Original article

doi: 10.1111/j.1365-2729.2008.00282.x

Effects of multimedia and schema induced analogical reasoning on science learning

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Abstract The present study investigates the effects of multimedia and schema induced analogical reasoning on science learning. It involves 89 fourth grade elementary students in the north-east of the United States. Participants are randomly assigned into four conditions: (a) multimedia with analogy; (b) multimedia without analogy; (c) analogy without multimedia; and (d) non-multimedia and non-analogy. The multivariate analyses of covariance reveal significant main effects for multimedia and analogy learning as well as a significant interaction between multimedia and analogy. The findings show that schema induced analogical reasoning can significantly improve science learning and that multimedia becomes more effective when it is integrated with an instructional method such as analogy and less so when it is used only as a visual tool. The study also shows the field dependence/independence as a significant covariate that influences learners' schema induced analogical reasoning in learning. Discussions pertaining to the significance of the findings and their implications for teaching and learning are made. Suggestions for future research are included with an emphasis on developing multimedia supported analogical reasoning for science learning.

Keywords analogical reasoning, multimedia, schema, science learning.

Introduction

Over the past two decades, researchers and educators have been exploring methods to improve science learning. One of the heavily researched areas is to teach with analogy. There are essentially two types of analogies: conceptual inference and schema induced analogies, both of which can promote cognitive transfer in learning. Recently, using schema induced analogy to teach subject content such as science has drawn attention from educators and researchers (Nashon 2004; May *et al*. 2006). As learning technology has become increasingly prevalent in schools, there has been an effort to understand the role of learning technology on learning, especially when such technology is used to assist learners' analogical reasoning. So far, research on multimedia and analogical reasoning has remained descriptive. Few empirical studies have been conducted to investigate the effects of multimedia and analogical reasoning on learning. The present study thus examined the roles of multimedia and analogical reasoning, particularly schema induced analogical reasoning in science learning.

Accepted: 1 April 2008
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Literature

Conceptual inference and schema induced analogical reasoning

Analogies are tools for understanding concepts. Their construction and effective deployment require the use of a model to provide systematicity (Gentner & Gentner 1983). Several models (see Spearman 1927; Hollan, 1975; Sternberg, 1977; Pellegrino & Glaser 1982; Evans 1988) have been proposed to explicate the analogical reasoning process. Of those models, Sternberg's (1977) analogy model is perhaps the most studied and widely applied. According to Sternberg (1977), analogical reasoning essentially consists of encoding, inference, mapping, application and response. For example, if a learner wants to determine the relation between Red : Stop :: Green : (Go, Halt), he/she has to first encode the concepts of Red and Green. Next, he/she infers the relation between the concepts of Red and Stop (a red light means stop), and maps the relation between the concepts of Red and Green (both are colours of traffic lights). After mapping, the learner applies a relation analogous to the inferred one by choosing the closer option (a green light means go, not halt) and finally responds with the answer. The above model focuses on the conceptual inference in reasoning. That is, analogical reasoning is made based on the relationship between key concepts in the base and target domains. Some researchers (e.g. Gick & Holyoak 1983; Scholnick & Cookson 1994) argue that conceptual inference has some limitations, especially when semantic relationship between the base and target domains becomes less obvious to the learner.

Research shows that the learner's ability in analogical reasoning can be adversely affected by the constraints of language (Gick & Holyoak 1983; Nashon 2004). Consider the example of Professor : Knowledge :: Landlord : (Apartment, Insurance). The relation of 'Professor : Knowledge' can be encoded either as a professor is someone who transmits knowledge or a professor is someone who owns knowledge. With first encoding, the learner would have a difficult time mapping the base domain to the target domain [Landlord : (Apartment, Insurance)] because none of the answers in the target domain would fit. With second encoding, the learner would successfully map the base domain to the target domain because the analogy of 'a professor is someone who owns knowledge' is similar to the target domain of 'a landlord is someone who owns an apartment'. Holyoak and Thagard (1989) thus pointed out that the constraints of language may impede the learner's ability to make accurate inferences in analogical reasoning. They proposed that good analogies should relate to a large network of knowledge structure (i.e. schema) that can be primed to new learning.

Rather than focusing on conceptual mapping, schema induced analogical reasoning requires the learner to understand the analogy through an activation of prior knowledge. For example, when teaching a new subject like atom, the complex new subject may take root in the learner's mind through an activation of prior knowledge by telling him/her that the atom resembles a miniature solar system. Research on human memory suggests that memory for complex subject (e.g. atom) is determined not by the words and sentences actually presented, but by what the learner understands (Bransford 1979).

The schema theory posits that human knowledge is represented in an organizing structure called a schema, which provides the framework necessary to understand the new concept. The schema provides, for example, an outline of the structure (sun and planets) and relationship (gravitational and counter-gravitational forces) of the solar system which can be cognitively transferred to a new subject like atom in which the structure (atom and its particles, namely, protons, neutrons and electron) and relationship (positive and negative charges) are similar to the solar system. Evidence from general analogical reasoning studies has shown that analogical reasoning that involves schema induction facilitates better comprehension and knowledge transfer (Gick & Holyoak 1983). The close relationship between the processing of analogues and general schemas is supported both by experimental evidence (Schustack & Anderson 1979) and computational analysis (Winston 1980). Cosgrove (1995) investigated the effect of schema induced analogy on learners' comprehension in electricity. He asserted that schema induced analogy could be used to facilitate meaningful association between new content and prior knowledge, which would result in a perceived improvement in learning as measured by concept recall and knowledge transfer.

Taken together, the above discussion points to the fact that conceptual inference may cause a mismatch in concepts between the base and target domains because of semantic ambiguity. The schema induced analogical reasoning, however, draws on schema to make meaningful connection between the based and target domains. Therefore, it is considered more robust than conceptual inference when it comes to helping learners develop analogical reasoning skills. One of the recent efforts to promote analogical reasoning is to examine the effects of learning technology, especially multimedia on learners' analogical thinking. The next session thus focuses on the relationship between multimedia and analogical reasoning.

Multimedia and analogical reasoning

The role of multimedia in learning has been widely recognized. Kulik and Kulik (1991) argued that computer assisted learning including multimedia is an effective form of instruction because it produces high student outcomes of achievement in short periods of time. Zheng (2007) concurs with Kulik and Kulik's assertion by demonstrating the effects of cognitive functionality of multimedia on problem solving. It has been found that appropriately designed multimedia can lead to an improved performance in problem solving (Zheng *et al.* 2006).

Research has shown that learning becomes more effective when information is processed through multiple sensory input stimuli (i.e. verbal and non-verbal) (Paivio 1986; Rieber & Kini 1991; Rieber 1994). The theory of multimodal learning (Engelkamp 1998) further posits that haptic learning such as motor manipulation deepens learners' understanding in problem solving. Multimedia, especially interactive multimedia, engages learners in multiple sensory input information process in learning. According to Reed (2006), such process often leads to an improved comprehension and consequently, an improved performance in learning due to its multiple presentations of the information.

The apparent benefits of multimedia are illustrated in several studies. In a study conducted by Lee *et al.* (2006) who investigated the effects of multimedia on science learning, the researchers found that multimedia has a significant impact on students' problem solving in science. Schwartz (1993) used visuals to teach learners analogical reasoning skills and discovered a significant difference between learners who used visuals and those who did not, in favour of visual users. He thus concluded that visuals provide better cues in reasoning. Similarly, Angeli and Valanides (2004) conducted a study on visuals and reasoning, and found a visual effect on learners' problem solving reasoning.

Although many studies have examined the relative benefits of multimedia in general reasoning (Mayer *et al.* 2002; Zheng *et al.* 2006; Lee *et al.* 2006), little research has been conducted to investigate the relationship between multimedia and analogical reasoning. The present study investigated the effects of multimedia and analogical reasoning on learners' performance in science learning.

Individual differences and reasoning

Evidence from empirical research indicates that individual difference is significantly correlated with learners' reasoning ability (Stenning & Cox 2006; Ricco 2007). Stenning and Cox studied the undergraduate students' syllogistic reasoning and found that students' reasoning ability was influenced by such factors as field dependence/field independence (FDI). Similar findings were obtained by Noble (2006) who found a significant interaction between problem solving ability and cognitive styles for medical school students.

One of the most studied areas pertinent to individual differences is FDI (Liu & Reed 1994; Angeli & Valanides 2004; Noble 2006). According to Witkin and Goodenough's (1977), the FDI refers to the extent to which a person perceives part of a field as discrete from the surrounding field as a whole, rather than embedded in the field. Although FDI is primarily concerned with learner's visual perceptiveness, it is highly correlated with other cognitive abilities such as problem solving and reasoning (Witkin *et al.* 1971, 2002). The research on FDI has produced mixed findings. Some researchers (e.g. Liu & Reed 1994; Bernardi 2003) demonstrated that learners' performance may be influenced by the differences in cognitive styles such as FDI. Others (e.g. Vincent-Morin & Lafont 2005) have produced research evidence that has no bearing on the effect of field type on performance. Vincent-Morin and Lafont (2005) studied the relationship between performance and FDI and their findings indicated an absence of correlation between FDI and performance. Given the equivocal results, more research effort should be directed toward examining the relationship between field type and learner performance.

Specifically, the present study investigated the following questions:

1 Do interactive multimedia and schema induced analogical reasoning influence learners' performance in science learning?
2 Is field type a significant covariate that would influence learners' analogical reasoning?

Methodology

Participants

Participants included 89 fourth grade elementary students in the north-east of the United States. About 53% of the participants ($n = 47$) were female students. Of the 89 participants, 64 (71 %) were white, 11 (12%) were Hispanic, nine (10%) were African American, and five (7%) were others. None of the participants reported any familiarity with electrical circuits prior to learning the new material. Consent forms from both students and parents were obtained.

Procedures

Participants first took a cognitive style test entitled Group Embedded Figure Test (GEFT) (Witkin *et al*. 1971, 2002). They were then randomly assigned into one of the four conditions: interactive multimedia with analogy (MA), interactive multimedia without analogy (MNA), analogy without interactive multimedia (ANM) and no multimedia and no analogy (NMNA). In MA condition, participants were presented with two multimedia learning objects (MLOs): water system and electrical circuits, with the former serving as the base domain of the analogy (Fig 1). In MNA condition, only the electrical circuit multimedia object was presented (Fig 2). There was no water system analogy based on which the participants could infer the principle of electricity. In ANM condition, participants were verbally primed with the water system analogy but no MLOs were provided. In NMNA condition, participants were taught the electrical circuits in the traditional fashion. The instructor explained the principles of electrical circuits and asked the students to rote memorize a conductivity table which specified the conductivity of various materials and the variation of electrical resistance related to the conductivity of the materials.

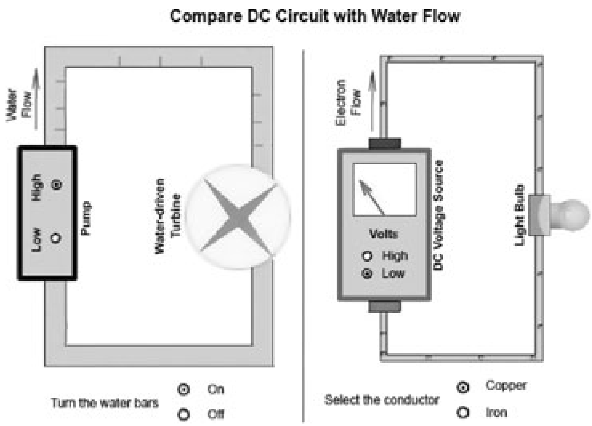

Fig 1 Electrical circuits with water analogy.

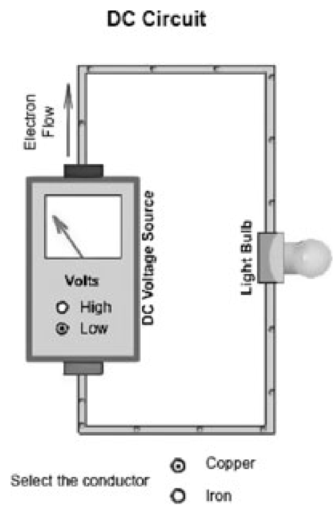

Fig 2 Electrical circuits without analogy.

Neither multimedia nor analogy was provided for the NMNA group.

At the end of the learning unit, participants took an achievement test that contained two subtests: recall and transfer. The entire study took about 40–50 min to complete. Each participant was given a consent form to sign before s/he participated in the study.

Instrumentation

GEFT

The GEFT was developed by Witkin *et al*. (1971, 2002). The test was designed to measure learners' perceptual ability. It consists of three sections, with the second and third sections being counted as valid GEFT test scores. The first section is not scored but can be used as reference for the final GEFT scores. The learner is provided with a sample form sheet that has eight sample figures. He/she is then required to identify the embedded figure in the test item that matches one of the figures in the sample form. It takes about 12 min to complete the entire test. The total possible score for the test is 18 points. A moderate-to-high reliability was reported for age groups of 10, 11 and 12 years old with a Cronbach's alpha of 0.86, 0.81; 0.84, 0.74; and 0.78, 0.74 for both males and females, respectively.

MLOs

The MLOs are composed of a water system and an electrical circuit. The water system MLO contains a water pump, water pipes and a water turbine that is driven by the water (Fig 1). There are nine bars within the pipe in the upper part of the water system. These bars can be turned either vertically or horizontally. The idea is to increase or reduce resistance to water that runs from the water pump to the turbine. For instance, if the bars are turned vertically, the resistance to the water flowing from the pump to the turbine will be created, thus a high pressure is needed for the pump to maintain an appropriate water speed so the turbine can keep running. Conversely, when the bars are turned horizontally which creates minimum resistance to the flow of water, the low pressure button should be selected. The water system delineates the relationship among water pressure (i.e. generated by water pump), water resistance (i.e. generated by the bars in the water pipe) and the turbine.

Like the water system, the electrical circuit system contains a direct current (DC) voltage source, electrical wires and a light bulb (Fig 1). The DC voltage source has high and low buttons that control the output of voltage. When a low conductivity material like iron is used, a high voltage power should be selected to keep the light bulb on. On the contrary, a low voltage power is needed when the material has high conductivity like copper because high conductivity means low electrical resistance. Because the concept of electrical resistance is very abstract and may be difficult for students to comprehend, the water system analogy was employed to provide a visual scheme based on which participants could draw conclusions about the principles of electrical circuits.

The purpose of employing the water system analogy was not to facilitate conceptual inference (see Sternburg's (1977) model) because mapping water pump to DC voltage source, turbine to light bulb, and water pipes to electrical wires would only provide isolated information about the parts contained in both systems. Rather, the analogy was used to activate participants' prior knowledge about how the water system worked, which would be mapped to an electrical circuit system. In other words, by activating participants' knowledge about the relationship among water pump, pipe and turbine in their schema, they were better equipped to comprehend the similar relationship in an electrical circuit system.

The achievement test

The achievement test consisted of two subtests: recall and transfer. Research has indicated that both recall and transfer tests are reliable measures for measuring content comprehension and knowledge application in learning (Mayer & Anderson 1991; Mayer *et al*. 2002; Lee *et al*. 2006; Doolittle *et al*. 2008). Thus, the recall subtest was designed to measure participants' conceptual and procedural knowledge, whereas the transfer subtest gauged their ability to transfer knowledge to a new situation. In the recall subtest, one point was given to the participant for the inclusion of a key concept or procedure. For example, the participant would get one point if he/she selected a high voltage source when the iron was used as conductor. The total possible score for recall questions was 10 points. The transfer section consisted of five questions with two points for each correct answer. The transfer questions tested participants' ability to apply the knowledge learned to a new situation. For example, participants were asked to explain why it was faster to slide down on a polished snowboard than on a piece of unpolished plywood. The total possible score for the transfer subtest was 10 points.

Results

A two-by-two factorial design was employed with multimedia (multimedia vs. non-multimedia) crisscrossing analogy (analogy vs. non-analogy) as independent variables, and recall and transfer scores as dependent variables. The GEFT scores which were treated as a continuous variable were entered as a covariate to determine the impact of field type on participants' analogical reasoning. The GEFT scores showed a mean of 7.85 ($SD = 1.72$) with a range from 5 to 14.

Table 1. Descriptive statistics for groups in terms of recall and transfer (n = 89).

Groups	Recall			Transfer	
	N	*M*	SD	*M*	SD
Multimedia with analogy (MA)	22	7.23	1.15	7.14	1.08
Multimedia without analogy (MNA)	23	5.78	1.27	5.65	1.66
Analogy without multimedia (ANM)	22	6.36	1.46	6.45	1.18
No multimedia and no analogy (NMNA)	22	5.82	1.05	5.68	1.32
Total	89	6.29	1.35	6.22	1.45

Table 2. The MANCOVA analysis.

Source	Dependent variable	Type III sum of squares	d.f.	*F*	Sig	Partial η^2
FDI	Recall	20.226	1	32.971	0.001	0.284
	Transfer	13.659	1	19.788	0.001	0.193
Analogy	Recall	10.227	1	13.672	0.003	0.167
	Transfer	10.586	1	15.336	0.001	0.156
Multimedia	Recall	4.419	1	7.204	0.029	0.060
	Transfer	6.735	1	9.758	0.012	0.085
Analogy[1]	Recall	3.440	1	4.607	0.039	0.043
Multimedia	Transfer	3.158	1	3.973	0.041	0.032
Corrected total	Recall	122.494	88			
	Transfer	119.551	88			

FDI, field dependence/field independence; MANCOVA, multivariate analysis of covariance.

A multivariate analysis of covariance (MANCOVA) analysis was conducted to determine (a) whether there were main effects for multimedia and analogy; (b) whether multimedia would interact with learners' analogical reasoning; and finally, (c) whether field type would significantly affect learners' analogical reasoning in problem solving as a covariate. The means and standard deviations for the groups are reported in Table 1. The results showed that the MA group outperformed all other groups in recall and transfer, followed by the ANM and NMNA groups. The MNA group had the lowest mean scores for both recall and transfer.

The MANCOVA analysis revealed that there was a main effect for multimedia in recall ($F_{(1,\ 88)} = 7.20$, $P < 0.05$) and transfer ($F_{(1,\ 88)} = 9.75$, $P < 0.05$), and a main effect for analogy in recall ($F_{(1,\ 88)} = 16.67$, $P <$ 0.01) and transfer ($F_{(1,\ 88)} = 15.33$, $P < 0.001$), which means there were significant differences between multimedia and non-multimedia, and between analogy and non-analogy learning. Consistent with the literature (Liu & Reed 1994; Bernardi 2003), the covariate of FDI had a significant impact on learners' analogical reasoning in terms of recall ($F_{(1,\ 88)} = 32.97$, $P < 0.001$) and transfer ($F_{(1, 88)} = 19.79$, $P < 0.001$) (Table 2).

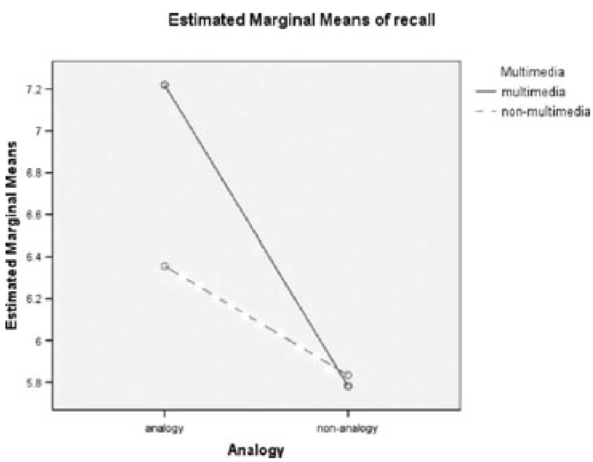

Fig 3 Analogy and multimedia interaction for recall.

Furthermore, a general significant interaction was detected for multimedia and analogy (Wilks' $\lambda = 0.83$, $\eta^2 = 0.16$) pertaining to recall and transfer. Figure 3 indicates a significant interaction between analogy and multimedia for recall. It shows that when multimedia was used with analogy, participants demonstrated highest performance among all groups in terms of recall ($M = 7.23$, SD = 1.15). However, when multimedia was

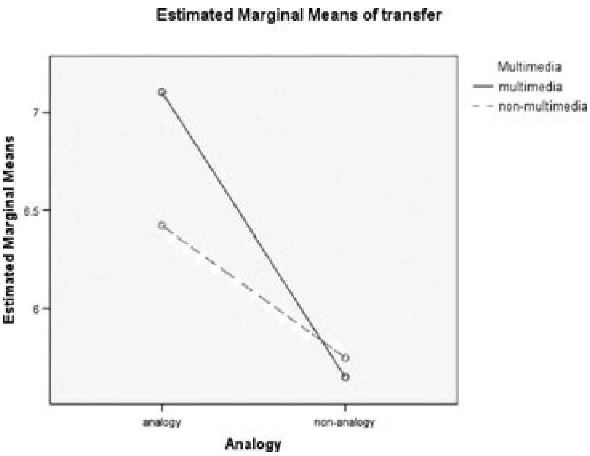

Fig 4 Analogy and multimedia interaction for transfer.

only used as a visual tool, participants displayed the lowest mean score ($M = 5.78$, SD = 1.27). A similar pattern was found for transfer (Fig 4) where the multimedia with analogy group ($M = 7.14$, SD = 1.08) outperformed the multimedia only group ($M = 5.65$, SD = 1.66). In non-multimedia environment, the group with analogy generally outperformed the group without analogy in both recall and transfer sub-tests.

Discussion and implications

The results strongly suggest that learners can significantly benefit from schema induced analogical reasoning in science learning and that multimedia may facilitate learners' reasoning ability. Furthermore, FDI has shown to be a significant factor influencing learners' schema induced analogical reasoning. The following discussion thus focuses on the significance and implications of the above findings by examining (a) the influence of multimedia and schema induced analogical reasoning on science learning, and (b) the influence of field type as a covariate on learner's analogical reasoning.

Influence of multimedia and schema induced analogical reasoning on science learning

The present study demonstrated that learners could benefit from analogical and multimedia instructional strategies in science learning. This was supported by the main effects detected for both analogy and multimedia in recall and transfer sub-tests. The study uncovered an overall effect for analogy on learning with the group that received analogy support outperforming the group that had no analogy support in both multimedia and non-multimedia learning environments. The findings of the study confirmed our postulation that schema induced analogical reasoning would provide necessary cognitive support to learners' science learning.

Along with the above findings were the role of multimedia and its relationship with analogy in science learning. Consistent with the theory of multimodal learning (Engelkamp 1998; Reed 2006), the present study proved that learners' schema acquisition and performance could be facilitated by interactive multimedia. However, the instructional effectiveness of interactive multimedia seemed to be effected through integration with analogy. This was shown in the interaction between analogy and multimedia for recall and transfer where multimedia became more effective when it was integrated with analogy and less so when multimedia was used only as a visual tool (see Figs 3 and 4). One of the possible explanations for learners' low performance in multimedia learning would be that simply using the multimedia without a sound instructional design approach could cause distraction in learning (Park & Hannafin 1993; Albion & Gibson 2000). Clark (1994) argued that media may influence the 'speed of learning but only the use of adequate instructional methods will influence learning' (p. 27). The above argument was further supported by the recent research in multimedia learning where instructional approaches like schema-based learning were integrated to optimize the effects of multimedia in learning (Lee *et al*. 2006; van Merrrienboer & Sweller 2005).

In conclusion, the findings confirmed the influence of multimedia and schema induced analogical reasoning on learners' performance as mentioned in research question one. However, caution should be taken when interpreting the above results. As mentioned earlier, the instructional role of multimedia became more prominent when an adequate instructional method was included. It became less robust if it was used only as a visual tool.

Influence of field type as a covariate on learner's analogical reasoning

Although learners' schema induced analogical reasoning was influenced by both multimedia and analogy variables, the field type also had a significant impact on learners' reasoning. Results showed that FDI covariated with multimedia and analogy in learners' recall ($F_{(1, 88)} = 32.97$, $P < 0.001$) and transfer ($F_{(1, 88)} = 19.79$, $P < 0.001$). This confirmed research question two that field type as a covariate significantly influenced learners' ability in analogical reasoning.

Consistent with the literature, the findings of the present study continue to support the view that FDI influences how people determine, make judgment and draw conclusions about the things they observe (Liu & Reed 1994; Angeli & Valanides 2004; Noble 2006). Yet, the findings extended beyond what has been identified in the literature to suggest that the influence of field type on reasoning is associated with the mode of learning. For example, the multimodal nature of interactive multimedia provided learners with a learner control that would assist learners, especially those who relied on the support of external resources, in their analogical reasoning. According to Witkin *et al*. (1971, 2002), field dependent (FD) people are more likely to rely on external resources in learning. Thus, by manipulating the analogical multimedia objects, FD learners were able to visually reason through the steps by relating the schema induced analogy to the new content.

As an instructional strategy, schema induced analogy has been proven to be effective in assisting learners to understand the new content. However, the effectiveness of schema induced analogy can be enhanced through the use of appropriately designed multimedia. The present study has revealed the effects of multimedia on learners' schema induced analogical reasoning. It has also shown that individual differences such as FDI could influence learners' schema induced analogical reasoning. Additionally, the present study revealed that the instructional function of multimedia can be significantly enhanced when multimedia is integrated with an adequately designed instructional method. Also noteworthy is the relationship between the FDI and the mode of learning involved in analogical reasoning. The interactive multimedia, characterized by its multimodal presentations, supports FD learners who resort to multiple cues including visual, oral, aural and other cues in learning.

There are several important implications for teaching schema induced analogical reasoning using interactive multimedia learning. First, it is important to put an instructional method in perspective when applying multimedia to learning. Second, the design of multimedia supported analogies needs to consider the impact of individual differences such as FDI on reasoning. Interactive multimedia provides the kind of learner control for effective schema acquisition and activation which would enable learners to reason more effectively, particularly for those who depend on external resources in learning.

This study was restricted to one elementary school which limited the variability of samples in terms of ethnicity as well as social and economical conditions. This limitation may affect the generalizability of the findings of the present study. It is therefore suggested that future research include a population with more variation in age, race, geography, and social and economical conditions. Additional research is needed to investigate the difference between conceptual inferences and schema induced analogies when both types of analogical reasoning are supported by multimedia. In the present study, the individual difference has been identified as a significant covariate on reasoning. Further investigation should be directed to identifying effective strategies, such as the use of certain mode of learning to mitigate such influence on learners' analogical reasoning.

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