Chapter 22
Effects of Prior Knowledge on Mathematics Different Order Thinking Skills in Mobile Multimedia Environments

Thomas K.F. Chiu

Abstract This chapter presents a study that examined the effects of prior knowledge and multimedia design on developing mathematical conceptual understanding in a mobile learning environment. Two different approaches—instructional and noninstructional—were used in the design of the multimedia representation to facilitate students learning for a more complete understanding. Seventy students with different levels of prior knowledge in a secondary school participated in the experiment. Participants were assigned to the 2 (high vs. low prior knowledge group) × 2 (instructional vs. noninstructional) factorial groups to receive the 100-min treatment. The results revealed that the low prior knowledge group outperformed the high prior knowledge group in conceptual knowledge of low order thinking; the instructional group outperformed than the noninstructional group in conceptual knowledge of high order thinking and procedural knowledge; and there was no interaction of prior knowledge and design approach. These findings suggest that mobile multimedia environment enhancing viewing is sufficient for the low order thinking skill development, but not for the high order in mathematics concept learning and procedural skill. Finally, recommendations for future research were suggested.

22.1 Introduction

Mobile technologies are the most widely used information and communication technologies; 90 % of the world population has available access to mobile networks (International Telecommunication Union 2012). Using the mobile devices in classrooms can offer diverse opportunities for teachers and students (Boticki et al. 2015; Gedik et al. 2012). Many schools have been introducing mobile devices in learning and teaching. Most of the devices are small screens. Therefore, one of the

T.K.F. Chiu (✉)
Faculty of Education, The University of Hong Kong, Hong Kong, SAR China
e-mail: tchiu@hku.hk

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main challenges in mobile learning is how to design multimedia representations of digital materials for the small screens (Chen et al. 2008; Churchill 2011; Gay et al. 2001); design of multimedia representation should be studied more in mobile environments (Churchill 2011).

Literature addresses that there are limitations on designing effective multimedia presentation of educational materials in mobile environments (see Albers and Kim 2001; Churchill 2011; Churchill and Hedberg 2008; Lee and Bahn 2005). Due to the limited display space, reading multimedia messages on mobile devices is more difficult than that on paper (Albers and Kim 2001). Besides, interactive feature should be the main focus in mobile learning design (Churchill 2011). Churchill (2011) gives some recommendations for designing mobile devices based on the results of his study with Churchill and Hedberg (2008) regarding investigating different design of learning objects via handheld devices. For example, landscape presentation of learning material should be provided to increase the learning space that improved learner experience; no scrolling is recommended; the learning content should be task-oriented; the interaction should be single (one-step), which allows learners to notice immediately responses after manipulation; and zooming function should be provided, which allows learners to be able to enlarge learning content for better reading. Their studies indicated that the suggestions for mobile environments can enhance viewing that lead to better learning. Although these suggestions sound promising, the effects of prior knowledge on design of the multimedia presentation on learning in mobile environments are unclear. This present study aims to investigate the effects of prior knowledge and multimedia design on mathematics concept learning in mobile environments.

22.2 Literature Review

22.2.1 Multimedia Learning and Prior Knowledge

How to design multimedia representation influences the processes and outcomes of learning (Ainsworth 1999; Chiu and Churchill 2015a, b; Mayer 2009). Multimedia learning as learning with both visual and audio representation: visual representation is defined as pictures, graphs or video, audio representation as written or spoken words (Mayer 2009). Multimedia learning is designed to foster meaningful learning that helps learners to construct their knowledge organized in an integrated representation. The goals of multimedia learning are to develop learners' abilities to reproduce and apply the learning content presented in the materials—i.e., facilitating remembering and better understanding. Learning with images and words are more effective than learning with words alone—learners remember more (Chiu and Churchill 2015a, b; Doolittle 2002; Levin et al. 1987; Sankey et al. 2012). Images and words can complement each other, resulting in a better representation than either images or words used in isolation (Bodemer et al. 2004; Clark 1994; Lusk et al. 2009; Fletcher and Tobias 2005; Low and Sweller 2005). Moreover, while words are the basic form of representation in learning environments, Stokes (2002) notes that many studies claim that teaching with visuals leads to a greater degree of learning. Memories of learners are improved when information is supplemented by the use of images (Lusk et al. 2009), which suggests that most people might be expected to retain more information using learning materials including appropriate visual content.

Learner prior knowledge has effects on multimedia learning (Lust et al. 2009; Mayer 2009) in mobile environments (Liu et al. 2013). Students with different levels of prior knowledge responded differently to a multimedia design. Schnotz and Bannert (2003) suggest that images facilitate learning of learners with low prior knowledge; interfere learning of learners with high prior knowledge when the subject matter is visualized. Mayer (1997) suggest that learners with low prior knowledge benefit more from images and words than those with high prior knowledge since learners with higher prior knowledge can construct their mental understanding by reading text only. However, Schnotz and Lowe (2003) suggest that well-designed images and text are important for both low and high prior knowledge learners. Low prior knowledge learners need the images support in developing their mental understanding; and high prior knowledge learners simplify processing for developing mental understanding. Therefore, prior knowledge and multimedia representation have interaction effects on learning.

Many experimental studies have further demonstrated that prior knowledge and multimedia representation have close relationships on two different order thinking skills—remembering and understanding (Kalyuga 2014; Kalyuga et al. 2000; Leslie et al. 2012; Potelle and Rouet 2003; Rey and Fischer 2013; Spanjers et al. 2011), in mathematics learning (Guo et al. 2013; Lee and Chen 2009; Rittle-Johnson and Star 2007, 2009). For example, the design that presented steps to learn with images presented on screen worked best for weak students, but not for strong students (Kalyuga et al. 2000); images helped younger (less prior knowledge) students learn *science better* (*Leslie* et al. 2012)*; and continuous animations were more effective than* segmented animations for experienced students (Spanjers et al. 2011). These studies measured remembering and understanding skills in their experiments (Leslie et al. 2012; Rey and Fischer 2013; Spanjers et al. 2011). The results indicated that the multimedia designs are beneficial to both weak and strong students on remembering, but the designs were only beneficial for weak students on understanding. In conclusion, there are causal relationships between prior knowledge and order thinking skill in multimedia learning. It also seems that low prior knowledge students performed better when developing higher order thinking skills.

22.2.2 Instructional Design in Mathematics

Learning outcomes can be improved significantly when applying instructional strategies in design (Clark 1994; Riffell and Sibley 2005; Wiredu 2005). Learning mathematics concepts, unlike learning language, involved massive amount of learning information and thinking. Specific-discipline instructional strategies should be considered in designing content representation for mathematics concept learning. In algebra teaching, many researches on presenting various forms of learning information for students learning have been conducted. Rittle-johnson and Star (2007, 2009) suggest that comparing and contrasting solution method—student learning better by comparing an equation and its different solution methods or comparing different forms of an equation and their solution method. Moreover, Mok (2009) conducted a study on teaching techniques evolved from variation theory. By applying variation to algebra teaching, students have better understanding of concepts by experiencing different solving methods and algebraic forms at the same time on the same screen. In order to facilitate concept learning, teaching, and learning activities should be intended to help students build relationships among different forms of the same problem (Gu et al. 2004; Mok and Lopez-Real 2006). Mok and Lopez-Real (2006) suggest that variation in equation or solving method should be adopted by teachers for teaching algebra. However, in their studies, either different equations or solving method was varied for students learning, but not equation and solving method together. Moreover, Rittle-Johnson and his colleagues (2009) found that prior knowledge had impact on the effectiveness of the variation in content representation. Their results showed that lower prior knowledge students benefited more when learned by comparing various problems, and high prior knowledge students benefited more when learned by comparing solution methods. Apart from teaching strategies evolved from the variation, algebraic, numerical, graphical, and descriptive should be shown simultaneously when mathematics concepts was taught (NCTM 2000) to ensure effective algebra learning and teaching. The representation intends to help students in perceiving the relationships and associations between conceptual and procedural knowledge. Therefore, the teaching strategies—variation method and four-section representation—should be taken account into designing content representation for algebra learning.

22.2.3 The Present Study

The aim of the present study was to investigate the effects of prior knowledge (low vs. high) and multimedia representation incorporating instructional strategies (noninstructional vs. instructional design approach) in a mobile environment on development of conceptual understanding emerging conceptual knowledge that includes low order thinking skill—graphical property and concept association and high order thinking skill—evaluation of solutions and written explanation (CDC and HKEAA 2007; Kastberg 2003; Schneider and Stern 2005; Thompson 2008; Usiskin 1999), and procedural knowledge of low order thinking skill—graphical representation skills. We focused on developing student conceptual understanding through manipulating learning objects (Chiu and Churchill 2015a; Wagner 2002). More specifically, a conceptual model, a type of learning object, was used in the experiment (Chiu and Churchill 2015a, b; Churchill 2007, 2011, 2013). The representations of the conceptual model are interactive and visual mediated experiment (Chiu and Churchill 2015a, b; Churchill 2007, 2011, 2013). The model that presented property, parameters and relationships of discipline-specific concepts in an interactive and audio and visual way intends to improve conceptual understanding experiment (Churchill 2007, 2011). The learning activity in the experiment was self-learning.

The study examined the following questions. In a mobile environment using multimedia representation, (1) Do students with low prior knowledge outperform those with high prior knowledge on their conceptual understanding? (2) Does the instructional design approach have more positive effect than noninstructional design approach on students' conceptual understanding? (3) Does the combination of design approach and prior knowledge have an effect on students' conceptual understanding?. Hence, we explored three hypotheses: In a mobile multimedia environment, (1) low prior knowledge students will achieve better performance on conceptual knowledge that requires low order thinking skill, (2) Students who learn with instructional design approach will achieve better performance on conceptual knowledge that requires high order thinking skill than those who would learn with noninstructional design approach. (3) Students who would learn with instructional design approach will achieve better performance on procedural knowledge than those who would learn with noninstructional design approach.

22.3 Method

22.3.1 Participants

Seventy students of a secondary school in Hong Kong participated and completed in this study. All the students had been taught the essential concepts about quadratic equation—solving and forming equation skills—by the same teacher approximately 2 weeks before the start of the experiment. The students were divided into two groups (high prior knowledge and low prior knowledge) according to their scores of a recent mathematics quiz on the essential concept taught. The students scored less than 2/3 of full mark in the quiz were assigned to the low prior knowledge group; and those scored more than or equal to 2/3 of full mark in the quiz were assigned to the high prior knowledge group.

22.3.2 Design

A 2 (different design approach: instructional vs. noninstructional) × 2 (prior knowledge: low vs. high) between-subjects design was used to address the hypotheses in this study. The low and high prior knowledge students were assigned to the two situations with different design approaches of a conceptual model. This resulted in the four experimental conditions—18 students with low prior knowledge learning with multimedia representation using instructional design approach, 18 students with high prior knowledge learning with multimedia representation using instructional design approach, 17 students with low prior knowledge learning with multimedia representation using non-instructional design approach, 17 students with lower prior knowledge learning with multimedia representation using non-instructional design approach. Moreover, this study used pre- and post- conceptual and procedural knowledge performance tests to measure the improvement of conceptual understanding in the experiment (Schneider and Stern 2005).

22.3.3 Materials

Materials in the experiment included learning materials, pre and posttests. Learning materials used in the experiment was conceptual models. The conceptual model was adopted from the studies of Chiu and Churchill (2015a, b). Two different designs were non-instructional and instructional approaches. The instructional approach adopted the four-form representation suggested by NCTM and variations of equations and solving method together; and the noninstructional approach showed an equation and its graphical representation. Since well-designed images and text are important for both high and low prior knowledge learners, five multimedia learning design principles—coherence, signaling, spatial contiguity, temporal contiguity, and segmenting—were applied to the two approaches to reducing cognitive load of students. These can make the image and text presented better. The topic was secondary school-level quadratic equations. The design of the conceptual model in the experiment followed the recommendations of the Churchill' mobile multimedia environment design. For example, presentation of the learning content was full-screen and landscape; and information of the conceptual model was tasked-centered; and control slides offered students to control for instant responses (one-step).

In the prior knowledge test, ten questions of multiple choices were given to students before the experiment and each of the questions was scored 1. In the conceptual knowledge performance tests, the four different thinking order skills were measured. They were graphical property, concept association, evaluation of solutions, and written explanations. Total score of each measure was 12.

22.3.4 Procedure

We conducted the experiment in the students' school. The students finished pretests in 40 and 20 min, respectively before the experiment in their classroom. In the experiment, the students conducted self-learning with the conceptual models in two lessons. The students followed a worksheet to learn in the first lesson and conducted their own self-learning by manipulating the models without having the worksheets in the second lesson. After the experiment, the students finished posttests in their lesson.

22.4 Result

The data of gain score in the pre- and post- conceptual knowledge performance tests were analyzed using multivariate analyses of variance (MANOVAs) with graphical property and concept association as dependent variables and evaluation of solution and written explanation as dependent variables. Moreover, the data of gain score in the pre- and post- procedural knowledge performance tests were analyzed using univariate analyses of variance (ANOVAs) with the dependent variables—solving equation skill, forming equation skill, and graphical representation skill. The data of the conceptual and procedural knowledge performance tests are presented in Table 22.1.

22.4.1 Graphical Property and Concept Association

For the dependent variables graphical property and concept association, the MANOVA revealed a significant main effect of prior knowledge, Wilk's $\lambda = 0.81$, $F(2,65) = 7.65$, $p < 0.001$, partial $\eta^2 = 0.19$, with low prior knowledge students performing better than the high low prior knowledge students. No significant main effect of design approach was found, Wilk's $\lambda = 0.94$, $F(2,65) = 1.97$, $p > 0.05$, partial $\eta^2 = 0.06$. No significant interaction effect between prior knowledge and design approach was found, Wilk's $\lambda = 0.98$, $F(2,65) = 0.61$, $p > 0.005$, partial $\eta^2 = 0.018$.

Table 22.1 Means and SDs of the dependent variable

Measures	Instructional design approach				Noninstructional design approach			
	High prior knowledge		Low prior knowledge		High prior knowledge		Low prior knowledge	
	M	SD	M	SD	M	SD	M	SD
Conceptual knowledge performance test								
GP	3.72	3.74	5.83	3.73	1.47	2.12	5.35	3.50
CA	1.67	1.91	2.56	2.53	0.76	1.99	2.00	2.32
ES	3.28	240	1.56	2.43	0.59	3.20	0.59	1.50
WE	3.39	3.24	2.00	3.41	0.53	1.59	0.82	1.67
Procedural knowledge performance test								
GR	2.33	4.06	4.89	5.40	1.29	4.22	1.53	4.49

Note GP Graphical property; *CA* Concept association; *ES* Evaluation of solution; *WE* Written explanation; *GR* Graphical representation

The follow-up ANOVAs' results showed the main effect of prior knowledge yielded an F ratio of $F(1, 66) = 13.96$, $p < 0.001$, partial $\eta^2 = 0.18$, indicating that the mean gain score was significantly greater for low prior knowledge ($M = 5.6$, $SD = 3.57$) than for high prior knowledge ($M = 2.63$, $SD = 3.23$).The main effect of design approach yielded an F ratio of $F(1, 66) = 2.90$, $p > 0.05$, partial $\eta^2 = 0.042$, indicating that the mean change score was not significant. The interaction effect was not significant, $F(1, 66) = 1.22$, $p > 0.05$, partial $\eta^2 = 0.018$.

With regard to concept association, a significant main effect of prior knowledge was found, $F(1, 66) = 4.08$, $p < 0.05$, partial $\eta^2 = 0.058$. The mean gain score was significantly greater for low prior knowledge ($M = 2.29$, $SD = 2.41$) than for high prior knowledge ($M = 1.23$, $SD = 1.97$). No significant main effect of design approach was found, $F(1, 66) = 1.92$, $p > 0.5$, partial $\eta^2 = 0.28$. The interaction effect was not significant, $F(1, 66) = 0.11$, $p > 0.05$, partial $\eta^2 = 0.002$.

For the dependent variables graphical property and concept association, the significant main effect was found for the independent factor prior knowledge but not the design approach. This result revealed that low prior knowledge students achieved higher conceptual knowledge performance that requires low order thinking skill when they learned with interactive multimedia representation.

22.4.2 Evaluation of Solution and Written Explanation

For the dependent variables evaluation of solution and written explanation, the MANOVAs' results showed a significant main effect of design approach was found, Wilk's $\lambda = 0.81$, $F(2,65) = 7.51$, $p < 0.001$, partial $\eta^2 = 0.19$, with the instructional design approach group performed better than the noninstructional design group. No significant main effect of prior knowledge was found, Wilk's $\lambda = 0.97$, $F(2,65) = 1.15$, $p > 0.05$, partial $\eta^2 = 0.03$. No significant interaction effect between prior knowledge and design approach was found, Wilk's $\lambda = 0.96$, $F(2,65) = 1.48$, $p > 0.005$, partial $\eta^2 = 0.04$.

The follow-up univariate ANOVAs with dependent variable evaluation of solutions yielded a main effect for the design approach, $F(1, 66) = 9.69$, $p < 0.01$, partial $\eta^2 = 0.13$, such that the mean gain score was significantly greater for instructional design approach ($M = 2.42$, $SD = 2.53$) than for noninstructional design approach ($M = 0.59$, $SD = 2.46$). The main effect of prior knowledge was nonsignificant, $F(1, 66) = 2.15$, $p > 0.05$, partial $\eta^2 = 0.032$. The interaction effect was nonsignificant, $F(1, 66) = 2.15$, $p > 0.05$, partial $\eta^2 = 0.03$.

With regard to the dependent variable written explanation, univariate ANOVAs yielded a main effect for the design approach, $F(1, 66) = 10.20$, $p < 0.01$, partial $\eta^2 = 0.13$, such that the mean gain score was significantly greater for experimental design ($M = 2.69$, $SD = 3.35$) than for control design ($M = 0.68$, $SD = 1.61$). The main effect of prior knowledge was nonsignificant, $F(1, 66) = 0.75$, $p > 0.05$, partial $\eta^2 = 0.01$. The interaction effect was not significant, $F(1, 66) = 1.77$, $p > 0.05$, partial $\eta^2 = 0.03$.

For the dependent variables evaluation of solution and written explanation, the significant main effect was found for the independent factor design approach but not the prior knowledge. This result revealed that students learned with the instructional design approach achieved higher conceptual knowledge performance that requires high order thinking skill than those learned with the noninstructional design approach.

22.4.3 Procedural Knowledge

For the dependent variable graphical representation, an univariate ANOVA yielded a main effect for the design approach, $F(1, 66) = 4.04$, $p < 0.05$, partial $\eta^2 = 0.06$, such that the mean gain score was significantly greater for instructional design approach ($M = 3.61$, $SD = 4.88$) than for noninstructional design approach ($M = 1.41$, $SD = 4.29$). The main effect of prior knowledge was nonsignificant, $F(1, 66) = 1.62$, $p > 0.05$, partial $\eta^2 = 0.02$. The interaction effect was not significant, $F(1, 66) = 1.12$, $p > 0.05$, partial $\eta^2 = 0.02$.

The significant main effect was found in the dependent variable graphical representation, for the independent factor design approach but not the prior knowledge. This result revealed that students learned with the instructional design approach achieved higher performance on the question of graphical representation than those learned with the noninstructional design approach.

22.5 Discussions

As predicted, students' prior knowledge had impact on the effectiveness of design approach in the mobile multimedia environment. The results of this experiment indicated that there were no interactions between design approach of multimedia representation and level of prior knowledge on concept learning. That is, only one factor—either design approach or prior knowledge—affected the effectiveness of development of conceptual understanding. These results were in line with the results of Guo et al. (2013) study.

22.5.1 Prior Knowledge and Low Order Thinking Skill in Conceptual Knowledge

The results of the present study indicated that the effectiveness of design approach was absent for students on improving conceptual understanding that was easily transferred to conceptual knowledge that requires low order thinking skill—graphical property and concept association. Those students did not show any preferences for either design approach of multimedia representation. However, students' prior knowledge effect was significant. Low prior knowledge students benefited more from the multimedia representation than high prior knowledge students, which is in line with the research of Mampadi et al. (2009). That is, prior knowledge of students are the main effect of the improvement of their conceptual understanding that were easily transferred to the conceptual knowledge of graphical property and concept association when a well-designed mobile learning environment were provided.

22.5.2 Design Approach and High Order Thinking Skill in Conceptual Knowledge

The findings showed that design approach of multimedia representation was the main effect on improving students' conceptual understanding that was transferred to conceptual knowledge that requires higher order thinking skill—evaluation of solutions and written explanation. These findings support the teaching techniques evolved from variation theory (Gu et al. 2004; Mok and Lopez-Real 2006) and the four-form representation (NCTM 2000). The effect of prior knowledge was not significant. The improvement of conceptual understanding depended on the design approach rather than prior knowledge. This suggests effective multimedia representation was the significant predictors on predicting improvement of conceptual understanding developed through manipulation. Students learned better in a specific design using teaching strategies rather than a general design. That is, how to design multimedia representation in a mobile learning environment affects the effectiveness of high order thinking skill in algebra.

22.5.3 Design Approach and Procedural Skill

The findings suggested that design approach of multimedia representation was the main effect on developing students' conceptual understanding for answering the questions regarding to procedural knowledge. The specific multimedia representation—using instructional approach—had a more promising effect in the experiment, suggesting the instructional approach is likely to help students to develop a more complete conceptual understanding that was translated to graphical representation skill than the noninstructional approach. This also suggests that the interactive multimedia representation was not sufficient in designing mobile learning environment even though the graphical representation skill only requires conceptual understanding regarding to the relationships between equations and their graphs.

22.6 Conclusions

This study addresses the issue of multimedia representation in designing mobile learning environment and how different level of prior knowledge responses the environment. To measure the improvement of conceptual understanding, conceptual and procedural knowledge performances were measured. Several pedagogical implications for mobile design can be drawn from this study. First, mobile multimedia environment designed using recommendations enhance viewing can provide different level of prior knowledge students with learning opportunities that improve on conceptual knowledge requires low order thinking skill; and low prior knowledge students can benefit more. This also implicates that learning opportunities for mathematics low order thinking skill offered by mobile environment is as effective as other environment as long as it is designed for enhancing effective viewing. Second, the results suggest instructional design approach was more beneficial to students than that noninstructional approach in improving conceptual knowledge that requires high order thinking skill. This indicates that although enhancing viewing in mobile design recommendations is important, it can be insufficient for higher order thinking skill development. It can be better when instructional design approach was applied to provide more pedagogical aspect—representations of relationships among, equations, graphs, solving methods and descriptions. Therefore, multimedia representation design is very important in mobile environment when it comes to improving high order thinking skills. Students likely required a more structured and pedagogical multimedia representation to develop a more complete understanding. Finally, the combination of prior knowledge and multimedia representation could not significantly predict student conceptual and procedural knowledge performances. Therefore, in mobile multimedia learning environment, ways to incorporate students' prior knowledge was the key to promoting their conceptual understanding that leads to low order thinking skills; and focusing on the multimedia representation design was important to development of conceptual understanding that easily transferred to conceptual knowledge of high order thinking skill and procedural knowledge.

The present study shows good results, but there are some limitations. First, only one procedural skill was measured in the knowledge performance test. More research efforts are necessary to consider other types of procedural skills. Finally, future research could explore other factors that may have effects on the mobile multimedia learning environment design.

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