne (1981) and Tiberghien (1983) point out those children aged 8–12 years tend to believe that batteries provide flashlight bulbs with some type of material to make them work. Again, Osborne and Freyberg (1985) showed that students in New Zealand aged eight to twelve years old used four learning models—the unipolar model, the clashing currents model, attenuation models and the scientific model—when exploring the different types of electrical current. Maichle (1981) found that 85% of the 400 secondary school students he studied considered that a battery is a reservoir for electricity or energy. Shepardson and Moje (1994) interviewed fourth graders and found that the majority of students understood the electric circuit via prior procedural and declarative knowledge. Before instruction, the students used more than one model and tended to use operational processes of procedure to describe an electrical circuit. After instruction, the students had a more precise procedural knowledge, but still had difficulty conceptualising the concepts of current with respect to parallel or series circuits. Magnusson, Boyle, and Templin (1997) argue that many studies have focused on serial connections; however, students might conceive serial or parallel connections differently. The researchers designed a variety of problems to explore students’ ideas of parallel circuits. The results showed that students mainly have eight mental models: the crossing currents model, the bipolar bouncing model, the bipolar serpentine model, the bipolar branch model, the bouncing model, the loop mode, the serpentine model and the scientific model.

Analogies are ubiquitous in physics. They are used by working physicists, physics teachers, and students learning physics. James Clerk Maxwell explicitly stated his belief that analogies were essential to his own work. In formulating a theory on electrical phenomena, 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” (Maxwell, 1890).

Some analogies may be both communicative and generative. David Bartlett has written recently on “Analogies between electricity and gravity” (Bartlett, 2004), providing an historical account and application of analogy. As a historical example, consider Rutherford’s planetary model of the atom (Taylor and Zafiratos, 1991). While the original utility was generative –producing a model that explained experimental results (which it accomplished more satisfactorily than competing analogies, such as the “plumb pudding” model of the atom) – the analogy is often used to communicate an introductory atomic model to physics students.

Therefore, analogies are not only useful to working physicists, but also to physics teachers. For instance, 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. Understanding how these analogies work is a rich area of physics educational research. Significant effort has gone into developing a theoretical framework for describing analogies, which is discussed in depth below. Simultaneously, experimentalists have asked specific research questions about the use of analogy in teaching physics concepts. For example, which analogy leads to better student learning about electric circuits –

water in a pipe, or a moving crowd? In the 18th century the first serious experimenters with electricity saw analogies between the flow of charge and the flow of water, an analogy that persists today in the term ‘electric current’ (Roland, 2006).

The purpose of this study was to examine the effectiveness of analogical instruction on students’ learning of electric concepts and how eliminate students’ misconceptions. The aim of this study was not to test the effectiveness of any analogical model. It was aimed to discover how the analogical instruction affected students’ success and their understandings of electric concepts.

Methods

Subjects: Participants in this study were 51 high school students who enrolled in the introductory physics courses, from the two classes of the same teacher. One class was randomly assigned to the experimental group (n = 27) while the other formed the control group (n = 24). These groups were selected according to an examination result by the school administrative committee. Therefore, the students in both groups have very similar knowledge levels. So, randomly selecting one of the groups as the control and the other as the experimental group. While the experimental group was taught with analogical instruction, the control group was taught with traditional instruction. During a five-week period, each group received an equal amount of instructional time and was provided with the same materials and assignments, apart from the analogical instruction that was used in the experimental group. The duration of the lessons was four 50-minute periods, and the language of the instruction used for both the experimental and control class was Turkish.

In this study, non-equivalent control group design is used to discover the effectiveness of the two different methods. The dependent variable was the students’ electric concept achievement measured by post concept test scores. The independent variable was the type of treatment referred to as ‘group’.

In this study, analogical instruction was used on the experimental group treatment. The analogies used were collected from the literature cited (Glynn, 1991; Dupin and Joshua, 1989; Chiu and Lin, 2005; Sağırlı, 2002).

Electric Concepts Test (ECT): The ECT test consisted of 12 items. The items of this test comprised three parts. In the first step, students were asked to give an answer to the question. In the second step, the reason of his/her answer to the first questions was asked, and in the third step the student was asked to reveal how confident she/he felt about the answers given to the first two questions. A blank box was added for students who had different ideas on the first two questions. In this study, the responses of the students who gave wrong answers to the first two questions and marked the “very confident” choice were accepted as misconceptions. Responses such as “fairly confident”, “not confident” and “just guessed” were not accepted as misconceptions, because the students who gave such answers may have forgotten the lesson, or may have given such responses because of a lack of knowledge.

During the development stage of the test, which constituted the qualitative part of the study, the following steps were taken into consideration: first, instructional objectives related to electric concepts were developed, based on the national curriculum. This step was carried out to define the content of the test. Literature related to the students’ alternative conceptions about the electric concept was then examined. The test was composed of questions that were intended to measure students’ understanding of different concepts related to electric concepts. In some cases, however, the same concept was tested using two different types of questions. All questions were piloted and the required modifications were made prior to the administration of the test. A group consisting of one professor of physics and two research assistants carried out the content validity of the test items. The reliability coefficient of the test was computed by Cronbach Alpha estimates of internal consistency, was found to be 0.69. The final form of the test was administered to both experimental and control groups as a pre-test before the treatment and post-test after the treatment. The questions in the text are about the amount of current, resistance connected series and parallel, brightness of the bulbs and conservation of current.

Attitude to Physics Scale: This scale was used to measure students' attitudes to physics. It consists of 15 likert-type items. Subjects were asked to express their agreement or disagreement on a five point scale (strongly agree, agree, undecided, disagree, strongly disagree). The reliability of the scale was found to be 0.83. The scale was administered to both experimental and control groups as a pre-test and administered to only the experimental group as a post-test after treatment. Three items on the scale in the following illustration are given as an example.

Attitude to Physics Scale

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
I like reading books related to Physics					
I like solving Physics problems					
I would like to learn more about Physics subjects					

Procedure: In this study, the same topics were covered for both the experimental and control groups. In general, students were given equal opportunities to perform the activities in each group. The control group received traditional instruction, which involves lessons using lecture/discussion methods to teach the concepts. Teaching strategies relied on teacher explanation and textbooks, with no direct consideration of the students' alternative conceptions. The students studied the textbooks individually before the class hour. The teacher structured the entire class as a unit, wrote notes on the chalkboard about the definition of concepts, and handed out worksheets to students for them to use to complete the treatment. The teacher described and defined the concepts and after teacher explanation, some concepts were discussed and were directed by teacher-directed questions. The majority of the instruction time was devoted to instruction and engaging in discussion stemming from the teacher's explanation and questions.

Students in the experimental group worked with analogical instruction. Glynn's Teaching-With-Analogy (TWA) model was used to teach each topic and topics were developed from an analysis of science textbooks to provide the most adaptable to classroom teaching (Harrison and Treagust, 1993). During the instruction time, the step-by-step TWA model was used and six such analogies were analysed (see Appendix). During the instruction, some analogies were showed directly to students in the classroom by using the required tools; for example; train, aquarium, u-pipe and water circuits-electric circuit analogies. However, the pictures of other analogies were drawn on the blackboard and presented to the students. During the presentation of the analogies in the classroom, students were assisted to both join the lesson and make a connection between basic electricity concepts and analogies with the help of a few questions. In this way, we contributed to the maximum participation of students in the lessons. At the end of the presented analogies (after the discussion between the students) the teacher explained the similarities and differences between the analog and target concepts again. Therefore, the students who made an incorrect connection between the analog and target concepts were able to re-organise their opinions.

Results

In this study, the independent group t-test was used in order to compare the effectiveness of analogical instruction and traditionally designed physics instruction with respect to students' understanding of electric concepts. The dependent variable was the students' electric concept achievement measured by Post Electric Concept Test Scores (POSTECA). The independent variable was students' Pre Electric Concept Achievement (PREECA) measured by pre electric concept test scores.

Table 1. Independent group t-test results for pre and post test scores of concept test

	PREECA		POSTECA	
	Experimental Group	Control Group	Experimental Group	Control Group
N	27	24	27	24
Mean	3.81	3.62	8.41	6.21
Standard Deviation	0.92	1.01	0.69	2.06
t	0.69		4.97	
p	P>0.05		P<0.00	

As seen in Table 1, in the pre-test, there are no statistical differences between the experimental and control groups in terms of success. This means there were no differences between the control and experimental group in terms of knowledge about the topic at the beginning of the study. Again in Table 1, after treatment according to the post-test results there are significant statistical differences between the experimental and control groups, which indicate the successful nature of the experimental group, compared to the control group. While the correct answer percentage of experimental group was 31.75% for the pre-test, the correct answer percentage has been 70.8% for the post-test. These results indicated that the success percentage of experimental group was considerably increased after treatment. For the control group, the correct answer percentage of control group was 30.1% for the pre-test, after treatments the correct answer percentage reached 51.75% for the post test. So, it indicated that the success rate of control group, which were learned the topic in traditional way, was increased slightly. According to pre-test results, there are no statistical difference between control and experimental group's students in terms of the achievement. (as seen Table 1, $P>0.05$). After treatment, experimental group's students showed better performance than control group's students. This success ratio caused significant statistical difference favor of experimental group ($P<0.05$).

According to the results, conceptual misunderstandings were not eliminated completely in the two groups, although the experimental group's misunderstandings were reduced more than in the other group.

Table 2. Percentages of the misconceptions according to pre and post test scores

Questions		1	2	4	3	5	6	7	8	9	10
Experimental Group (%)	Pre-test	37 (10)	33.3 (9)	40.7 (11)	29.6 (8)	44.4 (12)	22.2 (6)	29.6 (8)	48.1 (13)	37 (10)	40.7 (11)
	Post-test	14.8 (4)	14.8 (4)	18.5 (5)	18.5 (5)	11.1 (3)	03.7 (1)	18.5 (5)	18.5 (5)	11.1 (3)	-----
Control Group (%)	Pre-test	37.5 (9)	29.2 (7)	33.3 (8)	37.5 (9)	50 (12)	25 (6)	33.3 (8)	41.7 (10)	41.7 (10)	45.8 (11)
	Post-Test	29.2 (7)	25 (6)	20.8 (5)	29.2 (7)	41.7 (10)	20.8 (5)	25 (6)	37.5 (9)	37.5 (9)	29.2 (7)

( ): Students' numbers having misconceptions for two groups before and after instruction.

Table 3. Percentages of the success of experimental and control groups' students (pre and post-test)

Questions		1	2	3	4	5	6	7	8	9	10
Experimental Group (%)	Pre-test	37 (10)	29.6 (8)	33.3 (9)	37 (10)	33.3 (9)	44.4 (12)	33.3 (9)	44.4 (12)	40.7 (11)	48.1 (13)
	Post-test	81.5 (22)	77.8 (21)	74.1 (20)	81.5 (22)	81.5 (22)	96.3 (26)	77.8 (21)	81.5 (22)	88.9 (24)	100 (27)
Control Group (%)	Pre-test	37.5 (9)	33.3 (8)	29.2 (7)	41.7 (10)	33.3 (8)	45.8 (11)	29.2 (7)	29.2 (7)	37.5 (9)	45.8 (11)
	Post-Test	66.7 (16)	62.5 (15)	62.5 (15)	66.7 (16)	54.2 (13)	70.8 (17)	66.7 (16)	54.2 (13)	58.3 (14)	58.3 (14)

( ): Students' numbers

As seen in Table 3, the experimental and control groups students' correct answers rates for diagnostic test to pre-test and post-test are shown. Generally before the instruction both of two groups correct answers ratio are similar (experimental group 38.1% and control group 35.25%). According to the pre-test scores, there is no significant statistical difference between the two groups (as seen in Table I). Nevertheless, as seen in Table 3, after the instruction, the rates of the experimental groups' correct answers considerably increased; but the control group students' correct answers did not increase at the same rate as that of the experimental group (experimental group 84.09% and control group 62.09%).

Table 4. Independent group t-test results for pre and post test scores of the attitude test

PREATP	N	Mean (points)	Standard Deviation	t	p
Experimental group	27	52.22	12.81	-0.35	0.72
Control group	24	53.33	10.21		
POSTATP					
Experimental group	N	Mean (points)	Standard Deviation	t	p
Pre-test	27	52.22	12.81	-1.93	0.06
Post-test	27	55.18	8.37		

PREATP: Pre Attitude Test Towards Physics, POSTATP: Post Attitude Test Towards Physics

As seen in Table 4, according to the pre-test results, there were no meaningful statistical differences between the control and experimental groups on the students' attitudes towards physics. After treatments, the analogical instruction has no effects on the experimental group's attitudes towards physics.

Discussion

The main purpose of the present study was to determine whether or not an instructional manipulation that was designed to facilitate conceptual change and learning about electric concepts would improve students' performance. Research related to instruction that is designed to remove students' alternative conceptions focused on strategies to promote conceptual change by challenging students' alternative conceptions, causing dissatisfaction followed by a correct explanation that is both understandable and plausible to the students. We hypothesised that the students using the analogical instruction would demonstrate better conceptual understanding of the electric concept than students exposed to traditionally designed instruction. As hypothesised, the analogical instruction did lead to better conceptual understanding of electric concepts. These results confirm the findings of previous studies in that an analogical instruction can facilitate the learning of scientific concepts (Glynn, 1991; Dupin and Joshua, 1989; Thiele and Treagust, 1995; Harrison and Treagust, 1993; Chiu and Lin, 2005; Brown, 1993; Thiele and Treagust, 1994).

A new approach to change misconceptions of students is to build on ideas which match their students' existing intuitive knowledge. This can be done by analogy. The use of an analogical relation between the known and the unknown can help students learn new information and discard or modify misconceptions (Stavy,2006). The results from this study suggest that analogical instruction helped students to change their pre-existing conceptions or alternative conceptions with the scientific conceptions by activating their alternative conceptions, producing dissatisfaction and presenting a correct explanation that is both understandable and plausible.

The current study revealed that some alternative conceptions were still held onto, even in the experimental group after treatment. Chinn & Brewer (1993) explained why conceptual change is so difficult. Given information that contradicts a strongly held belief, an individual can ignore it, trivialise it, compartmentalise it, hold it in abeyance, change an insignificant part of the current belief but otherwise keep it intact, or undergo a more complete conceptual change.

The analogical instruction did not make a significant difference to the experimental group students' attitudes towards physics after treatments. It can be said that the teaching methods do not effective factor on students' attitude in a short time.

The results demonstrated that using analogies both promoted profound understanding of complex scientific concepts and it helped students to overcome their misconceptions of these concepts. According to pre and post test results, in the pre-test the correct answers rates of the two groups are very similar (there is no statistical difference). At the post-test, the control group's correct answers ratios increased by considerable rates, although in the control group's increase is limited. Wong (1993) considered generative analogies to be dynamic tools that facilitate understanding. Other researchers (Harrison and Treagust, 1993; Wong, 1993) consider the use of analogies to be beneficial for conceptual change in the learning of science. Duit (1991) also stated that analogical reasoning can facilitate understanding and problem solving.

Conclusion

The study shows that analogical instruction when applied to physics students will affect their understanding of physics concepts. These efforts all contribute to the broad effort by the physics education research community to enhance instruction through a better understanding of student learning. This study has shown that when analogical instruction is used in a systematic manner, students' understanding of electric concepts and elimination of misconceptions is more enhanced than with traditional instruction.

Science teachers can often use analogical instruction in their classroom to enhance students' understandings and eliminate misconceptions. While using analogical instruction, analogies should address the correspondence of its attributes and the relationships between the target concepts in order to make the connections more explicitly, the science teacher must become familiar with students' difficulties in understanding scientific concepts in order to design meaningful materials to provide meaningful learning. In short, when analogical instruction is used, it is highly probable that these lead to a significantly improved understanding of scientific conception and the elimination of alternative conceptions.

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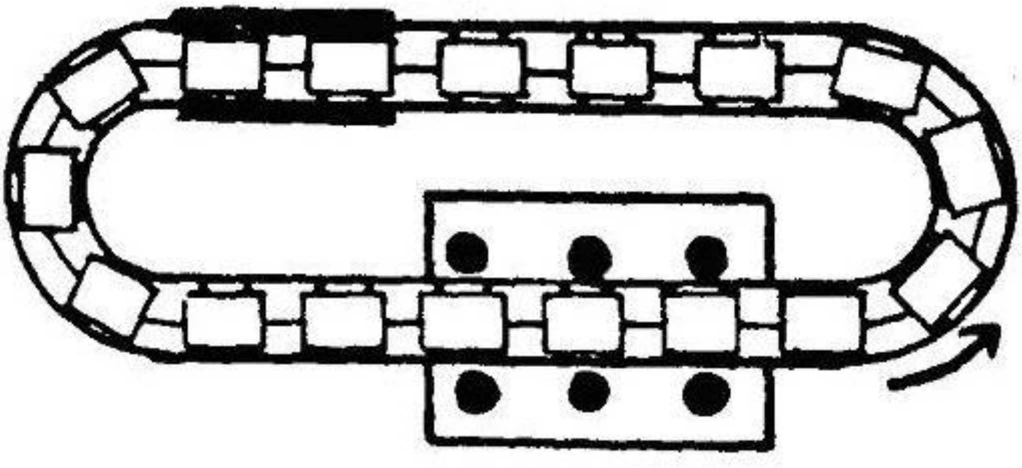
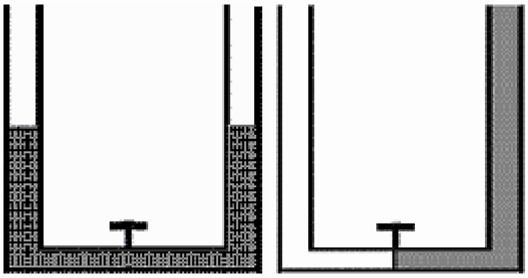
Appendix. The Analogies Used In This Study

1. Train Analogy



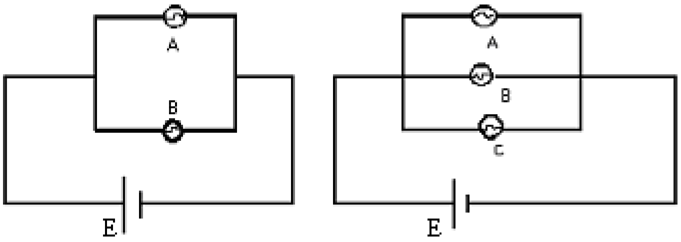
Train Electricity
cars -- electricity
cars movement -- electric current
cars flow -- current intensity
obstacles -- resistance
closed railway circuits -- electric circuits
pushing workers -- power supply
muscular fatigue -- battery wearing down
(Dupin and Johsua 1989)



Analog Target
U – pipe -- cell
water -- electricity
water level difference -- potential difference
water flow -- electric current
glass pipe -- conductor wire
at the same water level in the pipe -- same potential difference between the two poles of the cell
(Sağırlı 2002)

2. Sample Question

Q1. Consider the following circuits. Lamps A, B and C are identical. What would happen to the brightness of bulbs A and B in the circuits if bulb C is added to the circuits?



a. The brightness of both lamps get lower.

b. The brightness of both lamps gets higher.

c. The brightness of both lamps does not change.

How would you explain this?

☐ The current in both lamps gets lower, so the brightness of both lamps gets lower.

☐ The current in both lamps gets higher, so the brightness of both lamps gets higher.

☐ The current that pass through the circuits does not change, so the brightness of the lamps does not change.

☐ The potential differences across the lamps do not change, so the brightness of the lamps does not change.

If you have a different idea, please write it in the following blanks with your reasons.

☐ …………………………..

How confident are you that your answers to this question are correct?

a) very confident, b) fairly confident, c) not confident, d) just guessing