Prior Knowledge and Mathematics Different Order Thinking Skills in Multimedia Learning

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Abstract: This experimental study investigated prior knowledge and instructional visual aid on different mathematical order thinking skills of remembering, understanding and analyzing in multimedia learning. One hundred and twenty-three secondary school students was randomly assigned to a condition, in a 2 (prior knowledge: weaker vs stronger) x 2 (aid: with vs without) between subjects factorial design. In the experiment, the aid was evolved from variation theory and multiple representations and the materials were designed using multimedia learning principles. The results showed that the stronger group learned better on remembering, only the weaker group benefited from the aid on understanding, and the aid was more beneficial on analyzing. We suggest that multimedia presentation designs should take into account prior knowledge and order thinking. Limitations and future research are discussed.

Keywords: prior knowledge, multimedia learning, mathematics, order thinking skill, cognitive processing

Introduction

Multimedia presentations should display images and words simultaneously for learning (Mayer, 2009). The use of the presentations are considered effective in learning for mathematics, as it results in better remembering (retention) and understanding (transfer) skills (Chiu & Churchill, 2015a, 2015b; Mayer, 2009). Learner prior knowledge can influence the effectiveness of learning with multimedia presentations (Kalyuga, 2014; Mayer, 2009; Schnotz & Lowe, 2003). Many experimental studies showed that learners of different prior knowledge level responded differently to a multimedia design (Kalyuga, 2014; Leslie, Low, Jin, & Sweller, 2012, Liu, Lin, & Paas, 2014; Potelle & Rouet, 2003; Spanjers, Wouters, Van Gog, & Van Merrienboer, 2011). In their experiments, the tests used assessed remembering and understanding, but not higher order thinking skills. Their additional designs, treatments, were not customized for a specific domain (e.g. Spanjers et al. 2011; Leslie et al., 2012). Higher order thinking skills that require dynamic and relational internal (mental) representations would receive different effects from the additional designs. Therefore, this study aims to investigate the effects of prior knowledge and visual aid on three different order thinking skills of remembering, understanding and analyzing for algebra. Since many studies were conducted for remember and understanding, this study focuses on the higher thinking skill of analyzing. It is expected that the aid would differently affect the development of the three thinking skills. The aid was designed specifically for algebraic learning.

Prior knowledge and multimedia design

The cognitive theory of multimedia learning suggests that learners select relevant multimedia messages from the presentations (extraneous processing), organize them into a mental structure (essential), and finally integrate it with relevant prior knowledge (generative) retrieved from long-term memory (Mayer, 2009). Therefore, prior knowledge level and recalling process directly influence the effectiveness of the integration process – acquiring new knowledge – in multimedia learning (Chiu, 2015; Kalyuga, 2014; Mayer, 2009).

Many experimental studies support prior knowledge has impact on remembering and understanding in multimedia learning (Chiu, 2015; Kalyuga, 2007, 2014; Kalyuga et al., 2000; Leslie et al., 2012; Rey & Fischer, 2013; Spanjers et al., 2011). The experimental materials included additional designs, such as presenting aids audibly and/or visually, and controlling the pace of learning (see segmenting principle). For example, the design that showed steps to learn with images presented on screen worked best for weaker learners, but not for stronger learners (Kalyuga et al., 2000); visual representations helped younger children (less prior knowledge) learn science, but not older children (Leslie et al., 2012); segmented animations were more effective than continuous animations for less knowledgeable learners (Spanjers et al., 2011); and adding expository examples and illustrations was more beneficial for weaker undergraduate students rather than stronger students when developing the statistical skill (Rey & Fischer, 2013). The studies suggested that the designs – treatments – helped weaker learners understand the images and words presented. The designs provided information or environments to guide weaker learners to connect images and words presented thereby easing the cognitive processing for searching or recalling. In contrast, stronger learners may found the information is duplicated or the environments are discouraging. The designs became a burden, which required additional cognitive processing (Kalyuga, 2014).

This processing was unnecessary and resulted in less cognitive capacity for other kinds of processing, which is more important for stronger learners (Kalyuga, 2014). Moreover, most of the studies indicated incorporating additional design in multimedia representations was effective for both learners on remembering, but was effective for weaker learners only on understanding when learned from the presentations (Leslie et al., 2012; Rey & Fischer, 2013; Spanjers et al., 2011).

Instructional design for presentation – algebra

An important factor in experimental studies is the additional design. Instructionally providing appropriate and relevant learning messages for a specific-domain is beneficial for learners (Brophy, 2001; Marton et al., 2004; NCTM, 2000). In algebra teaching, numerous studies on presenting various forms of learning information for students have been conducted. Rittle-Johnson and Star (2007, 2009) endorse comparing and contrasting solution methods – students learn better by comparing an equation and its different solution methods, or by comparing different forms of an equation and their solution method. By applying variation to algebra teaching, students understand concepts better by seeing and experiencing different algebraic forms and solving methods simultaneously (Marton et al., 2004; Mok, 2009; Mok et al., 2002). Other than teaching strategies evolved from the variation, NCTM (2000) suggests that mathematics concepts should be presented in four forms that are numerical, graphical, algebraic and descriptive simultaneously to ensure effective algebra learning.

Mathematics orders of thinking skills and cognitive processing

The revised Bloom's Taxonomy categorized skills into six cognitive process dimensions (Anderson et al., 2001). The taxonomy suggests six orders of thinking skills. They are remembering, understanding, applying, analyzing, evaluating and creating. Remembering requires learners to retrieve, recognize and recall relevant knowledge from long-term memory; understanding requires them to construct their knowledge by way of classifying, summarizing and comparing; applying requires learners to implement procedure; analyzing requires learners to determine how parts relate to each another and to an overall idea; evaluating requires students to make judgments and explain their decisions; and creating requires students to reorganize what they have understood into a new pattern.

In mathematics, a higher order thinking skill requires more complete understanding (Berger & Torner, 2002; Derry, 1990; Rabinowitz, 1988) – a large number of knowledge and concepts needed for its development (Derry, 1990; Sweller & Cooper, 1985). Instructional methods for the higher order thinking skill will be more effective if they helped learners acquire prerequisite knowledge beforehand (Derry, 1990; Sweller & Cooper, 1985), for example, acquiring procedures of reassigning variables in an algebraic equation before solving conventional problems (Sweller & Cooper, 1985). Learning methods of lower order thinking skills can contribute to development of higher order thinking skill (Derry, 1990; Silver & Marshall, 1990). Developing a higher order thinking skill can involve different types of thinking/cognitive processes of its own and/or other lower order thinking skills (Derry, 1990; Silver & Marshall, 1990). In other words, more different thinking processes are likely to be involved when developing higher order thinking skills, which may lead to heavier learner essential and generative processing.

According to cognitive theory of multimedia learning, essential processing comprises selecting multimedia messages from a presentation (Mayer, 2009). An instructional design better instructs learners how to learn with images and words, which requires less time in selecting process, suggesting a more-structured design has less essential processing than a less-structured design. In other words, in less-structured environment, learners will have heavier essential processing and need more help. Less-structured environments are more effective to develop higher order thinking because the environments do not impede conceptually oriented interactions (Cohen, 1994). An instructional design, such as visual aid, that complicates development of lower order thinking skills may become more helpful for stronger learners when developing higher order thinking skills in less-structured environments.

Methods

The present study

The present study aims to investigate prior knowledge and visual aid on remembering, understanding and analyzing for secondary level algebra in multimedia learning. The materials used in the experiment were designed using Mayer's multimedia learning principles; the aid was designed for algebraic learning. We hypothesized that (1) the stronger students would performed better on remembering, (2) only the weaker students benefited from the aid on understanding (Leisle et al., 2012; Spanjers et al., 2011), and (3) with the aid was a better design than without on analyzing.

Participants and design

We invited 140 senior secondary level students aged from 16 to 18 years from a Hong Kong school to participate this study. Only 123 (around 60% boys) completed the experiments. We also invited two teachers in the school to conduct the experiments. A 2 x 2 between subjects factorial design with the factors prior knowledge (weaker vs stronger) and visual aid (with vs without) was used. This resulted in the four experimental conditions – 30 weaker students learning with the aid, 32 weaker students learning without the aid, 31 stronger students learning with the aid, and 30 stronger students learning without the aid.

Materials

This experiment included learning material and a posttest. We used the learning materials of Chiu and Churchill (2015b), see their online video in the experiment and Figure 1. The materials were developed using Mayer multimedia learning design principles under a design-based approach. The design aims to maximize learner cognitive capacity. Moreover, the visual aid design, evolved from variation theory, presented different forms of a quadratic equation and its different solving methods, and the four-section presentation – graph, equation, solving method and description. The description and solving method sections demonstrated the relationships between the graph and equation sections.

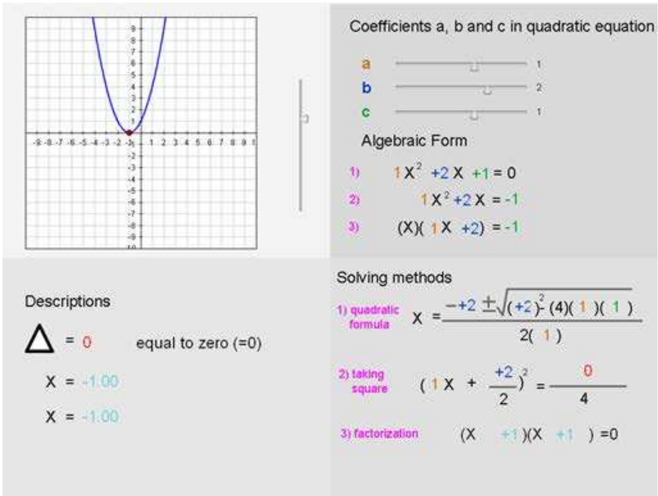
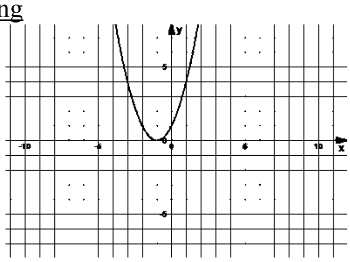


Figure 1. The material in the treatment group.

In the posttest, the questions were tested in the study of Chiu and Churchill (2015a). The questions assessed remembering (retention, level 1 in Anderson, Krathwohl, & Bloom, 2001), understanding (transfer, level 2) and analyzing (transfer, level 4). In the questions of remembering, students were required to write down the value(s) of roots and discriminant of a graph, see Figure 2; in that of understanding, the students were asked to identify graph(s) of a quadratic equation or a condition; and in the analyzing questions, students were required to consider two pairs of statements or expressions and decide whether they were related (or true) or not related (or false). Each of the questions was scored out of 1; and each skill was scored out of 12.

Remembering

What are



the values of roots of an equation f(x)=0?
What is the sign of the discriminant of an equation f(x)=0?

Understanding
Which of the following graph is $y=ax^2+bx+c$ if when $a<0$?

Analyzing

Statement or expression 1	Statement or expression 2
$\Delta=b^2-4ac$	Determines number of x-intercepts
value of a	Determines shape of the function $y=ax^2+bx+c$.

Figure 2. Questions used in the post-test.

Procedure

We first got the consent of the principal, teachers and parents. A pilot study was used to determine the time allowed for learning tasks. Before the experiment, the students completed an online 10-minute multiple-choice question quiz. The students were divided into the four experimental conditions based on a median split using the quiz scores obtained in the pretest (Kalyuga, 2007). We conducted the experiments in a computer room. In the experiments, the students were assigned to an individual seat in front of a personal computer. We first briefed them on the procedure of the experiment, and explained how to control the materials and what they would learn from the learning activities. The students had 40 minutes to manipulate the multimedia materials assigned, to understand the relationships between the graph and equation for learning. After the experiment, the students completed the posttests in 30 minutes.

Results

A t-test analysis showed that there was a significant difference between the weaker and stronger learner groups in the quiz, all p values <0.001. This showed that stronger group had significant better skills to remember, apply and analyze graphical representations of algebraic equations.

We conducted univariate ANOVAs with remembering, understanding and analyzing as dependent variables. The results of Levene's tests, all p values >0.05, indicated that all dependent variables met the assumption of homogeneity of variance. Means and standard deviations for scores of the three skills for both weaker and stronger students were shown in Table 1.

Table 1. Means and standard deviations of remembering, understanding and analyzing in the posttest.

Condition	Remembering		Understanding		Analyzing	
	M	SD	M	SD	M	SD
Weaker group with the aid (n=30)	7.47	1.00	7.40	1.30	6.87	1.20
Weaker group without the aid (n=32)	6.88	1.13	6.34	1.31	5.69	1.18
Stronger group with the aid (n=31)	9.42	1.29	7.16	1.50	7.35	1.40
Stronger group without the aid (n=30)	9.13	1.50	8.10	1.71	5.97	1.03

The results of ANOVA on dependent variable remembering showed the main effect of prior knowledge was found, $F(1, 119) = 83.66$, $p < 0.001$, partial $\eta^2 =0.41$, indicating that there was a significant difference for the stronger ($M = 9.38$, $SD = 1.50$) over weaker groups ($M = 7.16$, $SD = 1.10$). There was no main effect of multimedia design, $F(1, 119) = 3.722$, $p =0.056$, partial $\eta^2 =0.03$, nor was there a multimedia design by prior knowledge, $F(1, 119) = 0.339$, $p =0.561$, partial $\eta^2 <0.01$.

With regard to the dependent variable understanding, univariate ANOVAs showed that there was no significant effect of multimedia design, $F(1,119) = 2.60$, $p =0.110$, partial $\eta^2 =0.021$. A significant main effect was found for prior knowledge, $F(1, 119) = 17.96$, $p < 0.001$, partial $\eta^2 =0.13$, such that the stronger group ($M = 8.00$, $SD = 1.62$) outperformed the weaker group ($M = 6.85$, $SD = 1.40$). A significant interaction effect was found, $F(1, 119) = 5.52$, $p =0.020$, partial $\eta^2 =0.04$, see Figure 3. A significant simple effect was found for the weaker group who learned better with the aid, $F(1, 60) = 10.12$, $p=0.002$, partial $\eta^2 =0.144$; a significant simple effect was for the stronger group who learned better without the aid, $F(1, 59) = 0.22$, $p=0.32$ (one-tailed), partial $\eta^2 =0.004$. A significant simple effect was found for the multimedia design without the aid, such that the stronger group learned better than the weaker group, $F(1, 60) = 20.78$, $p<0.001$, partial $\eta^2 = 0.257$; no simple effect was found for the material design with the aid, $F(1, 59) = 1.87$, $p=0.177$, partial $\eta^2 = 0.031$.

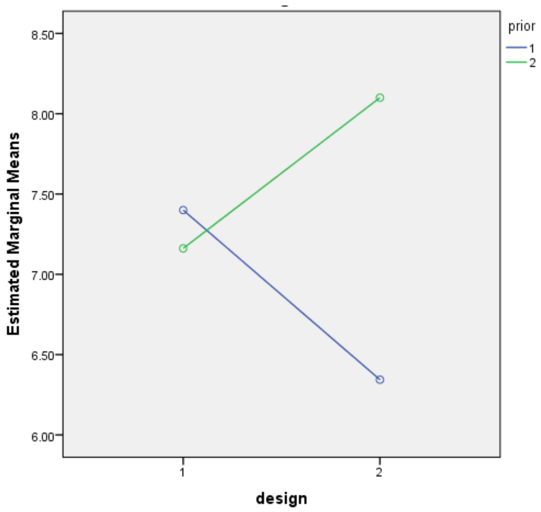


Figure 3. The interaction between prior knowledge and visual aid on remembering.
Note: Design 1 – with aid; 2 – without aid. Prior 1 – novice group; 2 – advanced group.

For dependent variable analyzing, a two-way ANOVA indicated there was a significant main effect of multimedia design, $F(1, 119) = 34.55$, $p<0.001$, partial $\eta^2 = 0.225$. The groups learned better with the aid (M=7.11, SD=1.32) rather than without the aid (M=5.83, SD=1.11). No significant effects were found for either prior knowledge, $F(1, 119) = 3.09$, $p=0.082$, partial $\eta^2 = 0.025$, or interaction effect, $F(1, 119) = 0.23$, $p=0.633$, partial $\eta^2 = 0.002$.

Overall, these results show that the aid have negative effects on the stronger group when developing understanding skills in multimedia environments, but not for remembering and analyzing.

Discussion and conclusion

The experiment reported in this paper was designed to investigate the effect of the instructional visual aid that is designed using variation theory and four-section representation in digital multimedia learning environments for mathematics students with different levels of prior knowledge on different order thinking skills – remembering, understanding and analyzing skills. The goal of this study was to investigate prior knowledge and visual aid on remembering, understanding and analyzing for secondary level algebra in multimedia learning.

The results of remembering and understanding supported the studies of Leslie and colleagues (2012), and Rey and Fischer (2013). Remembering was influenced by prior knowledge. The stronger group remembered better than the weaker group, suggesting the visual aid is not necessary for facilitating remembering. On understanding, the weaker group who received the aid outperformed those weaker students did not receive the aid. In contrast, the stronger group who received the aid performed less well than the strong group who did not receive the aid. These results suggest that the aid did help the weaker group see the relationships between the equation and the graph to understand the properties of the graph better. The description section in the aid, which may be seen as an explanation, directly explained the relationship between the graph and equation. The section appeared to be redundant for the stronger group who may have stronger graphical property skills. Processing the aid was extraneous processing in working memory and thereby reduced cognitive capacity available for other processing. Therefore, this demonstrates that for weaker group, graphs and equations might be facilitated by the inclusion of a visual instructional aid that facilitates essential processing. Also demonstrated was that the same visual aid had negative consequences for stronger group.

The results further showed that the with the aid group outperformed the without group in developing analyzing. A plausible explanation is that the learning task for analyzing involved heavier cognitive processing. The analysis questions required the students to justify if there were any relationships between pairs of statements. The students were required to see the connections among most multimedia messages when the learned with the material, which became less structured environment. The cognitive process in this environment is heavier

(Nievelstein et al., 2013) for both weaker and stronger students. The students would need more help to connect multimedia messages for constructing a more complete understanding. Processing the aid that may provide essential information could be necessary for all the students, therefore, the aid were not be redundant for the stronger students, but facilitated essential processing.

Implications and suggestions

The findings also show multimedia materials were more effective when designed for learners of different levels of prior knowledge (Kaluga, 2014; Mayer, 2009) and order thinking skills. The studies have three implications. First, the findings confirmed that the visual aid format – variations and multiple representations – were more effective for weaker students in understanding. The aid explained the relationships between graphs and equations, and thereby helped weaker students have better understanding algebra (see Leslie et al., 2012; Rey & Fischer, 2013) in multimedia learning. Second, if not carefully orchestrated in order thinking skill, students of different prior knowledge may not receive the best design. In our experiment, for weaker students, the aid was more effective in understanding compared to analyzing and remembering. There may have better designs for remembering and analyzing skill development. As discussed before, numerous experimental studies support the effects of prior knowledge on multimedia learning, but most of them did not consider higher orders of thinking skills. Our findings suggested that the order of thinking skills could influence the effects of prior knowledge on the instructional design in multimedia learning. Third, processing the aid for higher order thinking skills can facilitate essential processing for better learning outcomes. In other words, designs that are ineffective for stronger learners in structured tasks may become effective for them in less structure tasks.

The results also afford two suggestions. First, multimedia presentation designs should consider order thinking skill and prior knowledge. Using order thinking skills to identify instructional formats or procedures can balance the degree of guidance offered to learners. Second, in algebra learning, providing graphs and equations can be enough for students when developing remembering, but when developing understanding, an aid should be added to weaker students only. An aid should be included for all the students when developing the higher order thinking skill of analyzing.

In conclusion, the findings can contribute to the design principal for learner prior knowledge in multimedia learning, such as Kalyuga (2014) and Mayer (2009). One multimedia learning design cannot fit all learners of different prior knowledge levels (Kalyuga, 2007, 2009, 2014, Mayer, 2009). This study further suggests that one multimedia learning design also cannot fit all different order thinking skills. Instructional designs for the weaker learners may become useful for the stronger learners when developing higher order of thinking skills that require higher cognitive processing.

Limitations and future directions

The present findings are also relevant to adaptive digital multimedia learning environments. Multimedia learning will be used in many adaptive learning environments (Van Merrienboer & Sweller, 2005) in the future. Most studies suggest using learner behavior, characteristics and prior knowledge (Astleitner & Wiesner, 2004; Chiu, 2016; Chiu & Churchill, 2015c; Kalyuga, 2006, 2008) to modify the environment or to give personalized feedback to learners. This present study suggests that the adaptive environment should include order thinking skills and learner prior knowledge to identify multimedia presentations or tasks for delivery to promote individual learning.

It is important to better evaluate the effects of instructional designs and learner prior knowledge level on different order thinking skills. The results of the present experiment could also be extended by additional studies on other higher order thinking or in other subject domains.

Overall, future research on adaptive learning environments should focus on cognitive processing, and interactions among learner prerequisites, multimedia presentations and learning outcomes.

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