

Effectiveness of Analogy on Students' Success and Elimination of Misconceptions



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Abstract

This study investigated the effects of analogy instruction on students' success and removing misconceptions as compared with traditional instruction. The sample of this study consisted of 78 high school students from two classes enrolled in an introductory physics course. These students are about 15-16 years old. One of the classes was assigned randomly to the control group, and the other class was assigned to the experimental group. During teaching the topic of electric concepts in the physics curriculum, analogical instruction was applied in the experimental group whereas traditional instruction was followed in the control group. The results showed that the students in the experimental group performed better performance with respect to electric concepts than control groups' students.

Keywords: Analogical instruction, misconceptions, success, conceptual change and physics education.

Resumen

Este estudio investigó los efectos de la instrucción analógica en el éxito de alumnos y la remoción de errores conceptuales comparados con la instrucción tradicional. La muestra del estudio consiste de 78 alumnos de secundaria de dos clases matriculados en un curso de física introductoria. Estos estudiantes son de edades entre 15 y 16 años. Una de las clases fue asignada al azar como grupo control, y la otra clase fue asignada como grupo experimental. Durante la enseñanza de tópicos de conceptos de electricidad en el currículo de física, se aplicó la instrucción analógica en el grupo experimental mientras que en el grupo control se siguió con la instrucción tradicional. Los resultados muestran que los alumnos en el grupo experimental tuvieron un mejor desempeño en conceptos de electricidad que los alumnos del grupo de control.

Palabras clave: Instrucción analógica, errores conceptuales, éxito, cambio conceptual y educación en física.

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I. INTRODUCTION

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 [1]. Many models have been presented regarding analogy by Brown and Clement [2] bridging analogies, Dupin and Johsua [3] analogy teaching model, Glynn [1] Teaching-With-Analogy (TWA) and Zeitoun [4] general model of analogy teaching. When using an analogy in science teaching, 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 analog which are unlike the target, and these can cause impaired learning if incorrectly matched. Consequently, the use of analogies in science teaching 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

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learned. Some students only remember the analogy and not the content under study, while others focus upon extraneous aspects of the analogy and draw spurious conclusions about the target concept.

Analogies are believed to help student learning by providing visualization of abstract concepts, by helping compare similarities of the students' real world with the new concepts, and by increasing students' motivation [5]. 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 science they open new perspectives [6, 7, 8].

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 [9], if students lack 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 [10]. 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 analog and target are often a cause of misunderstanding for learners who attempt to transfer or map unshared attributes from the analog to 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 [5]. Uncritical use of analogies may generate misconceptions and this is especially so when unshared attributes are treated as valid, or where 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 target concept [11, 12].

Many students do not realize that analogies operate at 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 [13, 14]. Systemic similarities between analog and target induce functional relationships in the target which transfer explanatory structure from the analog to the target. Superficial attributes promote analogy recognition, accessibility, and recall but produce little growth in knowledge [15]. The systematic mapping of true inductive analogies promotes deep understanding but is difficult for unskilled learners to transact. Because students have difficulty recognizing 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 [16].

Many researchers have provided different perspectives of the functions of analogies [17]. According to Holyoak and Thagard [18], 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 analogy can convey the new ideas to other people. For instance, Benjamin Franklin [17] 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 [19] considered that generative analogies are dynamic tools that facilitate understanding, rather than representations of the correct and static explanations or solution. Other researchers [11, 20, 47] consider the use of analogies beneficial for conceptual change in science learning. Glynn *et al.* [21], stated that analogies serve an explanatory and creative function. Duit [5] also agrees with Glynn that analogical reasoning can facilitate understanding and problem solving. There is substantial support for Glynn's conclusion [22]. However, there are some studies that conclude that findings on analogical reasoning are not especially 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 [2, 9, 23, 24].

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 concept. Dagher [25] reviewed several studies and comments on the role of analogies. She argues that although several studies claim conceptual change occurred, analogies simply served as references for initial explanations or conjectures rather than bringing forth a conceptual change. Chi [26] argues that analogies are considered a way of assimilating new knowledge to an existing structure and, thus, 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 [27] and Tiberghien [28] 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 [29] show that students ages eight to twelve years old in New Zealand used four learning models—unipolar model, clashing currents model, attenuation models, and scientific model—when exploring the different types of electrical current. Maichle [30] 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 [31] interviewed fourth graders and found that a 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 more precise procedural knowledge but still had difficulty conceptualizing the concepts of current with respect to parallel or series circuits. Magnusson, Boyle, and Templin [32] 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: crossing currents model, bipolar bouncing model, bipolar serpentine model, bipolar branch model, bouncing model, loop mode, serpentine model, and 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 feeling that analogies were essential to his own work. In formulating a theory of 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.” [33].

On an analogy between heat conduction and electricity, Maxwell wrote that “The similarity is a similarity between relations, not a similarity between the things related.” [34]. Over a century later, this idea is reflected in contemporary theories of analogy.

Some analogies may be both communicative and generative. David Bartlett has written recently on “Analogies between electricity and gravity” [35], providing an historical account and application of analogy. As an historical example, consider Rutherford’s planetary model of the atom [36]. While the original utility was generative – producing a model that explained experimental results (which it accomplished better 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.

Thus, analogies are not only useful to working physicists, but to physics teachers as well. 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 education research. A significant effort has gone into developing a theoretical framework for describing analogies, 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’ [37].

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 learn how the analogical instruction affected students’ success and their understandings of electric concepts.

II. MATERIALS AND METHODS

Subjects: Participants in this study were 78 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 ($n = 40$) while the other formed the control group ($n = 38$). These groups were selected according to an examination result by school administrative committee. Therefore, both groups’ students have very similar knowledge levels. So, selecting one of the groups as control and the other as experimental group randomly is not a problem. While the experimental group was taught with the analogical instruction, the control group was taught with traditional instruction. During a four-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 in the experimental group. Duration of the lessons was four 50-min periods and the language of the instruction used for both the experimental and control class was Turkish.

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

Materials: In this study, analogical instruction was used on the experimental group treatment. The analogies used were collected from the literature cited [1, 3, 17, 38].

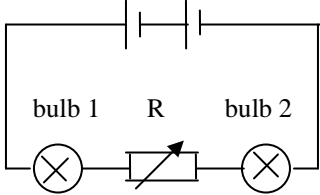
Electric concepts test (ECT): The ECT test consisted of 12 items. The items of this test comprised three parts. In the first step, students are asked to give an answer to the question. In the second step, the reason of his/her answer to the first questions is asked and in the third step, the student is asked to reveal how confident she/he is about the answers given to the first two questions. A blank box is added for the students who have different ideas on the first two questions. One example of test questions is presented in Figure 1. 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. The responses like “Fairly confident”, “Not confident” and “just guessed” were not accepted as misconceptions because the students who gave such answers may have forgotten the subject or may have given such responses because of the 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 students’ alternative conceptions about 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 0.75. 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 amount of current, resistance connected series and parallel, brightness of the bulbs, conservation of current.

Q1. This circuit consists of two bulbs and a variable resistor, R. Both bulbs are lit.



a) The resistance of R is increased.

What will happen to the brightness of bulb 1? Tick ONE box ()

What will happen to the brightness of bulb 2? Tick ONE box ()

It will get brighter
 It will stay the same
 It will get dimmer

It will get brighter
 It will stay the same
 It will get dimmer

b) Tick ONE box () below to explain your reason for choosing these answers.

Increasing R makes the current smaller all round the circuit.
 Increasing R makes the current smaller after it. It has no effect on a bulb before it.
 Increasing R makes the current smaller after it. So the current before it gets bigger.
 The battery always supplies the same current to the circuit.

How confident are you that your answers to these questions are correct? Tick ONE box ()

Very confident	Fairly confident	Not confident	Just guessing

Procedure: In this study, the same topics were covered for both 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 passed out worksheets to students for completing 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 instruction time was devoted to instruction and engaging in discussion stemming from the teacher's explanation and questions.

The remaining time was taken up with a worksheet study. Worksheets developed specifically for each lesson were used as practice activities; they required written responses and reinforced the concepts presented in the classroom sessions. While the students were studying worksheet exercises, the teacher circulated and provided assistance if needed. The students had the opportunity ask questions, and the teacher was available to both answer questions and make suggestions. The worksheets were collected and corrected by the teacher, and the students reviewed their sheets after correction.

Students in the experimental group worked with analogical instruction. Glynn's Teaching-With-Analogy (TWA) model to teach each topic was used and topics were developed from an analysis of science textbooks to provide the most adaptable to classroom teaching [11]. At the instruction time, the step-by-step TWA model was used and six such analogies were analyzed (see Appendix). During the instruction, some analogies were showed directly to

students in classroom by using needed tools; for example; train, aquarium, u-pipe and water circuits-electric circuit analogies. However, the pictures of other analogies were drawn on the blackboard to be presented to the students. During the presentation of the analogies in the classroom, students were assisted to both join the lesson and make relation between basic electricity concepts and analogies by the help of some questions. By this way, we contributed to maximum participation of students in the lessons. At the end of the presented analogies (after the discussion between students) the teacher explained the similarities and differences between analog and target concepts again. So the students who found incorrect relation between analog and target concepts re-organized their opinions.

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TABLE I. 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	40	38	40	38
Mean (12 item)	7.05	7.8	10.8	8.7
Standart Deviation	1.64	1.68	0.97	0.90
t	-0.77		9.12	
p	>0.05		<0.05	

PREECA: Pre electric concept test. POSTECA: Post electric concept.

As seen in Table I, in the pre-test, there is no statistical differences between experimental and control groups in terms of success. It means there were no differences between the control and experimental group in terms of knowledge about the topic at the beginning. Again in Table I, after treatment according to the post-test results there are meaningful statistical difference between experimental and control groups indicating the successful nature of the experimental group compared to the control group.

While the correct answer percentage of experimental group was approximately 58.25% for the pre-test, for the post test the correct answer percentage has been approximately 90%. These results indicated that the success percentage of experimental group was considerably increased after

III. 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 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.

treatment. While the correct answer percentage of control group was approximately 65% for the pre-test, the correct answer percentage reached approximately 72.5% 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, control group's students are more successful than experimental group's students. But this situation didn't cause significant statistical difference favour of control group (as seen Table I, $P > 0.05$). After treatment, experimental group's students showed better performance than control group's students. This success ratio caused significant statistical difference favour of experimental group ($P < 0.05$).

TABLE II. Percentages of the misconceptions according to pre and post test scores.

Questions	1	2	3	4	5	6	7	8	9	10	11	12	
Experimental group (%)	Pre-test	55 (22)	47.5 (19)	50 (20)	37.5 (15)	42.5 (17)	52.5 (21)	32.5 (13)	40 (16)	30 (12)	35 (14)	25 (10)	22.5 (9)
	Post-test	15 (6)	17.5 (7)	20 (8)	12.5 (5)	10 (4)	7.5 (3)	2.5 (1)	7.5 (3)	5 (2)	10 (4)	5 (2)	7.5 (3)
Control Group (%)	Pre-test	60.5 (23)	68.4 (26)	47.3 (18)	50 (19)	39.4 (15)	44.7 (17)	36.8 (14)	36.8 (14)	42.1 (16)	44.7 (17)	21 (8)	28.9 (11)
	Post-test	28.9 (11)	34.2 (13)	21 (8)	23.6 (9)	18.4 (7)	15.7 (6)	10.5 (4)	13.1 (5)	18.4 (7)	13.1 (5)	7.8 (3)	5.2 (2)

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

According to results, conceptual misunderstandings were not eliminated completely in two groups, but the

experimental group's misunderstandings were reduced more than other group.

TABLE III. 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	11	12
Experimental group (%)	Pre-test	54	46	45.3	61.7	64.7	56.2	73.5	53.5	64.3	58.2	63.2	76.9
	Post-test	91.3	84.7	83	86.9	82	94.5	97.8	82.6	95.6	93.6	97.8	96
Control Group (%)	Pre-test	58.3	48.6	62.4	57.2	58.2	66.8	85.9	64.3	59.3	61	83.8	69.5
	Post-test	69.1	57.1	67.3	76.5	63.2	75.5	96.5	58.1	77.5	79	88	74

As seen in Table III, 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 58.25 % and control group 65%). According to the pre-test scores, there is no significant statistical difference between the two groups. Nevertheless, as seen in Table III, after the instruction, the rates of experimental groups' correct answers considerably increased; but control group students' correct answers didn't increase at the same rate as that of the experimental one (experimental group 90% and control group 72.5%).

IV. DISCUSSION

There is considerable evidence [26] that students in science courses have confronted difficulties understanding complex and abstract concepts at a qualitative level. Most often, these concepts are contradictory to personal experiences in daily life. This phenomenon is not unique to physics but is also seen in chemistry and biology. To overcome these inconsistent conceptions of scientific concepts, many interventions were designed to challenge those conceptions. Among them, analogies were considered to be powerful for theory construction, mental model change, concept understanding and reasoning [17, 39].

The main purpose of the present study was to determine whether an instructional manipulation was designed to facilitate conceptual change and learning about electric concepts would improve students' performance. Research related to instruction which 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 which is understandable and plausible to the students. We hypothesized that those students using the analogical instruction would demonstrate better conceptual understanding of electric concept than students exposed to traditionally designed instruction. As hypothesized, 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 learning of scientific concepts [1, 3, 8, 11, 17, 20, 40, 41, 48, 49].

The results from this study suggest that analogical instruction helped students change their pre-existing conceptions or alternative conceptions with the scientific ones by activating their alternative conceptions, producing dissatisfaction and presenting a correct explanation which is both understandable and plausible.

Analogies were helpful for learning abstract and complex concepts of electricity. As delineated earlier, the analogies served several functions in promoting conceptual understanding: namely supplementation, correction, alteration, enhancement, magnification, perspective shift, competition and sequential collocation [17, 42].

The current study revealed that there were still some alternative conceptions held onto, even in the experimental group after treatment. Chinn & Brewer [43] explained why conceptual change is so difficult. Given information that contradicts a strongly held belief, an individual can ignore it, trivialize it, compartmentalize 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.

A growing amount of research has shown that the use of analogies in science teaching and learning promotes meaningful understanding of complex scientific concepts [11, 13, 24, 44, 45]. The results demonstrated that using analogies both promoted profound understanding of complex scientific concepts and it helped students overcome their misconceptions of these concepts. According to pre and post test results, in pre-test both of two group correct answers rates are very similar (there isn't statistical difference). At the post-test control group's correct answers ratios are increased considerable rates but in control group's increasing is limited. Wong [24] considered that generative analogies dynamic tools that facilitate understanding. Other researchers [11, 19, 46] consider the use of analogies beneficial for conceptual change in science learning. Duit [5] also stated that analogical reasoning can facilitate understanding and problem solving.

CONCLUSION

This paper has briefly surveyed the effectiveness of analogical instruction on students' understandings of electric concepts. The analogical instruction when applied to physics, students' generate 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' understandings of electric concepts and elimination of misconceptions are more enhancing than traditional instruction.

Science teachers can use often 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 relationships between the target concepts in order to make the connections more explicitly, science teacher must become familiar with students' difficulties in understandings a 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 cause significantly better understandings of scientific conception and elimination of alternative conceptions.

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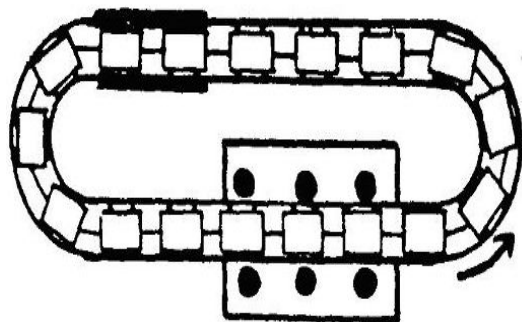
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1

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

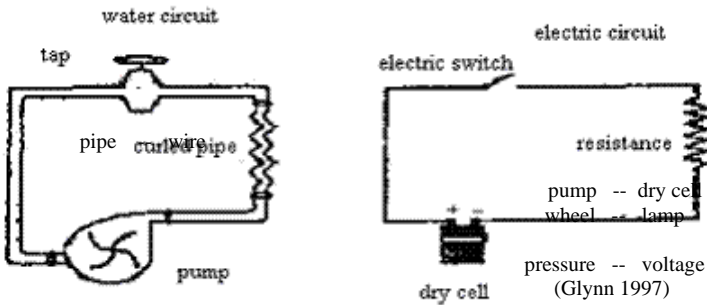
(Dupin and Johsua 1989)

2. An analogy is founded between basic electric circuit and aquarium

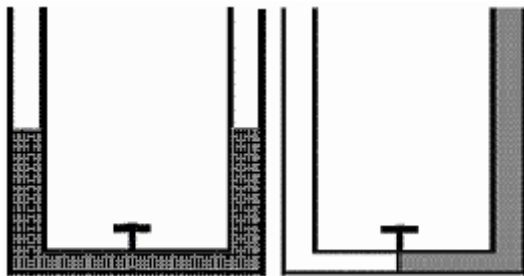
Analog	Target
water	-- electricity
water flow	-- electric current
water pipes	-- conductor wire
water pump	-- Battery
pressure	-- Voltage
water filter	-- weak conductor
slow down water	-- resistance

(Glynn *et al.* 1996)

3. An analogy is founded between water circuit and electric circuit



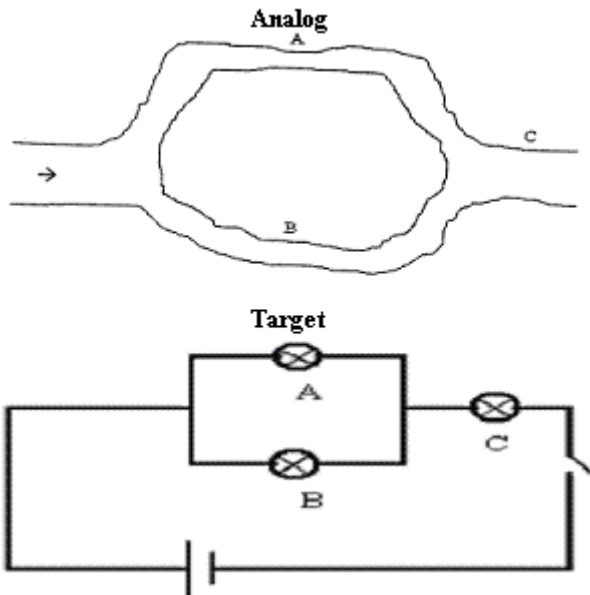
Analog	Target
water	-- electricity
water flow	-- electric current
curled pipe	-- resistance
tap	-- electric switch



Analog	Target
U – pipe	-- cell
water	-- electricity
Water level difference	-- Potential difference
water flow	-- electric current
glass pipe	-- conductor wire
at the same level water in pipe	-- same potential difference between two pole of the cell

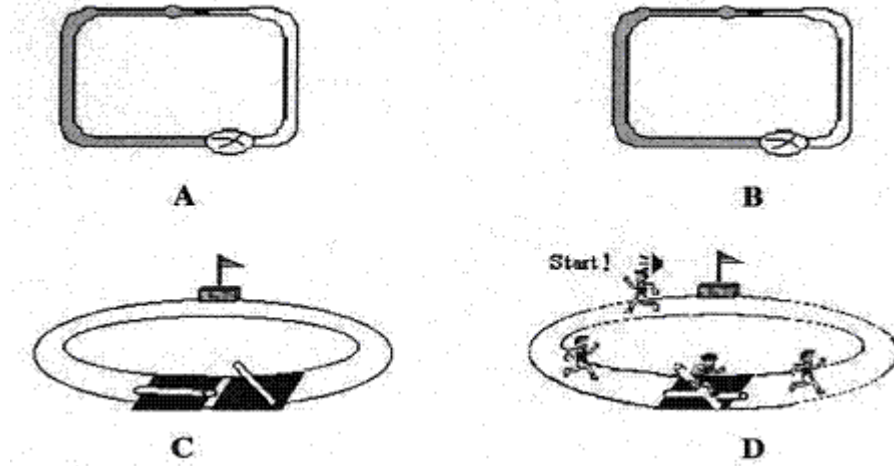
(Sağırılı 2002)

5. An analogy founded between brightness of the bulbs and water flowing in the river.



In this analogy, the current shared two wires is imitated water in a river separated two branch. Here the electric current is imitated flowing water in the river. At the above electric circuit, the bulbs are identical. The brightness of the bulbs depend the current on the bulbs. The analogy founded between current portion on the lambs and the flowing water portion of the A, B, C points in the river.
(Sağırılı 2002)

6. Water flow and block running analogies



(Chiu and Lin 2005)