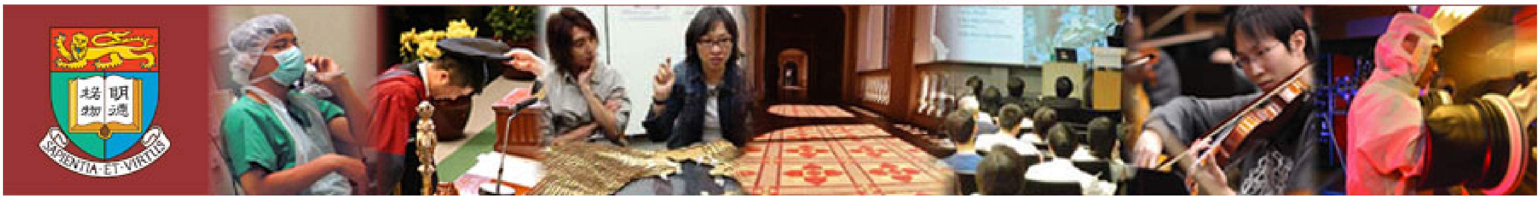

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Design of Learning Objects for Concept Learning: Effects of Multimedia Learning Principles and an Instructional Approach

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Abstract

Literature suggests using multimedia learning principles in the design of instructional material. However, these principles may not be sufficient for the design of learning objects for concept learning in mathematics. This paper reports on an experimental study that investigated the effects of an instructional approach, which includes two teaching techniques – (a) variation theory, and (b) representations of subject matter - on the design of learning objects for secondary school algebra concept learning. The results of this study showed that the experimental group performed significantly better than the control group on algebra learning achievement. The results also showed that only the experimental design with the addition of the instructional approach resulted in higher-order mathematical thinking skills and improved procedural skills of the students. Further analysis reveals that concept learning was simplified when multimedia learning principles were applied and the information was presented by the instructional approach.

Keywords: design, learning object, mathematics, concept learning, multimedia learning

1. Introduction

The teaching of mathematics in secondary schools is content-rich and focuses on procedural skills. Students learn how to solve problems by using procedures modelled by their teachers, but their conceptual knowledge remains incomplete and undeveloped (Cai & Hwang, 2002). One approach that may support conceptual understanding development is the use of *conceptual models*.

A conceptual model is defined as a special form of learning object that provides instructional components that are reusable and can be personalized to individual learners. The conceptual model is designed to support concept learning (see Churchill, 2007, 2011, 2013, in press; Churchill & Hedberg, 2008), see figure 1. The key characteristic of conceptual models is that they present properties, parameters and relationships of discipline-specific concepts in an interactive and visual way (Churchill 2013). Since conceptual models are interactive, visual representations (Churchill, 2013), the design principles of multimedia learning (Mayer, 2009) provide useful ideas for their design. However, recommendations in the literature on the application of multimedia learning principles are scarce (Churchill, 2013). Multimedia learning that focuses on cognitive capacity may not be sufficient to meet the needs of concept learning in mathematics. Indeed, an additional *instructional approach* may need to be taken into account in the design of a conceptual model. The additional approach can identify the learning information is necessary in concept learning. Before describing the research, we will first address the multimedia learning principles, variation theory and representation for algebra teaching in more detail.

1.1. Multimedia learning principles

Multimedia learning is defined in the literature as learning through both visual and audio channels. It assumes that learners can only process a limited amount of information at a time through each channel (Mayer, 2009). The concept of learners' limited cognitive capacity has been discussed in the theory of working memory (Baddeley, 1992) and cognitive load theory (Sweller & Chandler, 1991; Paas, Renkl & Sweller, 2003). When learners are given a large amount of information at a time, they may be unable to process the information. This excess cognitive processing is called cognitive overload, which can cause learners to lose focus and direction during learning. Instructional designers are highly recommended to take into account this limited cognitive capacity when designing learning materials (Sweller & Chandler, 1991; Kirschner, 2002; Mayer, 2009).

Mayer and colleagues (2009) conducted many experiments in different subjects and suggested 12 design principles for multimedia learning as guidelines for effectively presenting data or information through the two channels—audio and visual. These principles aim to avoid redundancy and help learners reduce cognitive overload to promote learning and thorough understanding, and enhance long-term memory (Mayer, 2009; Moreno & Valdez, 2005). Seven of these principles for written text are discussed in this paper are: a) Coherence – presentation of essential information only, rather than essential material and additional material; b) Signaling – highlighting of important information or key concepts; c) Spatial contiguity – placement of essential descriptions next to the corresponding picture; d) Temporal contiguity – presentation of corresponding words and pictures at the same time; e) Segmenting – allowing learners to control the pace of the learning material instead of being engaged in a continuous learning process; f) Pre-training – informing learners about the names, functions and characteristics of the learning material; and g) Multimedia – learning with both images and word than better than either images or words. These principles are intended to relieve learners of the burden of dealing with unnecessary cognitive processes.

1.2. Variation theory and representation for algebra teaching

In secondary school algebra, an effective teaching technique is one that provides students with a structured learning environment, and aims to stimulate student's thinking to develop their own understanding. Arguably, one of the most effective algebra teaching techniques is derived from 'variation theory' (Gu, Huang & Marton, 2004). According to this theory, learning is a process in which students develop the ability to see and experience algebra concepts in various ways (Marton et al, 2004). The theory includes conceptual and procedural variations: conceptual variation enables students to experience concepts from different perspectives, and procedural variation helps students to understand how to form concepts and acquire knowledge (Gu, Huang & Marton, 2004). Applying conceptual variation to algebra teaching may help students to understand concepts better by seeing and experiencing different algebraic forms and solving methods simultaneously (Mok, 2009). Moreover, in order to foster concept learning, classroom activities should be designed to help students understand connections among different forms of the same problem (Gu, Huang & Marton, 2004; Ling & Marton, 2004; Mok & Lopez-Real, 2006). For example, Mok and Lopez-Real (2006) described an effective Hong Kong secondary school algebra lesson that adopted variations in the subject content. This real case supported the effectiveness of the theory in concept learning. Ling and Marton (2004) further suggested variation theory can be used to design school learning and teaching activities in different subjects.

In addition, what and how teachers present the content are also very important in mathematics teaching. The National Council of Teachers of Mathematics (NCTM) suggests that mathematics concepts should be presented in four forms simultaneously—numerical, graphical, algebraic and descriptive—to ensure effective algebra learning and teaching (NTCM, 2000). The four-section representation is intended to assist students in perceiving the relationships and associations between conceptual and procedural knowledge. To develop a more complete concept, students are required to understand the relationships among the four forms. This is different from the idea of multiple representations (Ainsworth, 1999; Mallet, 2007). With multiple representations, learners are likely to compensate for any weakness in one representation by switching to another representation (Ainsworth, 1999; Mallet, 2007). The representation suggested by the NCTM requires students to understand all information presented in the four forms as a whole, but for multiple representations, students may not have to have a complete understanding of the information in each form.

In sum, the application of these two teaching techniques to the design of conceptual models may result in an interface with large amounts of information that causes cognitive overload. The design principles of multimedia learning may be a way to ameliorate this, and thereby ease and engage students' cognitive process in concept learning.

1.3. The present study

The aim of the present study was to investigate the value of the instructional approach for the design of a conceptual model that best facilitates student learning in algebra. This study explored two design possibilities: one based on multimedia learning (Mayer, 2009) and the other based on multimedia learning with the addition of an instructional approach specific to algebra teaching techniques that involves a) the use of variation theory (Gu, Huang & Marton, 2004), and b) four-section representations for algebra learning (NCTM, 2000). This instructional approach suggested the learning content should be arranged according to effective specific-domain teaching techniques or suggestions. This study investigated whether and how the proposed design of the conceptual model significantly affects the development of conceptual understanding of algebra. The research objectives were to: a) Investigate whether there is a significant difference in learning improvement between the control and experimental groups; and b) Analyze how the multimedia learning principles and instructional approach facilitate concept learning.

We expected the two design possibilities would have effects on student redevelopment of conceptual understanding to improve procedural and conceptual knowledge performance, because of the promising results with multimedia learning principles in design, and with variation theory and four-section representation in teaching.

In this study, we explored three hypotheses: (1) Students in the both group have effective improvement in both procedural and procedural knowledge tests; (2) Students who learn with the experimental design model perform better in both procedural and conceptual knowledge tests; and (3) using multimedia learning principles simplify learning when faced with large amounts of learning content provided from an instructional approach.

2. Method

2.1. Design

This study was an experimental design with semi-structured individual interviews. By using the results from the pre- and post- tests, we investigated the effects of multimedia learning principles and an instructional approach on the improvement of procedural and conceptual knowledge. Semi-structured individual interviews were conducted in the experimental group to answer the secondary research objective that cannot be done by pre- and post- tests – how the principles and additional approach foster student learning.

2.2. Participants

A total of 78 senior secondary level students, aged from 16 to 18, from three classes in a Hong Kong school were invited, 70 completed the experiment. The students were taught the essential concept presented in the experimental models, such as discriminants and solving methods by a teacher. The overall academic level of the students in the school was average by Hong Kong standards. They were randomly divided into two groups – a control group and an experimental group – with the treatment being the instructional approach. The size of the control and experimental groups were 34 and 36 students, respectively.

2.3. Procedure

We described the study to the principal, the teachers, and the students, and they read and signed the consent form. The study lasted two years, during the first of which we spent almost 1 month developing the material in the development cycle. Two different versions of a conceptual model for learning secondary school-level quadratic equations were developed for the control and experimental groups in a redesign development cycle included five stages – (a) review of the literature and digital educational resources; (b) identification of characteristics; (c) design and development of the model; (d) trials in real situations; and (e) evaluation. Two experienced mathematics teacher and one subject expert from a university were involved the first two stage. The author and two mathematics teachers designed and developed the models, and tested and trialed in the classroom with students involved. None of the students were invited in the second year experiment.

In the second year, we conducted the experiment in a school where the students studied. The timing of the experiment was planned and adjusted to fit the school schedule. The students in the control and experimental groups completed two separate paper-based pre-tests in their classrooms before the experiment. The time allowed for the procedural and conceptual knowledge tests were 20 and 40 minutes, respectively. The experiment was conducted in two sessions on two consecutive school days in a computer room at the school. They were seated in front of a desktop computer and learned with one of the two conceptual models. The conceptual models used in the experimental and control groups are shown in Figures 3 and 4, respectively. In the first sessions, all the students were given a 10-minute simple briefing on the information to be learned and how to use the model, and then they were given one four-page worksheet (see appendix A) to complete in a 50-minute self-learning period. In the second session, the students had 50 minutes to continue their own self-learning by manipulating the models without having the worksheets. After the experiment, the students completed two separate paper-based post-tests in their classrooms. The author and two mathematics teachers in the school conducted the pre- and post-tests. The tests were marked by either the author or the two mathematics teachers.

Moreover, in the period between the pre- and post-tests, there were no learning activities inside and outside the classroom involving the topic of quadratic equations.

To examine further how multimedia learning principles and the instructional approach fostered concept learning, six students who demonstrated a considerable improvement in their conceptual knowledge tests in the experimental group were invited to semi-structured interviews, but only five participated. No students in the control group were invited in the interview because of no instructional design approach in the control model. The author interviewed the students individually at their school in one session that lasted an average of 30 minutes. Before interviews, the students had 10 minutes to write down their experience about learning with models. During the interviews, the author asked all the students four major questions that had been constructed before the experiment. The questions focused on the information provided by the model, design features of the model, and what and how they learned with the model. The questions were: a) What learning contents in the model helped you learn?; b) What design features in the model helped you learn?; c) What knowledge or concept did you develop?; and d) How did you learn with the model? The author also asked questions based on the experience they written before the interview. During the interview, the students had no problems on understanding the questions and answered the questions right away. We also showed the learning material to facilitate the interviewing. The students were less active in the first two questions, but very active in the last two questions. When answering the last two questions, they also answer the first two questions. The interviews were conducted in Cantonese, recorded, transcribed and translated into English. To analyze the interview data, we categorized the data as two areas: a) what foster learning; b) what potential problems complicated learning. Then, in each area, we identified what principles and additional approach caused it.

2.4. Materials

2.4.1. The experimental conceptual model

The first conceptual model, the experimental model, was designed using both multimedia learning principles and an instructional approach based on two teaching techniques: variation theory and the four-section representation for the experimental group (see Figure 2). Review in the development cycle showed that teachers audio output was not appropriate in the school envrionment; therefore, we focused on written text. The seven design principles discussed in the previous **section** were applied in the design of the conceptual model. Multimedia design principle was applied to include a graph (image) and equaitons (written text); and spatial contiguity and temporal contiguity design principles were applied to the presentation of the four kinds of information, which were placed next to each other and shown simultaneously. There are four sections on the interface to present concepts numerically, graphically, algebraically and descriptively. The top section comprises the picture representation: the left side shows the graphical representation, and the right side the numbers and equations. The bottom section comprises word representation: the left side shows the descriptions, and the right side shows the different solving methods. Variation theory is also adopted for the conceputal model: a quadratic equation is shown in different common algebraic forms along with different solving methods – quadratic formula, completing square and factorization.

Moreover, the signaling principle was applied to the design to show the links and relationships between the algebraic forms, solving methods, the graph and the descriptions. The colors of the coefficients matched the colors of the numbers of the algebraic forms and the different solving methods; and the colors of the roots matched one of the solving methods; a “dot” was shown at the interception of the parabola and the x-axis (indicating the solution to the quadratic equation. Furthermore, the segmenting principle applied allowed students to manipulate the sliders on the top right corner to see how the coefficients change algebraic forms, the graph, solving methods and descriptions.

The conceptual model used with the control group was based on the multimedia learning principles only, without using the instructional approach that included four-section representation and variations (see Figure 3).

2.4.2. Measures

Concepts of algebra are defined as the relationships among numbers, algebraic symbols, algebraic expression and graphs; the skills to select appropriate problem-solving methods from those available; algebraic and graphical methods; and the ability to justify the validity of the results and to describe the mathematical ideas (Birkoff & Maclane, 1967; CDC & HKEAA, 2007; Usiskin, 1999). The Curriculum and Assessment (C&A) Guide jointly prepared by the Curriculum Development Council (CDC) and the Hong Kong Examinations and Assessment Authority (HKEAA) in 2007 states that students are expected to understand quadratic equations in any form, to understand the relationships among coefficients and the nature of roots and graphical representations, and to justify which method is best in order to arrive at solutions. This can be considered as conceptual knowledge**.** The properties of algebra concepts can be classified into 4 categories (e.g. Schneider & Stern, 2005): a) Graphical properties: understanding the features of graphs of quadratic functions; b) Concept association: understanding relationships between concepts and other knowledge; c) Evaluation of solutions: justifying the quality of a solution to a problem; and d) Written explanations: explaining or reasoning through some problems and drawing concept maps of conceptual understanding. The first two catergories can be classified as applying and analysing skills; and the second two categories can be classified as explaining and evaluating skills (CDC & HKEAA, 2007; Kastberg, 2003; Thompson, 2008). Explaining and evaluating skills are considered higher-order thinking; while applying and analyzing skills are considered lower-order thinking. Therefore, in the pre- and post- conceptual knowledge test, the four measures were graphical properties (graph-related questions), concept association (justification of pairs of concepts), evaluation of solutions (justification of solutions) and written explanations (explaining, and concept map) (see Appendix B). Each measure was scored out of 12, adding up to a total of 48.

Procedural skills are usually considered to involve routine skill, computation skill, and the knowledge of how to identify methods and execute procedures (including the knowledge of definitions and theories, specific skills and algorithms, techniques and methods) in a certain problem (Rittle-Johnson & Siegler, 1998). This reflects the guidance from the Joint CDC-HKEAA C&A Guide (2007) which states that students are expected to solve quadratic equations using different methods and forms of a quadratic equation. Therefore, in the two experiments, in the pre- and post- procedural knowledge test, there were 13 questions included for solving equations; forming equations and graphical presentation skills (see Appendix C). Each question was scored out of 3, adding up to a total of 39.

In the tests a full mark of 3 was given for completely correct answers, 2 for correct but incomplete answers, and 1 if partially correct. A score of 0 was given for incorrect and unanswered questions.

In this study, other than using t-test, to analyze the strength of relationship between the pre- and post-tests, Cohen's d effect size (the standardized mean difference) was used. If the effect size was ≥0.2, the learning activity was considered to be positive but the activity was only considered to be effective (see Mayer, 2009, p54), if the effect size was medium (≥0.5) or large (≥0.8).

3. Results

The data collected from the pre- and post-tests reflects the improvement of students' performance from the treatment in the experiment. The analysis of the data using Cohen' d suggested that the two models in the experiment effectively improved performance on conceptual knowledge requiring lower-order thinking skill, but only the experimental design effectively improved performance on conceptual knowledge requiring higher-order thinking skill and procedural knowledge. The analysis also showed that there were no significant differences in both types of prior knowledge; and also showed the experimental group significantly performed better than the control group in all measures of the post-tests. The analysis of interview data further showed that the learning information presented by the instructional approach were important, but could complicate concept learning; and the multimedia learning design principles helped students accept the learning information.

3.1. Analysis of the conceptual knowledge tests

Table 1 shows the independent sample t-test of the pre-tests for the two groups. The results showed there was no significant difference in prior conceptual knowledge of graphical properties, concept association, evaluation of solutions and written explanation between the control group and experimental group with t(64) = -0.56 (p=0.58), t(64) =1.04 (p=0.30), t(64) = -0.04 (p=0.97) and t(68) = -0.84 (p=0.41) respectively.

As listed in Table 2, the experimental group significantly attained higher improvements in all the conceptual knowledge – graphical properties, concept association, evaluation of solutions and written explanation with t(35) = -7.48 (p<0.001), t(35) =-5.62 (p<0.001), t(35) = -5.72 (p<0.001) and t(35) = -4.82 (p<0.001) respectively. The Cohen's d values of the four types of conceptual knowledge were 1.25, 0.94, 0.95 and 0.80 respectively, showing large effect size. Moreover, that is, the students learned with the experimental model effectively improved all the four types of conceptual knowledge.

Moreover, Table 3 shows the control group significantly attained higher improvements in graphical properties, concept association, written explanation and procedural knowledge with t(33) = -5.74 (p<0.001) , t(33) =-3.64 (p<0.01) , t(33) = -2.45 (p<0.05) and t(33)= respectively. The Cohen's d values of the three types of conceptual knowledge were 0.81, 0.53 and 0.23 respectively, showing only graphical properties and concept association had medium or above effect sizes. These showed that the students who learned with the model in the control group only effectively improved their conceptual knowledge of graphical properties and conception association.

Table 4 is the results of applying independent sample t-test of the post-test. The experimental group students' concept association, evaluation of solutions and written explanation were significantly higher than the control group students with t(63) = 2.83 (p<0.01), t(68) =2.01 (p<0.05) and t(65) = 3.17 (p<0.01) respectively.

3.2. Analysis of the procedural knowledge tests

No significance difference was shown in prior procedural knowledge between the control (M=20.06, SD=11.83) and experimental group (M=21.24, SD=10.91), t(67)=1.96, p=0.054. Moreover, according to a dependent sample t-test in then experimental group, the score in the post-test (M=32.31, SD=8.58) was significantly higher than that in the pre-test (M=26.22, SD=10.35), t(35)= -5.57, $p<0.001$, d=0.93, showing a large effect size. Furthermore, there was significant difference in score between the pre-test (M=21.24, SD=10.91) and post- test (M=25.24, SD=12.29) in the control group, t(33)=-3.14, $p<0.01$, d=0.35, showing a low effect size. Finally, the experimental group (M=32.31, SD=8.58) significantly outperformed the control group (M=25.24, SD=12.29) in the procedural knowledge test, t(59), t=2.78, $p<0.01$.

3.3. Analysis of the semi-structured interviews

To examine how the instructional approach and multimedia learning principles foster concept learning in mathematics, five of the students who had considerable improvement in the experimental group were interviewed in order to investigate how the design stimulated their thinking to redevelop their algebra conceptual understanding. The data collected from the interviews were very consistent. Most of the students shared similar ideas about how the design facilitated their learning. The analysis of the interview data showed the students found that the four-section information, and various solving methods, quadratic equations and formulae presented by the model were important to concept learning, and that the information presented may have been confusing if the functions of manipulating and color matching had not been included.

3.3.1. Importance of the instructional approach

Data from the interviews showed that the four-section representation helped students see the relationships among equations, solving methods and the graphs, and the section description supported this with direct explanations of the three sections. Moreover, without the information presented by the four-section representation, the students felt they may have experienced difficulties during learning. The following excerpts show the students talking about the four-section representation.

Student 1: 'It would have been difficult to learn without the four-section interface ...'

Student 2: 'I think the sections of the description and solving method are very important to the design. Without them, it would be very difficult for me to figure them problems out myself, and see their connections.... '

Student 5:'If the sections of descriptions and different solving methods had not been shown, I would have feel something was lacking…it would really have felt incomplete.'

The interview data also showed that the variations helped them to see the relationships among different solving methods and among equations. The students agreed that the different forms of an equation and its different solving methods allowed them to compare information and thus facilitate thinking, for example, as shown in the following excerpts:

Student 3: 'Different solving methods and forms of an equation shown at same time, and it was helpful. It showed all the information to me.'

Student 4: 'Different solving methods were helpful. I could understand that one quadratic equation could be solved by the different methods. ..'

3.3.2. Potential problems of the instructional approach

The various forms of information on the four-section representation were helpful to the students. However, the data of the interviews showed that students still experienced difficulties with large amounts of information. The students expressed the information presented by the instructional approach, equations and graph presented by the model was annoying; and the information became meaningless without the color matching. These were supported by the following excerpts.

Student 2: 'If there were no color matching, the interface would be a lot more difficult: just a set of numbers and no way to know how they were related. The color matching provided useful hints for understanding the information. '

Student 4: 'The different numbers, equations and graph were anonying.'

Student 5: 'There was too much information…'

3.3.3. The role of the multimedia learning principles

Furthermore, the data revealed that the two major design elements – color matching and interactive, derived from the signaling and segmenting principles, helped students accept the various information presented the four-section representation.

During the interviews, the students mentioned the color matching very often when they explained how they learned with the model. They agreed that the color matching and the graph dots did not confuse them. On the contrary, these features alerted them to the relationships among numbers, solving methods, graphs, descriptions and equations. This, derived from the signaling principles, allowed them to conceptualize all the subject content by understanding how the coefficients affect the properties of the graph, the solving methods and the solutions, and by understanding differences in the solving methods. This is shown in the following excerpts of some of the students talking about how the color matching and the graph dots worked with the information provided.

Student 1: 'The color matching linked the related content and I could see relationships among the equations. It was faster for me to see their relationships. '

Student 1: 'It was clear that the dots were roots.-They were the x-intercepts on the graph.'

Student 2: 'They (colors) showed the relationships among the numbers, a, b and c (coefficients). They were represented in the same color (color matching).'

Student 3: 'I could look at the colors and know which of a or b were related.'

Student 4: 'It was easier to understand because the colors matched: a matched a, b matched b and c matched c'

Student 5: 'This color matching helped me see the connections among the sections.'

In addition, the interviews also showed the importance of the segmenting principle in the design. The data revealed that learning occurred when the students experienced the changes in different information by trying different values at their own pace. Different students tried different values; they had individual experiences with the information. One of the students referred to learning with this model as "one-to-one" learning. They explained that typical classroom teaching methods did not create an effective concept-learning environment, whereas the interactive and individual self-learning activities did. The followings excerpts illustrate how students learned by trying different values.

Student 1: 'When I tried different appropriate values, I could see the changes in the values of A, B and C. Because I experienced it, I understood the changes...'

Student 2: 'I successfully learned new concepts when I experienced changes in the subject content by adjusting the values.'

Student 3: 'I could try and change the values to see which values correspond to this graph and which values do not. This helped me understand.'

Student 4: 'I think it is better for me to control how I learn because I will remember it longer and have a deeper understanding.'

Student 5: 'I think this one-to-one learning is better. Normal lessons offer fewer opportunities to think. '

4. Discussion

The main goal of this study was to investigate the effects of multimedia learning principles and an instructional approach on the design of a conceptual model for algebra learning. The results revealed that both groups effectively improved mathematical applying and analyzing skills - graphical representation and concept association. These skills can be referred to as lower-order skills. This finding supports the results of transfer tests of coherence signaling, spatial and temporal contiguity, and segmenting principals of multimedia learning (Mayer, 2009). However, only the experimental model resulted in an effective improvement in higher-order thinking mathematics - explaining and evaluating skills. This may be because the higher complexity of explaining and evaluating skills, compared to the lower-order thinking skills, that requires deeper conceptual understanding on the topics. This finding suggests that the use of multimedia learning principles alone may not be sufficient for an effective conceptual model design for mathematics learning.

Learning with a conceptual model develops or redevelops the conceptual understanding (Churchill, 2007, 2011). This understanding represents how students organize and generalize knowledge and concepts (Brophy, 2001). A more complete conceptual understanding allows students to access and apply easily for framing their knowledge (Brophy, 2001). In addition, there were no learning activities for developing explaining and evaluating skills during the study period. The experimental model effectively developed the skill in the students, but the control model did not. This suggests that the conceptual understanding developed by the experimental design is more accessible and easily applied. That is, the understanding is more transferable to explaining and evaluating skills. Furthermore, the experimental group outperformed the control group on procedural knowledge. There was no procedural knowledge learning activity during the study period. This shows that the conceptual understanding of the participating students redeveloped in the experimental group is more likely to be transferred to procedural skills, supporting the research that students develop conceptual understanding first and use this knowledge to choose the right solutions or procedures to solve mathematics problems (see, Geary, 1994; Gelman & Williams, 1998) . This suggests that the experimental design helped students redevelop a more complete conceptual understanding of quadratic equations that is easily translated to procedural skills.

Analysis of the interviews for the experimental group helped the author to understand how the participating students learned with the conceptual model. The different forms of a piece of information presented simultaneously were shown to stimulate thinking by suggesting comparisons, and the description section that coordinates the other three sections engaged student thinking by connecting the other three sections, which are in line with the suggestions from NCTM 2000.

Moreover, students were required to understand all the information presented in the model to get a more complete conceptual understanding. This large amount of information may complicate learning. However, the results showed that by applying multimedia learning to the design, students had more opportunity to catch the relationships between numbers, equations, formulae and the graph. The signaling principle (color matching and dots) facilitates concept learning by alerting students to points on the graph and other algebraic forms to see their differences, allowing them to identify the formula and the solving methods easily. The segmenting principle also allowed them to observe and understand the information presented in the model at their own pace. Applying multimedia learning principles helped the students understand learning information presented by the instructional approach. These results strongly suggests that the extra information from the instructional approach, which includes the variations and four-section representation, could be simplified in students' concept learning when multimedia learning design principles are applied.

Finally, these findings indicate a positive belief in using the instructional approach and multimedia learning principles in the design of the conceptual model for algebra learning.

5. Conclusions

In the experimental design, multimedia learning principles and the instructional approach work together to maximize the effectiveness of the redevelopment of conceptual understanding-students are likely to process effectively different items of information shown simultaneously by exploring and experiencing, and to develop their own more complete conceptual understanding in mathematics. The more complete conceptual understanding is easily assessed and applied by students for transferring to higher-order thinking skills and procedural knowledge. Therefore, the learning objects for concept learning in mathematics should be designed to reduce risk of cognitive overload and stimulate thinking in such a way that teaching takes place in a specific domain. Other than applying multimedia learning principles, learning information should be arranged and presented using effective teaching techniques related to the concept that the learning object intends to develop.

The results of this study are very important for guiding the instructional designers to design and develop more effective learning objects for concepts learning, and guiding teachers to identify effective digital educational resources for their teaching and learning. The instructional designers and teachers should take cognitive processing and instructional method account into designing or choosing their resources. By using an additional instructional approach, the positive effects of conceptual models can be improved. This study supports developing conceptual understanding can be beneficial in mathematics education.

Moreover, the experiments conducted on multimedia learning design principles covered many other subjects (Mayer, 2009); and variation theory is suggested to be used as guiding principle to design teaching and learning activities in schools (Ling & Marton, 2004). The results of this study support a belief for exploring the possibility of using instructional approach in other non-mathematics subjects.

Although this study appears to support the applicability of multimedia learning principles and the instructional approach in algebra concept learning, more experiments are needed to extend the findings of this study to other mathematics topics, and to determine the effectiveness of the instructional approach itself. Moreover, the different colors were used in the matching when signaling principles were applied. Students with learning abilities - color blind – may not be able to tell the differences. Future research needs to examine the effect of using different font, sizes, and styles. Final, to understand the impact that the experimental design may have on mathematical learning, future research needs to examine what other potential learning and instructional theories should be included in the instructional approach.

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Appendix A

Sample learning exercises in the worksheet.

Please try different values of a, b and c to fill in the tables.

Write down the values of discriminants, roots, x-intercepts and y-intercepts.

Are the values of the roots and the x-intercepts the same?

What is the relationship between the roots and y-intercepts?

Appendix B

Sample questions in the conceptual knowledge test.

Graphical representation

Sketch a graph to solve the $x^2–x–2=0$

Sketch two possible graphs for y=f(x) and y=g(x) if the roots of the quadratic equations f(x)=0 and g(x)=0 are 2 and 1, respectively.

Concept association

Consider the quadratic equation $ax^2+bx+c=0$ and the graph $y=ax^2+bx+c$, where a, b, c are real numbers, and x and y are unknowns in a domain of real numbers. (a is not equal to 0)

Rate the following pairs of statements or expressions. (1 – related or true, 2 – not related or false)

Statement or expression 1	Statement or expression 2	Rate
$\Delta=b^2-4ac$	number of y-intercepts	
$ax^2+bx+c=0$	always can be solved by factorization method	

<u>Evaluation of solutions</u>

The solution of the quadratic equation (x-1)(x-2)=1 is

$(x-1)(x-2)=1$

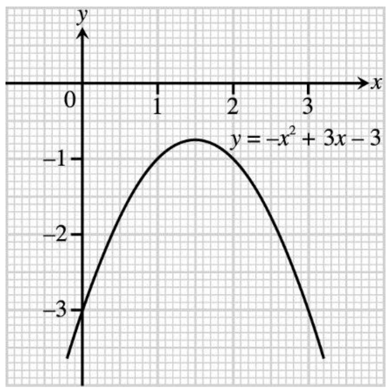
$(x-1)=1$ or $(x-2)=1$

$x=2$ or $x=3$

Do you agree with this solution? Please explain.

Written explanation

Using the following graph, give comments on the statements provided.



(i) The roots of the quadratic equation $-x^2+3x-3=0$ are real.

(ii) One of the roots of the quadratic equation $-x^2+3x-3=0$ is –3.

Appendix C.

Sample questions in the procedural knowledge test.

The following are sample questions in the procedural knowledge test

Solve the following equation: (x-1)(x-2)=0

Form a quadratic equation in *x* with roots 1 and –2. Please give the answer in general form.

Solve the equations graphically and determine the signs of the values of discriminants.