Analogy-Enhanced Instruction: Effects on Reasoning Skills in Science

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ABSTRACT

The study examined the reasoning skills of first year high school students after learning general science concepts through analogies. Two intact heterogeneous sections were randomly assigned to Analogy-Enhanced Instruction (AEI) group and Non Analogy-Enhanced (NAEI) group. Various analogies were incorporated in the lessons of the AEI group for eight weeks. The Scientific Reasoning Test (SRT) was administered to assess the students' reasoning skills before and after the intervention. The group exposed to AEI was expected to have a higher mean score in the SRT. However, no significant difference was found on the posttest mean score of the AEI and NAEI groups. Also, no significant difference was found on the two groups' posttest mean scores in each of the five reasoning skills (conservation of mass and volume, proportional reasoning, identification and control of variables, probabilistic reasoning and correlational reasoning). The study has implication for researchers who are interested to replicate it.

Keywords: *analogy, scientific reasoning skills in science*

INTRODUCTION

Filipino students often find learning science to be a challenging endeavor. Their performance in international tests in science ranked way below other participating countries (Tan, Bosi as cited by Atillo-Daplan, 2008). The results from the 2003 and 2008 Trends in International Mathematics and Science Study (TIMSS) showed that the Philippines was among the lowest ranked in terms of performance. In the local scene, science had the lowest mean percentage score among the five subjects tested in the 2008 National Achievement Test (Atillo-Daplan, 2008). These tests require deep understanding of concepts and advanced reasoning skills.

Because of this alarming situation, Filipino science teachers are looking for teaching methods, which can enable students to develop reasoning skills in science. One way to achieve this is through the use of analogies.Studies on using analogies in science classrooms have shown its impact on: achievement (Baker & Lawson, 1995); retention (Glynn & Takahashi, 1998); conceptual understanding (Gabel, 2003); conceptual change (Chui & Lin, 2005; Pittman, 1999); inferential reasoning (Donelly& McDaniel, 1993; Yanowitz, 2001); thinking skills (Salih, 2010); and attitudes toward science (Baker & Lawson, 1995; Paris & Glynn, 2003).

Locally, Apolonio (2010) examined the effects of analogical instruction on comprehension and attitude of slow learners in physics. She recommended that her study should be validated in other science areas and that other variables should be further explored. This led to the conceptualization of the present study on Analogy-Enhanced Instruction (AEI) in general science. The main purpose of this study was to investigate the possible effects of analogies on first year high school students' reasoning skills in science.

This study addressed the following research questions: Do students exposed to Analogy-Enhanced Instruction (AEI) have higher mean posttest score than the students exposed to Non Analogy-Enhanced Instruction (NAEI) in the Scientific Reasoning Test (SRT)?; and, do students exposed to AEI have higher mean posttest score than the students exposed to NAEI in each of the five reasoning skills (conservation of mass and volume, proportional reasoning, identification and control of variables, probabilistic reasoning, and correlational reasoning)?

Reasoning Skills in Science

Reasoning has been the subject of a long line of research within psychology and education. Plotnik (2006) defined reasoning as a mental process that involves using and applying knowledge to solve problems, make decisions, and achieve goals. Other researchers have also provided their definitions of reasoning (Kuhn *et al.* as cited by Bjorklund, 1999; Hazen & Tefil, Brikle & Mauldin, Zimmerman as cited by Bao *et al.*, 2009; Johnson-Laird, Anderson as cited by She & Liao, 2010; Hogan & Fisherkeller, Holyoak & Morrison, Overton as cited by Zeineddin & Abd-El-Khalick, 2010).

Scientific reasoning can be developed, improved and transferred through training and practice (Adey & Shayer, Chen & Klahr as cited by Bao *et al.*, 2009). Fenci (2010), she and Liao (2010), and Abdullah and Abbas (2006) found out that students who were exposed to the type of instruction they were investigating made significant gains in scientific reasoning skills. The present study investigated whether AEI will also make significant gains in terms of students' reasoning skills in science.

Scientific reasoning involves deductive and inductive processes (Plotnik, 2006; Waters & English as cited by Zeineddin & Abd-El-Khalick, 2010). Deductive reasoning begins with making a general assumption that one knows to be true and then drawing specific conclusions based on the assumption. Inductive reasoning begins with making particular observations and then drawing a broader conclusion based on the observations.

Piaget (as cited by Plotnik, 2006) characterized four stages of intellectual development – sensorimotor, preoperational, concrete operational, and formal operational. The latter two stages are relevant to scientific reasoning in that these are the stages during which advanced reasoning skills begin to develop. Lawson (1995) renamed concrete operational stage as empirical-inductive thought, which comprises class inclusion, conservation, and serial ordering. He also renamed formal operational stage as hypothetical-deductive thought, which includes proportional reasoning, identification and control of variables, probabilistic reasoning, combinatorial reasoning, and correlational reasoning.

This study focused on four of the scientific reasoning skills at the hypothetical-deductive stage and one at the empirical-inductive stage. Hence, Table 1 presents the five scientific reasoning skills as described by Lawson (1995) as cited by Martin (2003).

Table 1 The Scientific Reasoning Skills

Scientific Reasoning Skills	Description
Conservation of Mass and Volume	The individual applies conservation thinking to perceptible objects and properties.
Proportional Reasoning	The individual recognizes and interprets relationships between relationships in situations described by observable or theoretical variables.
Identification and Control of Variables	The individual considers all the known variables in a given hypothesis and designs a test that controls all variables except the one being investigated.
Probabilistic Reasoning	The individual recognizes that natural phenomena themselves involve chances variation and that any conclusions or explanations must require likelihood considerations.
Correlational Reasoning	The individual recognizes the extent to which changes in one variable are incidental to the changes in another variable.

Source: Lawson, A. E. (1995). *Science teaching and the development of thinking.* Belmont, CA: Wadsworth.

Analogies in Science Classrooms

An analogy is a process of identifying similarities between two concepts. The familiar concept is called the base and the unfamiliar concept is called the target (Glynn & Takahashi, 1998). By associating the features of the two concepts, students tend to acquire better understanding of the unfamiliar or target concept.

Several researchers defined analogy differently. Mariah (as cited by Salih, 2010) defined analogy as a concrete and visualisable representation of the matches and mismatches between the base and target concepts. Gentner (as cited by Brown & Salter, 2010) defined analogy as a mapping of knowledge from the base to the target.

Analogies can be categorized based on relationship, presentation, and level of enrichment (Curtis & Reigeluth as cited by Harrison & De Jong, 2005; Orgill & Bodner, as cited by Spezzini, 2010). Table 2 summarizes the types of analogies.

Table 2 Types of Analogies

Types of Analogies	Description
Based on Relationship	
Structural	base and target share similar physical structures
Functional	base and target behave in similar ways
Based on Presentation	
Visual	non-linguistic
Verbal	linguistic
Based on Level of Enrichment	
Simple	grounds for comparison are not stated
Enriched	grounds for comparison are stated
Extended	comprises multiple enriched analogies that describe and explain the same target

Throughout the history of science, scientists and science teachers have used analogies to explain essential discoveries and concepts. Commendable textbook authors such as Hewitt (2002) and Campbell and Reece (2002) as well as local authors like Echija *et al.* (2003) and Palima and Ines (2004) also used analogies to expound science concepts.

Many studies have related the role of analogies in improving students' learning in science. For example, Chui and Lin (2005) investigated how multiple analogies affect student learning of the concept electrical circuit. The results show that using analogies not only advanced the profound understanding of intricate science concepts but it also helped students correct their misconceptions of these concepts. Salih (2010) discussed the potential of an analogical task in accelerating the thinking skills of Malaysian students. The analogical task given to the students enhanced the various thinking skills such as reasoning capabilities, and critical and creative thinking skills.

Yet, some studies have shown that analogies do not necessarily enhance learner performance (Radford as cited by Spezzini, 2010). Glynn (2007) warned that an analogy is a double-edged sword. It can cause misunderstanding among students. Thus, researchers proposed several models for teaching science with analogies. Glynn's (2007) Teaching-with-Analogies (TWA) model helps teachers use analogies systematically and effectively. Treagust, Harrison, and Venville (1998) offered guidelines for thinking about the target, the analog, and the students during instruction. They call their model Focus, Action, and Reflection (FAR).

Sample

The study involved 93 first year high school students in a private Catholic school in Isabela, Region 02. The students were heterogeneously regrouped at the start of the intervention. The AEI group was composed of 46 students, 20 males and 26 females. The NAEI group had 22 males and 25 females. The researcher taught the two groups for eight weeks for a total of 350 minutes per week. Each group met twice a week for 100 minutes (double period) and thrice a week for 50 minutes (single period). The same topics and amount of activities were given to both groups.

Instrument

The study used the Scientific Reasoning Test (SRT) to measure the reasoning skills of the students before and immediately after the intervention. The SRT measured students' reasoning for aspects of conservation of mass and volume, proportional reasoning, identification and control of variables, probabilistic reasoning and correlational reasoning.

A panel of experts evaluated the researcher-made test and its accompanying rubrics. It was revised accordingly before it was pilot-tested to students who were comparable to the sample. It has a reliability coefficient, Cronbach alpha of .779 and interrater reliability average, Kappa of .757.

The test consisted 20 two-tiered questions. The first tier is a multiple-choice question that asks the students to answer a question by choosing the best answer from four options. The second tier is a constructed-response question that asks the students to justify their chosen answer in the first tier. A scoring scheme was used for each answer of the students. Two points were given for the correct choice with fully correct reasoning, one point for correct choice with partially correct reasoning, and no point for correct/incorrect/blank choice with incorrect/blank reasoning.

Intervention

The researcher constructed three Understanding by Design (UbD) chapter learning plans for each of the two groups. The learning plans were submitted for evaluation to the science teacher, the science chair, and the principal of the host school. Their comments and suggestions were considered in the revision of the learning plans. The topics covered were: (1) Measurement in Science, (2) Laboratory Tools in Science, (3) States of Matter, (4) Properties of Matter, (5) Classification of Matter, (6) atomic Structure of Matter, and (7) Changes in Matter.

A. Analogy-Enhanced Instruction (AEI)

The study involved the intervention called Analogy-Enhanced Instruction (AEI). The AEI integrated analogies into the teaching of general science concepts, principles and laws. Table 3 shows the topics and analogies that were used in the AEI group.

The steps which were followed in delivering the analogies were: (1) introduce students to the unfamiliar concept, (2) remind students of a familiar concept, (3) compare and contrast the features of the two concepts, and (4) draw conclusion about the analogy and highlight the overall similarities between the two concepts. These steps were based from the Teaching-With-Analogies model developed by Glynn (2007).

Table 3 Topics and Analogies

Topics	Analogies
1. Measurement in Science	- School-Measurement Rules Analogy - Dartboard Analogy
2. Laboratory Tools in Science	- Kitchen Analogy
3. States of Matter	- Students at School Analogy
4. Properties of Matter	- Classmate-Matter Characteristics Analogy
5. Classification of Matter	- Supermarket Analogy - Lego Analogy - Fruit Salad Analogy
6. Atomic Structure of Matter	- Solar System Analogy - Fan Analogy for Electron Clouds
7. Changes in Matter	- Bicycle Analogy

The AEI used delivery strategies such as lectures, demonstrations, guided discussions, inquiries, and learning circles. The learning or scaffolding activities which were given to the AEI group were experiments, puzzles, games, simulations, science magic tricks, POE (Predict, Observe, Explain), graphic organizers, video integration, quizzes, and performance activities. These activities were variedly applied to equip students to engage with, develop, and demonstrate the desired understandings.

B. Non Analogy-Enhanced Instruction

The Non Analogy-Enhanced Instruction (NAEI) was different from the AEI because analogies were never integrated into the teaching of general science concepts, principles and laws. The topics, delivery strategies and learning or scaffolding activities for the NAEI group was parallel to the AEI except that of the use of analogies.

Data Analysis

Before the intervention began, the pretest mean scores in the SRT of the AEI and NAEI groups were computed and compared using the two-tailed t-test for independent samples.

To determine if there was a significant difference in the reasoning skills of the two groups after the intervention, the one-tailed t-test for independent samples was performed on the groups' posttest mean scores. Similarly, the one-tailed t-test for independent samples was performed on the groups' posttest mean scores in each of the five reasoning skills to determine if there was a significant difference between the two groups.

A one tailed t-test for related samples was performed on the mean pretest and posttest scores of each group to determine if an improvement in the reasoning skills had occurred. Likewise, their mean pretest and posttest scores in each of the five skills were also subjected to a one tailed t-test for related samples. Level of significance for all tests was at .05.

RESULTS AND DISCUSSION

The pretest mean scores in the SRT of the AEI (3.757) and NAEI (3.321) groups were not significantly different (p value = .622, α = .05). This indicates that the two groups had comparable reasoning skills prior to the intervention.

The difference between the posttest mean scores in the SRT of the two groups was not significant at .05 level (Table 4). This indicates that in terms of scores in the SRT, the use of analogies in science classroom instruction is not significantly different from the instruction with no analogies. Despite the lack of significant difference, it should be noted that the mean score of the AEI group is slightly numerically higher than that of the NAEI group.

Table 4 Test of difference between mean posttest scores of the AEI and NAEI groups in the SRT

Group	Mean	SD	t	Significance (1-tailed)
AEI	11.97 (29.93%)	5.900	.151	.440
NAEI	11.79 (29.48%)	5.430		

*Perfect score = 40

**Mean score in percentage enclosed in parenthesis

The difference between the two groups' posttest mean scores in each of the five reasoning skills (conservation of mass and volume, proportional reasoning, identification and control of variables, probabilistic reasoning and correlational reasoning) was not significant at .05 level (Table 5). This suggests that the two types of instruction were not significantly different from each other in terms of scores in each of the five reasoning skills. However, it should be noted that the AEI group had numerically higher mean score in conservation of mass and volume and had the same mean scores in proportional reasoning and probabilistic reasoning as those of the NAEI group.

Table 5 Test of difference between mean posttest scores of the AEI and NAEI groups in each of the Five Reasoning Skills

Reasoning Skills	Group	Highest Possible Score	Mean	SD	t	Significance (1-tailed)
Conservation of Mass and Volume	AEI	10	3.20	1.992	1.091	.139
	NAEI		2.74	2.062		
Proportional Reasoning	AEI	12	2.34	1.94	.001	.500
	NAEI		2.34	1.81		
Identification and Control of Variables	AEI	8	2.11	1.50	.526	.300
	NAEI		2.28	1.45		
Probabilistic Reasoning	AEI	6	2.56	1.42	.008	.497
	NAEI		2.56	1.25		
Correlational Reasoning	AEI	4	1.76	.729	.753	.227

The non significant difference between the mean scores of the two groups may have stemmed from attendance of students, unavoidable contamination of the treatment, similarity of some end-of-activity/experiment questions, and short discussion time as a characteristic of the new curriculum framework.

The attendance record showed that the mean attendance of the AEI students is 96.84% of the total number of days of the treatment while the NAEI group had a mean attendance of 98.06%. There were more students in the AEI group who had missed classes.

An unavoidable contamination of treatment in the two groups occurred. It was observed that during recess time, students discuss their class activities and share their notes with their peers who belong to the other group. It should be noted that prior to the regrouping, the students could have established friendship with their classmates. Therefore, NAEI students who have interacted with AEI students were also exposed indirectly to science analogies.

Another factor that could have affected the results of the study was the similarity of end-of-activity/experiment questions of AEI and NAEI groups which required them to use their reasoning skills. Hence, the NAEI group was also exposed to activities and questions, which may have helped them, develop their reasoning skills.

Lastly, the Understanding by Design (UbD) curriculum planning framework requires teachers to only guide the students, but not to instruct them directly the concept to be learned (Lee-Chua, 2011). It also demands more time for students to accomplish certain activities or tasks and less time for teachers to explain. As such, analogies were presented to students in a shorter period of time, more or less than five minutes, during class meetings. Consequently, some students in the AEI group could have easily forgotten the analogies learned and could have focused further on finishing the activities or tasks.

The pretest and posttest mean scores in the SRT of the AEI group, as well as those of the NAEI group, were significantly different at .05 level (Table 6). This indicates that there was significant difference in the reasoning skills of the two groups before and after the intervention. Both groups had significantly improved in terms of reasoning skills in science.

Table 6 Test of difference between mean pretest and posttest scores of the AEI and NAEI groups in the SRT

Group	Test	Mean	SD	t	Significance (1-tailed)
AEI	**Pretest**	**3.87 (9.68%)**	**3.757**	**-16.998**	**.000**
	Posttest	**11.97 (29.93)**	**5.900**		
NAEI	**Pretest**	**3.50 (8.75%)**	**3.321**	**-16.838**	**.000**
	Posttest	**11.79 (29.48)**	**5.430**		

The pretest and posttest mean scores in each of the five reasoning skills of the AEI group were significantly different at .05 level (Table 7). Students in the AEI group had posttest mean scores that were significantly higher than their pretest. It can be deduced that the improved performance of the AEI students could be credited to AEI, which they were exposed to.

The NAEI group's pretest and posttest mean scores in each of the five reasoning skills were also significantly different at .05 level (Table 8). Similar to the AEI group, students in the NAEI group had posttest mean scores that were significantly higher than their pretest. This indicates that both types of instruction enhanced the reasoning skills of the students.

Table 7 Paired samples test on the difference between pretest and posttest scores of the AEI group in each of the Five Reasoning Skills

Reasoning Skills	Pretest	Posttest	t	Significance (1-Tailed)
Conservation of Mass and Volume	0.67	3.20	10.349	.000
Proportional Reasoning	0.56	2.34	8.455	.000
Identification and Control of Variables	0.90	2.11	6.441	.000
Probabilistic Reasoning	1.14	2.56	8.160	.000
Correlational Reasoning	0.61	1.75	10.141	.000

Table 8 Paired samples test on the difference between pretest and posttest scores of the NAEI group in each of the Five Reasoning Skills

Reasoning Skills	Pretest	Posttest	t	Significance (1-Tailed)
Conservation of Mass and Volume	0.79	2.74	7.766	.000
Proportional Reasoning	0.78	2.34	7.793	.000
Identification and Control of Variables	0.48	2.26	8.994	.000
Probabilistic Reasoning	0.67	2.56	11.736	.000
Correlational Reasoning	0.58	1.87	11.403	.000

The comments written by the students in their journals regarding the use of analogies in classroom teaching signify that analogies helped them gain better understanding of the science concepts learned during the intervention. Moreover, the comments point out that the analogies can play an essential role in the meaningful learning of science as accounted for by Glynn and Takahashi (1998). In their study, they considered the efforts of the students in connecting familiar knowledge with unfamiliar ones as efforts to make learning meaningful.

In sum, the results of the study showed that AEI is not significantly different from NAEI in terms of the improvement of reasoning skills in science of students. However, as reflected in the journal entries of the students from both groups, the various delivery strategies and learning activities used during instruction were appreciated and enjoyed.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions may be deduced from the results of the study: (1) Students exposed to AEI did not have significantly higher mean posttest score than the students exposed to NAEI in the SRT; and (2) Students exposed to AEI did not have significantly higher mean posttest score than the students exposed to NAEI in each of the reasoning skills (conservation of mass and volume, proportional reasoning, identification and control of variables, probabilistic reasoning, and correlational reasoning).

Based on the results of the study, it is recommended that researchers can (1) replicate the study for one academic year or for a longer period of time with different sets of students from public or science high schools; (2) look into instruments that could measure relationship between students' reasoning skills and their overall achievement in science; (3) use other qualitative research techniques to validate results from the quasi-experimental study; (4) develop more concrete analogies that are within the context of students; (5) use AEI with other delivery strategies to test its effect on problem solving and science process skills; and (6) replicate the study using student-generated science analogies.

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