TÜRK FEN EĞİTİMİ DERGİSİ
Yıl 12, Sayı 1, Mart 2015

Journal of
TURKISH SCIENCE EDUCATION
Volume 12, Issue 1, March 2015

http://www.tused.org

Rectifying Analogy-Based Instruction to Enhance Immediate and Postponed Science Achievement

Maymoona AL-HINAI[1], Sulaiman AL-BALUSHI[2]

[1] Science Supervisor, Ministry of Education, OMAN
[2] Assoc. Prof., Sultan Qaboos University, College of Education, Muscat-OMAN

Received: 31.10.2013 **Revised:** 22.01.2015 **Accepted:** 15.02.2015

The original language of article is English (v.12, n.1, March 2015, pp.3-17, doi: 10.12973/tused.10129a)

ABSTRACT

The aim of this study was to examine the impact of analogy-based instruction on immediate and postponed science achievement. More specifically, the focus of the current study was on the retention of students at three cognitive levels: knowledge, comprehension and application. Two classes of 63 ninth grade female students in Oman participated in the study. These classes were randomly assigned to an experimental group (N=32) which used analogy-based instruction and a control group (N=31) which used the traditional method. An achievement test was designed at the three cognitive levels and was administered to both groups immediately after the conclusion of the study which lasted for five weeks and once again two weeks later. In the immediate administration of the test, the findings indicated that the experimental group significantly outperformed the control group in terms of two cognitive levels, comprehension and application, and also in the overall score of the test. In the postponed test, the experimental group outperformed the control group in all three levels and in the overall score. Also, there was a substantial decline in control group students' scores in the three cognitive levels and in the overall test score. This was not the case for the students in the experimental group. We have listed several justifications for these findings, recommendations for science teachers and textbook writers, limitations of the study and ideas for further research in the section headed "Conclusions and recommendations" below.

Keywords: Analogy-Based Instruction; Application; Comprehension; Immediate Achievement; Knowledge, Oman; Postponed Achievement.

INTRODUCTION

An epistemological difficulty that many students face with a considerable number of scientific concepts is the high level of abstractness associated with these concepts (Al-Balushi, 2011; Harrison & Treagust, 2000; Şekercioğlu & Kocakülah, 2008). Consequently, some students start to question the credibility of scientific models that represent natural entities and phenomena. Some doubt the ability of scientists to construct reliable models for highly abstract entities. The high level of spatial relations involved in some of these abstract entities and phenomena makes some low spatial ability students deny the existence of these entities and phenomena (Al-Balushi, 2011, 2012). Therefore, this high level of abstractness needs to be loosened so that students become able to visualise what scientists mean by the

Corresponding author e-mail: sbalushi@squ.edu.om

© ISSN:1304-6020

models they construct to make us better understand and predict the world around us. One way to do so is using pedagogical analogical models (Harrison & Treagust, 2000), or what are commonly known as analogies. It is a process of establishing similarities between a familiar concept (analogue) and a new concept (target) (Dilber & Duzgun, 2008).

Along with scientific models, analogies have played a crucial role in the development of meaning in science and its progress and have been an essential element of scientific theories and explanations (Guerra-Ramos, 2011; Harrison & Treagust, 1993; Marcelos & Nagem, 2010). The work of Boyle, Carnot, Darwin, Faraday, Kepler and Maxwell, for instance, reflects an extensive use of analogies in the construction of scientific models and theories. Besides their role in the construction of knolwedge, analogies facilitate the organisation, examination and communication of knowledge (Yilmaz & Eryilmaz, 2010). Marcelos and Nagem (2010) lists a number of classifications of analogies compiled by researchers; among which, structural and functional analogies are the most common.

Gentner et al. (1997) argue that using analogies is an everyday practice of science and, in doing that, successful conceptual change takes place and creativity is fostered. Analogies enable students to reconstruct their understandings (Nashon, 2004). Analogies enhance the visualisation of abstract concepts by learners, making them more tangible (Thiele & Treagust, 1994). If introduced effectively, analogies present scientific knowledge as plausible and intelligible and make abstract concepts more comprehensible and visualisable (Dilber & Duzgun, 2008; Marcelos & Nagem, 2010; Paris & Glynn, 2004). These are some conditions for conceptual change to take place as proposed by Posner and colleagues (cited in Khourey-Bowers, 2011).

Studies have shown that analogy-based instruction has a positive impact on students' learning of science (Guerra-Ramos, 2011; Harrison & Treagust, 1993; Sarantopoulos & Tsaparlis, 2004). This is, in most part, due to the fact that everyday entities and situations are frequent sources for analogies (Sarantopoulos & Tsaparlis, 2004). Learners' familiarity with these everyday entities and situations makes analogies more effective in bridging the gap between a familiar and concrete domain (analogue) and an unfamiliar and abstract domain (target). The process of finding the correspondences between the two systems, which is called mapping or matching, is what makes analogies an effective mental tool that loosens the abstractness of the newly introduced scientific entities and phenomena. They facilitate bridging between abstract and concrete learning experiences and provide students with an easy-to-imagine mental model. Thus, teachers use analogies to integrate previous knowledge into the new learning experience by activating related schemata and to help explain complex phenomena or processes (Clement, 2003). Their power lies in their ability to embrace a whole system of relations and features within the target phenomenon.

Analogies also act as a memory aid which promotes retention of new abstract target concepts (Glynn & Takahashi, 1998; Guerra-Ramos, 2011; Paris & Glynn, 2004). They enhance students' intrinsic motivations (Dilber & Duzgun, 2008) by building up their confidence in their ability to tackle difficult concepts (Guerra-Ramos, 2011). In addition, using carefully crafted analogies helps overcome students' misconceptions (Yilmaz & Eryilmaz, 2010). It has been reported that lower cognitive development (concrete) students benefit more from analogies than higher cognitive development (formal) students (Glynn & Takahashi, 1998; Sarantopoulos & Tsaparlis, 2004). Analogies also attract curious students, who are more actively engaged in exploratory activities than formal passive classroom settings (Sarantopoulos & Tsaparlis, 2004).

Analogies could be enhanced more to support students' construction of scientific knowledge by associating them with pictorial representations that resemble the analogy and facilitate the comparisons between the analogue and the target concept. Accompanying analogies with pictorial representations takes advantage of the role imagery plays in learning and assists students to create a visual mental model for the concept under study. This mental process supports the systematic mapping of verbal and visual shared features between the analogue and the target concept, that is, between what is already known to students and what is new for them (Paris & Glynn, 2004). It is worthy of note that research indicates that static analogies, which are sketched analogies, work as effectively as dynamic analogies, which are animated computerised sketched analogies, in promoting students' understanding (Chiu & Chen, 2005).

Analogies might be brought up by the teacher or students. They might be self-designed or adopted from external sources such as related literature or expert recommendations; with the former, the process of self-generation is likely to be more difficult (Clement, 1998, 2003). Individuals exercise their analogical reasoning when they are involved in self-generation and evaluation of analogies (Marcelos & Nagem, 2010). For some, experts or students, generation of analogies is a natural reasoning strategy. Interestingly, eighth graders, who are more abstract thinkers, have been reported to generate more analogies in their explanations of the target phenomena than sixth graders who are more concrete thinkers. These self-generated and spontaneous analogies are based on concepts in students' everyday lives (Glynn & Takahashi, 1998). Compared to ready-made and teacher-provided analogies, self-generated analogies promote deeper relational structures (Haglund & Jeppsson, 2012).

Given that analogies are sometimes spontaneously generated during the teaching-learning and problem solving settings, an evaluation mechanism should be in place to evaluate the validity of these analogies. Experts tend to take considerably more time to evaluate the validity of an analogy (Clement, 1998). Students might be encouraged to use analogies to evaluate their learning of a target concept by training them how to map features of the analogue to the shared features of the target concept (Paris & Glynn, 2004). Some science teachers think that analogies are "shortcuts" that save time and lead to the desired conceptual change in one "magic" step. They underestimate the size of the conceptual change needed and the fact that students need time to evaluate the provided analogy and reflect on its usefulness and applicability to the undertaken scientific concept or phenomenon. As a result, students with misconceptions, might spend more time than expected to comprehend an analogy and change their existing conceptions (Clement, 1998).

We need to admit that using analogies in teaching has not been always successful. Proposed analogies are sometimes complex by themselves and require a high level of thinking to be comprehended. Thus, students are not able to conceptualise both the anchor analogue and the target concept (Clement, 1998; Guerra-Ramos, 2011; Podolefsky & Finkelstein, 2007). Also, sometimes when teachers use an anchor analogue to explain the relations within a target phenomenon, students focus on the comparisons between the anchor and the target in terms of physical attributes such as colour, size and rigidity instead (Podolefsky & Finkelstein, 2007). Students might judge some unrelated attributes as valid. As a result, they start to form alternative conceptions and thus, conceptualise the analogy differently from the manner the teacher intends (Harrison & Treagust, 1993). Also, science teachers themselves might not be familiar as to where a particular analogy breaks down (Guerra-Ramos, 2011).

The process of misunderstanding starts when the comparison process considers detailed features in order to identify the similarities and dissimilarities between the analogue and the target (Guerra-Ramos, 2011). It also occurs when students are not warned of the limitations of the undertaken analogy and not given guidance on whether they should focus on the physical features or the functional attributes. There is sometimes a whole range of physical and functional attributes presented in one analogy-target comparison. Thus, classroom discussion of an analogy should lead students to explicitly identify the key related attribute(s) and the unshared ones within the given range of attributes (Guerra-Ramos, 2011; Harrison & Treagust, 1993; Marcelos & Nagem, 2010). For instance, the spiral staircase is used as an analogy to resemble the structure of DNA. Although this analogy focuses on a structural attribute, the shape of NA, other physical attributes such as the rigidity of the staircase should be excluded. In addition, an important step in analogy-based instruction should be that once the analogy job to explain the target phenomenon is complete, the target should be separated from the analogy and extended by providing more examples and clarifications (Nashon, 2004).

Also, superficial delivery and discussion of analogies without explicit elaboration and systematic mapping of target attributes verbally and visually lead to possible failure of analogy-based instruction (Paris & Glynn, 2004). In this respect, there is an underestimation of the role of visual imagery in learning science with analogies (Glynn & Takahashi, 1998) in both comprehension and retention of knowledge. Unfortunately, literature shows that explicit elaboration of the similarities and dissimilarities between analogues and target concepts is not a frequent classroom practice and science teachers underestimate the difficulty that students might face when introduced to an analogy (Guerra-Ramos, 2011).

There is another failure of the analogy-based instruction. Given that analogies are easier to remember than the target concepts because of their familiarity to students, some students remember the concrete attributes of the analogy and not the abstract attributes of the target scientific concept. Therefore, students come up with alternative conceptions regarding the target phenomena based on their knowledge of their anchored analogue (Dilber & Duzgun, 2008). By the same token, self-generated analogies might lead to personal explanations that are not in line with scientific consensus. Students assume ownership of their self-generated analogies and, consequently, they might over-generalise them to suit inapplicable contexts and omit the points of breakdown (Haglund & Jeppsson, 2012). Also, young students such as those in high school might not be capable of generating analogies that lead to successful conceptual change. They lack the ability to consistently maintain a well-developed analogy (Hagans, 2003; Harrison & Treagust, 2006).

For complex and highly abstract concepts and processes, it might be useful to use multiple analogies to compensate for the deficiencies in single analogies. Previous works emphasise the role of multiple representations in fostering students' comprehension of complex scientific concepts (Nichols, Ranasinghe, & Hanan, 2012). If a phenomenon is complicated, one analogy might work for one of its aspects and another analogy might be designed to explain another aspect of this phenomenon (Harrison & Treagust, 2006; Podolefsky & Finkelstein, 2007). For instance, while the water circuit analogy works well to explain the concept of batteries within the electric circuit, the moving-objects analogy works better to explain the concept of resistors (Podolefsky & Finkelstein, 2007). Also, multiple analogies allow students to select the most appropriate bridging method that links scientific concepts to everyday physical phenomena (Chiu & Lin, 2005).

However, the analogies to be involved in the multiple-analogies approach should be carefully chosen as research indicates that multiple analogies might sometimes cause cognitive difficulties. It happens that the second analogy, when poorly chosen, contradicts with the first one and consequently wipes out the positive accomplishment of the first analogy (Harrison & Treagust, 1993). Also, students sometimes are not keen on using several analogies. One type of explanation is usually preferred by most students (Yilmaz & Eryilmaz, 2010). It becomes difficult to some students to conceptualise the core abstract themes that regulate multiple representations of natural phenomena or entities (Al-Balushi, 2012; Gericke & Hagberg, 2007). This happens to students who believe in only one correct answer to each problem. Thus, they become confused when the teacher presents more than one analogy or explanation to the undertaken phenomenon (Harrison & Treagust, 2006).

The above review of previous works indicates that explicit discussion of shared attributes between analogies and target concepts is an effective mental tool that helps students recall, visualise and comprehend scientific concepts. Nonetheless, there is little empirical evidence available to date regarding whether the impact of analogy-based instruction lasts longer than traditional teaching. The work of Glynn and Takahashi (1998) is one of the exceptions in this regard. Their study indicates that analogy-enhanced text has greater immediate and postponed (two-week) retention as compared to a control text. The differences between the current study and that of Glynn and Takahashi are: 1) the current study examined the impact of analogy-based instruction instead of analogy-enhanced text only, 2) the treatment in the current study lasted for five weeks with six periods in each week (a total of 30 periods including the reviewing lessons) while it was a one-time administration of the treatment (25 minutes) in Glynn and Takahashi's study, and 3) the impact in the current study was measured according to different cognitive levels, recall, application and reasoning, and not only recall as Glynn and Takahashi did. Another study by Paris and Glynn (2004) divided the impact in terms of two different cognitive levels: retention and inferential. However, they tested the impact of one-time administration of an analogy-enhanced text and not the impact of analogy-based instruction for a whole science unit in the same manner that the present study did. Also, they did not measure the retention after a period of time as was recorded in the current study and in that of Glynn and Takahashi's. They only measured the achievement immediately after students' exposure to analogy-based text.

Because analogy-based instruction has not always been successful (Clement, 1998; Guerra-Ramos, 2011; Harrison & Treagust, 1993; Podolefsky & Finkelstein, 2007), we examined the implementation of some recommendations and advice given by previous researchers to avoid the pitfalls of analogy-based instruction. Examples of this advice are: elaborative discussion of the similarities and differences between the analogue and the target (Glynn & Takahashi, 1998; Paris & Glynn, 2004); ensuring students' familiarity with the analogy (Clement, 2003; Sarantopoulos & Tsaparlis, 2004); the importance of identifying where the analogy breaks down and emphasising the positive role of visualisation (Chiu & Chen, 2005; Paris & Glynn, 2004); and the careful use of self-generation strategy (Haglund & Jeppsson, 2012). By integrating these research-based recommendations into the design of analogy-based instruction, we hope that we provide science teachers and text writers with a working and rectified model for the use of analogies in science teaching.

PURPOSE OF STUDY

The current study examined the impact of analogy-based instruction on immediate and postponed retention at three cognitive levels: knowledge, comprehension and application related to electric energy and its technical applications.

METHODOLOGY

a) Participants

The participants were 63 ninth grade female students studying in two classrooms in a school in Al-Dakheliah province in Oman. The school was chosen based on the willingness of the school administration to host the study and the presence of an experienced teacher who expressed the interest to teach both groups of the study. We randomly assigned the two classrooms to an experimental group (32 students) and a control group (31 students).

b) Design of Study

A control group quasi-experimental design was used in the current study. The experimental group studied a unit called "Electric Energy and Its Technical Applications" using an analogy-based instruction while the control group used the traditional teaching method to study the same unit. We used results of students' science achievement in the first semester of the school year to test whether both groups were equivalent before the beginning of the study. The achievement scores of the students in the first semester were based on formative evaluation (40%) and summative evaluation (60%). The formative evaluation score was obtained by short quizzes, classroom participation and a mini project. The summative evaluation was in the form of a final written achievement test. Table 1 illustrates that both groups were equivalent and had no significant differences between them.

Table 1. *Independent samples t-test results of the comparisons between the two groups on students' science achievement before the beginning of the study*

Group	N	mean*	SD	df	t	p
Control	31	12.22	3.22	61	0.84	0.16
Experimental	32	12.29	3.72			

*Maximum mark = 20

We asked a cooperative teacher to teach both groups. She had eight years of teaching experience. Before the beginning of the study, the second author conducted a workshop for the teacher regarding the analogy-based instruction. The workshop lasted for two days comprising three and a half hours each day. The workshop was composed of three parts: the theoretical aspects of analogy-based instruction, the use of the teachers' manual and illustration of a sample lesson using the strategy. Since the teacher had significant teaching experience, we thought two days' training would be enough. She had studied analogy-based techniques in her teacher preparation programme and used analogies in her teaching before being chosen for the current study. Therefore, she did not have any difficulties in comprehending the topics presented in the workshop.

The study lasted for five weeks with six lessons during each week. The second author attended all the lessons taught in the experimental groups and most of the lessons taught in the control group. After the completion of the study, an achievement test was immediately administered to both groups. The same test was administered again after two weeks to measure the retention of both groups.

The teacher's control group was subjected to her regular teaching methods. Examples of these methods were lecturing, classroom discussion, discovery and hands-on activities, some guided inquiry activities and cooperative learning. The same instructional methods were used in the experimental group. Instead of presenting the scientific topics through regular classroom discussion, however, the teacher used the analogy-based model. She was instructed not to use any analogies when teaching the control group.

c) Materials

We designed a teacher manual to be used in the experimental group. The manual was designed around the "Electric Energy and Its Technical Applications" unit found in the ninth grade science textbook. This unit included topics such as electric charges, static electricity, electric circuits, transformations of electric energy, electrochemistry, electromagnetism and electric efficiency. Also in this unit, students learned about various devices and technical applications that accompanied different topics.

We adopted the Teaching With Analogy (TWA) model which has been widely reported in different literatures (Guerra-Ramos, 2011; Harrison & Treagust, 1993; Marcelos & Nagem, 2010). Below are the general steps in the TWA model:

1. Introduce the target (scientific) concept
2. Introduce the analogue
3. Identify the shared key features between the target and the analogue

4. Illustrate the similarities using a chart or a sketch
5. Identify the limitations of the analogy
6. Infer the conclusion(s)
7. Self-generate your own analogy

We added step no. 7 to encourage students to self-generate their own analogies especially in the homework with emphasis that students needed to list the limitations of their self-generated analogies.

The teacher manual has the following sections:

- An introduction
- The theoretical framework for analogy-based instruction which includes a description of the modified TWA model
- Instructions to the teacher
- Learning outcomes
- The unit plan
- The lesson plans and their related worksheets
- We included in the teacher manual different well-known analogies related to electricity. Table 2 illustrates examples of these analogies.

Table 2. *Examples of different analogies used in the current study*

Target concept	Analogue	no. of lessons
electric discharge	a water circuit which included: a water tower, pipes and water basins	2
moving charges	train	2
electric current	a water circuit which included: straight pipes, zigzag pipes, water pump, valves	2
potential difference	water tower, pipes, water wheel and water basins	2
resistance	a cat prevents a group of mice from reaching a piece of cheese	4
series connection	series water valves in a water circuit	3
parallel connection	parallel water valves in a water circuit	3
chemical batteries	food and human body	2
alternating current	ocean waves	3

As noted above, academic texts (Dilber & Duzgun, 2008; Glynn & Takahashi, 1998; Marcelos & Nagem, 2010; Paris & Glynn, 2004; Thiele & Treagust, 1994) emphasise the importance of using both the verbal and visual features of the analogies to promote students' learning of the target scientific concept. Therefore, activities in the teacher manual are designed to help the learners to create verbal and visual connections between the analogue and target concepts. To do so, we designed an activity worksheet for each analogy that accompanied each lesson. The worksheet presented a photograph or sketch (the *visual element*) for both the target concept and the analogy. Then, a comparison table was presented beneath these illustrations. In that table, students were asked to write similarities and differences (the *verbal element*) between the target concept and the analogy. Both the visual representations and the table worked as graphic organisers that students used to summarise and organise the information they discussed and inferred. Previous works considered graphic organisers as useful learning techniques that foster the comprehension of newly-learned information (Trowbridge & Wandersee, 1998). Appendix 1 shows an example of the worksheets used in the study.

We asked a panel of 13 science educators to review the teacher manual. The panel included three science education professors working in two different universities in Oman, seven physics supervisors working in the Ministry of Education and three physics teachers working in different public schools. We asked the panel to focus on the complexity level of each analogy and whether it was appropriate to grade nine students. They also checked the scientific content presented in the manual. Based on the comments of the panel, we made some modifications to the manual such as simplifying certain analogies, clarifying some others and re-phrasing several linguistic structures.

d) Achievement Test

We developed an achievement test to measure participants' achievement in the "electric energy and its technical applications" unit. Three cognitive levels were incorporated in the test: knowledge, comprehension and application. The test encompassed 27 items: 20 multiple-choice items and seven open-ended items. There were eight knowledge items (29.63%), five comprehension items (18.52%) and 14 application items (51.85%). The reason for having more application items was because of the nature of the unit used which focused on the applications of electric concepts. To ensure the test items were fair for both groups of students, all items were based on the content found in student textbooks.

The same panel that reviewed the teacher manual also judged the validity of the achievement test. The panel checked the appropriateness of the test for the purpose of the study, its scientific accuracy, its readability, its alignment with the content in the student text, its appropriateness for grade nine students and whether each item measured its assigned cognitive level. The panel suggested re-phrasing for some items and the clarification of certain figures.

We piloted the achievement test on a classroom of 31 female grade nine students who finished studying the "electric energy and its technical applications" unit. They were not from the same school that hosted the study. The aim of this process was to check the readability of the test items, measure the appropriate test time and calculate the reliability coefficient. The second author administered the test and asked the students to point out any ambiguous words or phrases. Thus, some minor modifications were made to the test items. The number of items remained the same. The estimated test time was 80 minutes (approximately two periods) and Cronbach's alpha coefficient was 0.83.

RESULTS AND DISCUSSIONS

The purpose of the present study was to assess the impact of analogy-based instruction on immediate and postponed students' retention in terms of three cognitive levels: knowledge, comprehension and application. Table 3 illustrates the results of independent samples t-test analysis of the immediate administration of the achievement test. The findings showed that there were significant differences between the two groups of the study in terms of two cognitive levels: comprehension and application. The mean differences between the two groups in these two levels indicated that the differences came in favour of the experimental group (effect size $r=0.71$ & $r=0.50$ respectively). Also, the experimental group outperformed the control group in the overall total score of the immediate administration of the achievement test (effect size $r=0.55$). However, there was no significant difference between the two groups in terms of the knowledge cognitive level.

Table 4 illustrates the results of independent samples t-test analysis of the postponed administration of the achievement test. The experimental group significantly outperformed the control group in the three cognitive levels (effect size $r=0.57$, $r=0.80$ & $r=0.62$ respectively) and in the overall score of the test (effect size $r=0.71$). Also, as shown in Table 5, a comparison of the immediate and postponed administrations of the test shows that students' scores in the control group declined significantly in all three cognitive levels and in the overall score of the test. On the other hand, there were no significant differences between the immediate and postponed administrations of the test in terms of the experimental students' scores in the three cognitive levels and in the overall score of the test. It is worthy to note that in the immediate administration of the test there was no significant difference between the two groups in terms of the knowledge level. Then, the score of the students in the control group declined significantly. Nevertheless, students' score in this cognitive level in the experimental group did not change significantly. In summary, it is plausible to conclude that students' retention in the experimental group was significantly higher than their retention in the control group in all three cognitive levels: knowledge, comprehension and application.

Table 3. *Means, standard deviations and independent samples t-test results for immediate achievement test*

Cognitive level	maximum mark	group	no	mean (Mi)	SD	df	t	p
Knowledge	9	control	31	6.48	1.09	61	0.92	0.36
		experimental	32	6.75	1.19			
Comprehension	6	control	31	2.81	1.08	61	8.12	0.001
		experimental	32	4.88	0.94			
Application	15	control	31	6.52	3.28	61	4.62	0.001
		experimental	32	9.94	2.55			
Overall test	30	control	31	15.81	4.88	61	5.22	0.001
		experimental	32	21.56	3.81			

Table 4. *Means, standard deviations and independent samples t-test results for postponed achievement test*

Cognitive level	maximum mark	group	no	mean (Mp)	SD	df	t	p
Knowledge	9	control	31	5.26	1.03	61	5.55	0.001
		experimental	32	6.94	1.34			
Comprehension	6	control	31	2.19	0.98	61	10.38	0.001
		experimental	32	4.91	1.08			
Application	15	control	31	5.42	2.91	61	6.31	0.001
		experimental	32	9.78	2.56			
Overall test	30	control	31	12.84	4.30	61	7.98	0.001
		experimental	32	21.47	4.28			

Table 5. *Mean differences and paired samples t-test results for immediate/postponed achievement test*

Cognitive level	group	decline (Mi-Mp)*	df	t	p
Knowledge	control	1.22	30	8.08	0.001
	experimental	-0.19	31	2.25	0.32
Comprehension	control	0.62	30	3.34	0.002
	experimental	-0.03	31	0.30	0.77
Application	control	1.10	30	3.72	0.001
	experimental	0.16	31	0.63	0.53
Overall test	control	2.97	30	6.84	0.001
	experimental	0.09	31	0.29	0.77

*Mi: Mean of the *immediate* achievement test; Mp: Mean of the *postponed* achievement test

This capacity of analogy-based instruction to help students in their comprehension and application of scientific concepts has been emphasised in the literature (Dilber & Duzgun, 2008; Guerra-Ramos, 2011; Harrison & Treagust, 1993; Marcelos & Nagem, 2010; Paris & Glynn, 2004; Sarantopoulos & Tsaparlis, 2004). In the current study, students in the experimental group had the opportunity to study visual representations that symbolise both the analogue and the target. The purpose was to infer the similarities and differences between the two. This incorporation of visual inspection in the learning of science concepts is responsible for reducing the level of abstractness associated with many science concepts and phenomena (Thiele & Treagust, 1994). Thus, science learning becomes more plausible and comprehensible (Dilber & Duzgun, 2008; Marcelos & Nagem, 2010; Paris & Glynn, 2004).

Also, students in the experimental group were actively engaged in their small groups when they were trying to complete the worksheets and negotiate the possible connections between the analogy and the target. This minds-on active learning process of student-student dialogue allowed for the sharing of ideas and negotiation of meaning in a social context. As students talk more about science and science concepts, they have more chance to develop and refine their science understanding (Khourey-Bowers, 2011).

The teacher in the experimental group would ask the students, as part of their homework, to think of an analogy to the concepts taught in the lesson. To avoid the formation of alternative conceptions, the teacher required students to also think of the limitations of the analogy they brought to the classroom. She encouraged them to think of one aspect at which the target and analogue intercepted. During the next lesson, students explained their analogies and the teacher would evaluate them and cautioned them on some limitations that they ignored. The authors noticed that students were eager to offer their own analogies. Some of them were preparing for the lesson by thinking of related analogies from their surroundings or examples from their previous experience. These efforts by students made learning more meaningful (Glynn & Takahashi, 1998). Compared with teacher-generated analogies, it is easier for students to map self-generated analogies (Harrison & Treagust, 2000).

Also, Haglund and Jeppsson (2012) argued that the process of self-generation of analogies by students seemed to align more logically with constructivism which emphasised the importance of involving students' pre-existing knowledge. When the teachers provide students with analogies, they assume that they know these analogies from their daily lives and previous experience. However, this assumption is not always correct. Some students might not know these examples or some of their details. On the other hand, when students generate their own analogies, the expectation that they are familiar with the analogy they bring and its details is higher. Also, we believe that this process of establishing associations with elements, events and processes in the environment helped students in the experimental group to expand their mental networks and recall the information longer than the control group. Previous studies indicated a positive impact of the use of analogies on students' recall and retention of scientific information (Glynn & Takahashi, 1998; Paris & Glynn, 2004).

The results of the immediate administration of the achievement test indicated that students in the control group were as good as their counterparts in the experimental group in terms of the recall of information (the knowledge cognitive level). This difference did not last for a long time. Two weeks later, the postponed administration of the test revealed a significant difference in favour of the experimental group. Paired samples t-test results showed a considerable decline in the control group's scores in the knowledge questions. This was not observed in the experimental group. The construction of visual associations and mental models during the analogy-based instruction should have played an essential role in helping students in the experimental group to preserve the information they learnt. This successful achievement in the current study was due partially to the realisation of the importance of visual imagery in analogy-based instruction (Glynn & Takahashi, 1998). Students in the experimental group were involved in explicit discussion of the verbal and visual mapping between the target and the analogy. This elaboration of the systematic mapping is considered a driving force in the success of teaching with analogy. In addition, the verbal and visual links made the target concept better represented in students' memories and therefore better enhancing their retention of information (Paris & Glynn, 2004).

The implementation of the analogy-based instruction in the current study emphasises the importance of discussing where the analogy broke down. Students were encouraged to talk about the limitations in their small groups, write them down on their worksheet and then present them to the whole class. As stressed in the literature (Glynn & Takahashi, 1998; Guerra-Ramos, 2011; Haglund & Jeppsson, 2012; Harrison & Treagust, 1993; Paris & Glynn, 2004), we believe that this important action helped students avoid being dragged into constructing alternative conceptions. Previous research indicated that when students were warned of the differences between the target and the analogue, no analogy-based alternative conceptions were reported (Glynn & Takahashi, 1998). Also, in the present study, this classroom practice made students conscious of the importance of always thinking of limitations for self-generated analogies while they were doing their homework and reported them when they presented their homework.

CONCLUSION AND RECOMMENDATIONS

The findings of the current study indicated that analogy-based instruction helped students to comprehend and apply scientific concepts at a level substantially higher than the traditional teaching methodology. Also, analogy-based instruction facilitated students' retention of scientific information at the three cognitive levels (knowledge, comprehension and application). On the other hand, there was a significant decline in the performance at the three cognitive levels for students who were taught by the traditional method. While there was no important difference between the two strategies in terms of the knowledge level (recall of information) in the immediate test, the experimental groups outperformed the control group in this particular level in the postponed test. This result is a new addition that the current study contributed to our knowledge of analogy-based instruction. We would like to emphasise the following conditions which we believe facilitated the positive impact of analogy-based instruction used in the current study:

1. *Familiarity:* the abstractness level of scientific concepts was reduced by using familiar everyday analogies.
2. *Elaboration:* the frequent mapping of the verbal and visual features between the analogue and the target.
3. *Limitations:* the emphasis on stating the limitations of each analogy to avoid forming alternative conceptions.
4. *Active-learning:* engaging learners in active learning discussions in their small groups and then as a whole class regarding different aspects of the undertaken analogy and target concepts.
5. *Graphic organising:* activity worksheets helped students to study a sketch used to infer similarities and differences between the analogue and the target and then organise them in a table. This graphic organising combination helped foster students' recall and comprehension of information.
6. *Self-generations:* encouraging students to come up with their own self-generated analogies that correspond to concepts under study with a clear caution about their possible limitations.
7. *Motivation:* the eagerness and high level of motivation noticed with the students in the experimental group had to come up with their own analogies.

To be successful, we recommend that any analogy-based instruction should take these conditions into consideration. Science teachers and text writers could benefit from these instructional ideas to design a learning environment that maximises the benefits from using analogies and, at the same time, overcomes their limitations.

The current research design was unique to this study. Exploration of retention at different cognitive levels has been rare in previous research that focused on analogy-based instruction. However, one limitation to the current study was the use of the same test in the immediate and postponed administration. There was a fear that students might remember the answers in the second administration of the test and this might turn responding to the application and comprehension question into mere recall of information. Nevertheless, it was not necessary that all students did care about the questions they were asked in the tests. Students did not receive any feedback to their answers in the immediate administration. No review sessions were conducted after the first administration. Also, we thought that a two week period would be long enough for most students to forget most test items. Add to this, the fact that we did not inform students about the second application of the test to avoid any attempt from them to remember the test items from the first application. We suggest that a future exploration might consider designing two compatible versions of the achievement test. Another limitation of the current study may be that its findings may not be generally applicable to fields other than physics which was the focus subject matter of the current study. Physics deals more with everyday objects and events compared to chemistry and biology. Therefore, it might be easier to find matching analogies to physics concepts than in other fields of science. A further study might use the same design but on another science field such as biology or chemistry.

REFERENCES

Al-Balushi, S. M. (2011). Students' evaluation of the credibility of scientific models that represent natural entities and phenomena. *International Journal of Science and Mathematics Education, 9*(3), 571-601. DOI:510.1007/s10763-10010-19209-10764.

Al-Balushi, S. M. (2012). The relationship between learners' distrust of scientific models, their spatial ability, and the vividness of their mental images. *International Journal of Science and Mathematics Education*, DOI: 10.1007/s10763-10012-19360-10761.

Chiu, M.-H., & Chen, I.-J. (2005, August). *Dynamic analogies promoting students' learning of behavior of gas particles.* Paper presented at the ESERA, Barcelona, Spain.

Chiu, M.-H., & Lin, J.-W. (2005). Promoting fourth graders' conceptual change of their understanding of electric current via multiple analogies. *Journal of Research in Science Teaching, 42*(4), 429-464.

Clement, J. (1998). Expert novice similarities and instruction using analogies. *International Journal of Science Education, 20*(10), 1271-1286.

Clement, J. (2003, March). *Abduction and analogy in scientific model construction.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Philadelphia, PA.

Dilber, R., & Duzgun, B. (2008). Effectiveness of analogy on students' success and elimination of misconceptions. *Latin American Journal of Physics Education, 2*(3), 147-183.

Gentner, D., Brem, S., Ferguson, R., Markman, A., Levidow, B., Wolff, P., & Forbus, K. (1997). Analogical reasoning and conceptual change: A case study of Johannes Kepler. *The Journal of the Learning Sciences, 6*(1), 3-40.

Gericke, N. M., & Hagberg, M. (2007). Definition of historical models of gene function and their relation to students' understanding of genetics. *Science and Education, 16*, 849-881.

Glynn, S. M., & Takahashi, T. (1998). Learning from analogy-enhanced science text. *Journal of Research in Science Teaching, 35*(10), 1129-1149.

Guerra-Ramos, M. (2011). Analogies as tools for meaning making in elementary science education: How do they work in classroom settings? *Eurasia Journal of Mathematics, Science & Technology Education, 7*(11), 29-39.

Hagans, C. (2003). *An analysis of the effectiveness of teacher versus student-generated science analogies on comprehension in biology and chemistry*. Unpublished Master Thesis, Defiance College, Defiance, OH.

Haglund, J., & Jeppsson, F. (2012). Using self-generated analogies in teaching of thermodynamics. *Journal of Research in Science Teaching, 49*(7), 898-921.

Harrison, A. G., & Treagust, D. F. (1993). Teaching with analogies: A case study in grade-10 optics. *Journal of Research in Science Teaching, 30*(10), 1291-1307.

Harrison, A. G., & Treagust, D. F. (2000). A typology of school science models. *International Journal of Science Education, 22*(9), 1011-1026.

Harrison, A. G., & Treagust, D. F. (2006). Teaching and learning with analogies. In P. Aubusson, A. G. Harrison & S. Ritchie (Eds.), *Metaphor and analogy in science education* (pp.11-24). Netherlands: Springer.

Khourey-Bowers, C. (2011, April/May). Active learning strategies: The top 10. *The Science Teacher, 78*, 38-42.

Marcelos, M., & Nagem, R. (2010). Comparative structural models of similarities and differences between vehicle and target in order to teach Darwinian evolution. *Science and Education, 19*, 599-623.

Nashon, S. (2004). The nature of analogical explanations: High school physics teachers use in Kenya. *Research in Science Education*, *34*, 475-502.

Nichols, K., Ranasinghe, M., & Hanan, J. (2012). Translating between representations in a social context: A study of undergraduate science students' representational fluency. *Instructional Science*, DOI 10.1007/s11251-11012-19253-11252.

Paris, N., & Glynn, S. M. (2004). Elaborate analogies in science text: Tools for enhancing preservice teachers' knowledge and attitudes. *Contemporary Educational Psychology*, *29*, 230-247.

Podolefsky, N., & Finkelstein, N. (2007). Analogical scaffolding and the learning of abstract ideas in physics: An example from electromagnetic waves. *Physical Review Special Topics-Physics Education Research, 3*(1), 010109.

Sarantopoulos, P., & Tsaparlis, G. (2004). Analogies in chemistry teaching as a means of attainment of cognitive and affective objectives: A longitudinal study in a naturalistic setting, using analogies with a strong social content. *Chemistry Education Research and Practice, 5*(1), 33-50.

Şekercioğlu, A & Kocakülah, M (2008). Grade 10 students' misconceptions about impulse and momentum. *Journal of Turkish Science Education, 5*(2), 47-59.

Thiele, R., & Treagust, D. F. (1994). An interpretive examination of high school chemistry teachers' analogical explanation. *Journal of Research in Science Teaching, 31*(3), 227-242.

Trowbridge, J., & Wandersee, J. H. (1998). Theory-driven graphic organizers. In J. J. Mintzes, J. H. Wandersee & J. D. Novak (Eds.), *Teaching science for understanding: A human constructivist view* (pp.95-131). San Diego, CA: Academic Press.

Yilmaz, S., & Eryilmaz, A. (2010). Integrating gender and group differences into bridging strategy. *Journal of Science Education and Technology, 19*, 341-355.

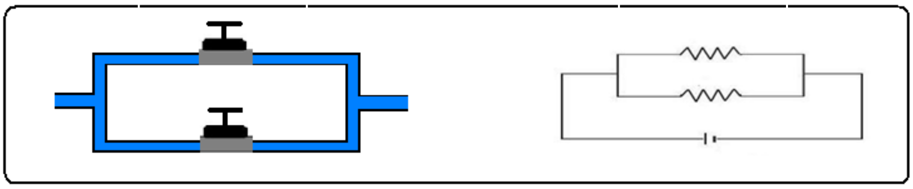
APPENDIX

A sample worksheet

Lesson 7: *parallel electric connections*

Study the sketches below to compare between the *analogue: parallel water valves in a water circuit* and *target: parallel electric connection*. Then, write the seminaries and differences between the analogue and the target.
Note that the differences are the limitations of the analogy used in this lesson.

Analogu **Target**



parallel water valves in a water circuit	parallel electric connection
Similarities	
------------------------------------	------------------------------------
------------------------------------	------------------------------------
------------------------------------	------------------------------------
------------------------------------	------------------------------------
------------------------------------	------------------------------------
------------------------------------	------------------------------------
Differences	
------------------------------------	------------------------------------
------------------------------------	------------------------------------
------------------------------------	------------------------------------
------------------------------------	------------------------------------
------------------------------------	------------------------------------
------------------------------------	------------------------------------

List the characteristics of parallel electric connection:

Think of some applications of parallel electric connections around you. List them below:
