A STUDY ON EFFECTIVENESS AND COGNITIVE LOAD OF SECONDARY MATH TEACHING USING DYNAMIC GEOMETRY SOFTWARE PG_LAB

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Abstract

The experiment-based dynamic math teaching method is an instruction model which enables students to acquire knowledge through personal operation and reflection with the aid of information technology. This study aims at investigating the effectiveness of secondary math teaching using the experiment-based dynamic teaching method. A quasi-experiment was conducted to compare the students' achievements and cognitive load (CL) between traditional teaching and experiment-based dynamic teaching groups. Results indicated that though there was no significant difference in either the test scores or the CL between the experimental group and the control group, the experiment group reported lower CL than the control group did. Combining the CL with the students' math achievements, it could be concluded that the traditional teaching was more suitable for the high performance students, while the experiment-based dynamic math teaching method was more suitable for the medium performance students.

Introduction

Cognitive load theory (CLT) originated in the 1980s and underwent substantial development and expansion in the 1990s by researchers from all over the globe. The theory is now a contributor to both research and debate on issues associated with instructional design. CLT, according to Sweller (2004; 2007), is an integrated theory that uses the evolutionary origins of human cognition as a base from which to generate instructional implications and applications. It is based on concepts from cognitive architecture and cognitive psychology, including working-memory, long-term memory, and schema theory.

CLT researchers have recognized three categories of load during instruction. They are Intrinsic, Extraneous and Germane cognitive loads (Paas, Renkl, & Sweller, 2003; Sweller, 2007; Sweller, van Merrienboer & Paas, 1998; van Merrienboer, Sweller, 2005). First, *Intrinsic cognitive load* refers to the load placed on working memory by the intrinsic of the materials to be learnt. It is entirely determined by levels of element interactivity (Sweller, 1994; 2007). Simultaneously, it is affected by the expertise levels of leaner (Kalyuga, Ayres, Chandler, & Sweller, 2003). Second, *Extraneous cognitive load* is the load placed on working memory by the instructional design itself (Ayres, 2006). Unlike intrinsic cognitive load, extraneous cognitive load is imposed by inappropriate instructional procedures

(Sweller, 2007). It is under control of the instructor. Last, *Germane cognitive load* is the load placed on working memory during schema formation and automation (Ayres, 2006; Paas et al., 2003; Sweller et al., 1998). CLT assumes a limited working memory connected to an unlimited long-term memory (Kirschner, 2002). How to decrease the extraneous cognitive load, in order to free the working memory for tasks associated with the germane cognitive load is the prime goal of instruction (Sweller, 2007).

There are three classic categories of cognitive load measurement techniques: Subjective, Physiological and Task Performance. Subject techniques use rating scales to report the experienced effort or the capacity expenditure (Sweller et al., 1998). This study used direct subject measurement to assess the extraneous cognitive load of the subject who was learning in the multimedia learning environment. According to a review of CLT measurement (van Gog & Paas, 2008), the instrument used the 9 points scale, ranging from 1 (Extremely Easy) to 9 (Extremely Difficult). Participants were required to rate "How easy or difficult was this task?"

The experiment-based dynamic math teaching method is a new teaching model which enables students to acquire knowledge through observation, reflection and induction with the aid of information technology. It is a combination of information technology and instruction. Dynamic geometry software PG_Lab (Plane Geometry Laboratory) is one of the teaching software series. They were developed by the school which conducted this experiment (Wai, 2002). Its function is similar to the Geometer's Sketchpad (GSP). It is a dynamic construction and exploration tool that enables students to explore and understand the mathematics in ways that are simply not possible with traditional tools. Students can construct an object and then explore its mathematical properties by dragging the object with the mouse. Students can work on independent explorations.

This study is set to investigate the following research questions:

- Is the experiment-based dynamic teaching method more effective than the traditional teaching method for secondary math teaching?
- Do the students have lower cognitive load (CL) in the experiment-based dynamic math teaching than in the traditional teaching?

Experiment Design

An experiment described in this paper was designed to compare student achievements and cognitive load from two groups of students. Since the students could not be randomly assigned, a quasi-experiment was used in the study. The independent variable was the two different teaching methods. The dependent variables include the following:

- Math achievement, which was defined as the scores achieved on the tests.
- Learners' perceived cognitive load, which was defined using the scales of the "Self-reporting Questionnaire of Cognitive Load".

Participants

The participants in this study consisted of 71 F2 students in a secondary school in Macao. Class A with 36 students was selected as the control group. This group was taught by traditional instruction alone. Class B with 35 students was selected as the experimental group and was taught using the experiment-based dynamic mathematics teaching. Based on the previous semester's math averages, each group of students were divided into three clusters: high performance, medium performance and low performance.

Teaching Materials and Measurement Tools

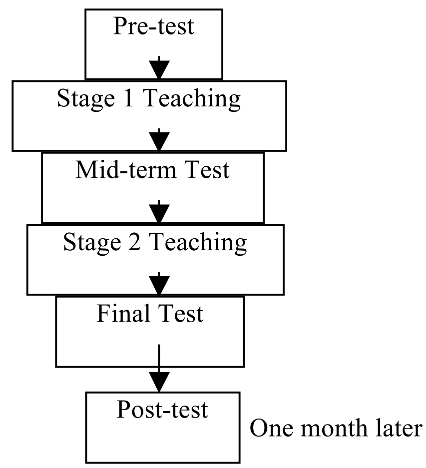
In this study, the Parallelogram Unit in elementary geometry was selected as the content which was to be taught to the students. The content primarily consisted of two sections: Basic Properties and Determinants of Parallelogram, Basic Properties and Determinants of Rectangle, Rhombus, and Square.

The measurement tool for student achievement was the school-based test papers "Parallelogram Unit Quiz I, II, and III." The reliabilities of these three tests are 0.889, 0.811, and 0.742, respectively. The product-moment correlation coefficient, that is, external validities of these three tests are 0.590, 0.799, and 0.682, respectively. So these three test papers had a relatively high reliability and validity. The Self-reporting Questionnaire of Cognitive Load was also used in the experiment to measure the perceived cognitive load. The questionnaire, which consisted of a single question with a 9 points scale, was adopted in this study. It had been developed by Chuang (2007) with reliability of $\alpha = 0.889$. Being adjusted with advice from the supervisor, professors, and senior math teachers, it had a relatively high validity of experts.

Teaching Design

The experiment took place over two weeks during the routine hours of the school day. Both the experiment and control group took 14 geometric lessons. Each lesson lasted 40 minutes. The topic "Basic Properties and Determinants of Parallelogram" was the stage one and was taught in 7 lessons while the topic "Basic Properties and Determinants of Rectangle, Rhombus, and Square" was the stage two and was taught in further 7 lessons. The flowchart of the experiment procedure is illustrated in Figure 1.

Figure 1: Flowchart of the Experiment Procedure



In the computer room, the students in the experimental group sat separately in front of the computers. At the beginning of each lesson, the teacher asked the students to review what they had learnt from the previous lab lesson. Then the teacher started to elaborate the principles and steps of the operation process by using PG_Lab and a LCD projector as an aid. It took about 10 minutes. Then the students were asked to use the dynamic geometry courseware PG_Lab by themselves, to support their exploration of basic geometry concepts. Meanwhile they needed to complete the Experiment Report Sheet step by step. For example, Experiment Report 1 included the following steps:

- Draw Parallelogram ABCD with tool icons in PG_Lab.
- Observe the diagrams.
- Check the authenticity of the Presumption: Use the calculation-tool to measure the length of the edges of the parallelogram ABCD, then come to a conclusion.
- Move any one of the parallelogram's vertexes to a new point. Observe the coordinates and measure the length of the edges again.

This session took approximately 20 minutes, during which the teacher could walk around and help the students' to solve the problems. Then another 10 minutes was given to the session of questions and conclusions. Students drew some conceptual conclusions themselves by answering teacher's questions according to the Experiment Report Sheet. At the end of the class, two exercise topics were left to the students as homework. During the experiment, 6 lab-based lessons were given in the computer room, and 8 exercise-based lessons were delivered in the traditional classroom.

The same math teacher delivered the entire courses to the control group in a traditional classroom. For the first session of every lecture, the teacher began by reviewing the main geometrical theorems from the previous lesson. This was followed by a session of geometric demonstration. First the teacher raised a geometry problem to promote student thinking. Then the teacher demonstrated the detailed problem solving procedures on the blackboard. If necessary, related images would be shown on an overhead LCD projector in front of the blackboard. Students followed the teacher's guidance; meanwhile they might make scribal notes of the geometric theorem proof and relative calculations. In last 10 minutes, students were given two questions for exercise or homework. The teaching contents were same in both the experiment and control groups.

Experiment Results and Analysis

The data of the study came from test papers of pre-test, Parallelogram Unit Quiz I, II, III and Self-reporting Questionnaire of Cognitive Load. Quiz I, Quiz II, and Quiz III were regarded as the mid-test, final-test, and post-test, respectively. The former two tests were conducted during the experiment period with the cognitive load questionnaire together. The post-test was conducted one month after the experiment with no cognitive load questionnaire assessment. All data was analyzed by independent sample *t*-tests on SPSS 15.0.

The experiment results consisted of two parts: students' math achievements, and self-reporting cognitive load.

Students' Math Achievements

Independent sample t-tests were conducted on four test scores. The results were illustrated in Tables1–5, respectively.

Overall students' math achievements comparison between the control group and the experiment group. Table 1 showed the means and standard deviations of the scores of the pre-test, mid-test, final-test and post-test in both the control and experiment groups. Table 2 showed that there were no significant differences of the four test scores between the experiment and control groups. Table 1 also illustrated that in the pre-test, the mean of the control group was higher than that of the experiment group. After the stage 1 teaching, the mean of the experiment group became higher than that of the control group. The means of the control group, however, turned to higher in the final and post tests than those in the experiment group. To explore the reason, further analysis was conducted to the different performance clusters — high performance, medium performance and low performance students in both the control and experiment groups.

Table 1: Means and Standard Deviations on Four Test Scores

	Teaching-method	N	Mean	Std. Deviation
Pre-test	Control Group	36	48.31	17.10
	Experiment Group	35	44.20	19.11
Mid-test	Control Group	36	60.92	17.76
	Experiment Group	35	61.11	18.22
Final-test	Control Group	36	54.00	18.15
	Experiment Group	35	47.00	16.08
Post-test	Control Group	36	61.14	21.23
	Experiment Group	35	58.14	17.36

Table 2: Summary of Variance Significance on Pre-test and Quiz I, II, III Test Scores

	df	t	Sig.
Pre-test	69	.954	.34
Mid-test	69	-0.46	.96
Final-test	69	1.72	.09
Post-test	68	0.65	.52

* The mean difference is significant at the .05 level. (P<.05)

Students' math achievements comparison between different performance clusters of the control group and the experiment group. There were no significant difference of the students' achievements between different performance clusters of the control and the experiment groups. The results were not illustrated in the paper. Tables 3–5 showed the means and standard deviations of test scores in high, medium and low performance clusters, respectively.

Table 3: Mean and Standard Deviation of High Performance Group on Four Tests

	Teaching-method	N	Mean	Std. Deviation
Pre-test	Control Group	9	58.67	14.95
	Experiment Group	9	55.44	9.85
Mid-test	Control Group	9	75.78	15.79
	Experiment Group	9	72.33	16.24
Final-test	Control Group	9	72.56	13.66
	Experiment Group	9	59.56	15.99
Post-test	Control Group	9	85.89	8.91
	Experiment Group	9	74.11	14.41

Table 4: Mean and Standard Deviation of Medium Performance Group on Four Tests

	Teaching-method	N	Mean	Std. Deviation
Pre-test	Control Group	18	47.33	14.88
	Experiment Group	17	43.47	20.67
Mid-test	Control Group	18	59.89	12.63
	Experiment Group	17	60.47	19.41
Final-test	Control Group	18	50.39	15.39
	Experiment Group	17	46.71	15.28
Post-test	Control Group	18	55.00	14.84
	Experiment Group	17	56.41	14.61

Table 5: Mean and Standard Deviation of Low Performance Group on Four Tests

	Teaching-method	N	Mean	Std. Deviation
Pre-test	Control Group	9	39.89	19.59
	Experiment Group	9	34.33	18.66
Mid-test	Control Group	9	48.11	18.89
	Experiment Group	9	51.11	11.74
Final-test	Control Group	9	42.67	13.77
	Experiment Group	9	35.00	6.06
Post-test	Control Group	9	47.13	21.32
	Experiment Group	9	45.44	13.10

From Tables 3–5, the following observations could be drawn.

- After the first stage teaching, the medium and low performance students in the experiment group got higher average scores than those in the control group. Considering that the pre-test scores of medium and low performance students in the experiment group were lower than those in the control group, the experiment-based dynamic math teaching method was helpful to the medium and low performance students in a short term to understand better the math concepts. To the high performance students, the experiment-based dynamic math teaching method did not show any advantage.

- After the second stage teaching all three different performance students in the experimental group got lower average scores than those in the control group. Among them the high performance students showed the largest difference in test scores in the experiment group than those in the control group. It indicated that in a long term, the experiment-based dynamic math teaching method seemed not only no advantage but also had negative effect for high performance students.

Self-reporting Questionnaire of Cognitive Load

The cognitive load questionnaire was conducted during the mid-test and final-test, respectively. The results are illustrated in Tables 6–10.

Overall CL comparison between the control group and the experiment group. Table 6 showed the means and standard deviations on CL of both the control and experiment groups during the mid-term and final tests. Table 7 showed that there were no significant differences of the two CL points between the experiment and control groups. Table 6 also showed that the CL claimed by the experiment group was lower than that claimed by the control group during both mid-test and final-test.

Table 6: Sum, Mean, Std. Deviation and Variance on Self-reporting Cognitive Load in Two Stages

	Teaching-method	N	Sum	Mean	Std. Deviation	Variance
Mid-term CL	Control Group	36	202.0	5.61	1.68	2.82
	Experiment Group	35	180.0	5.14	1.82	3.30
Final-term CL	Control Group	36	242.0	6.72	1.78	3.18
	Experiment Group	35	225.0	6.43	1.52	2.31

Table 7: Summary of Between Subjects Independent Samples t-test for Equality of Means on CL points

	df	t	Sig.
Mid-term CL	69	1.128	.263
Final-term CL	69	0.746	.458

* The mean difference is significant at the .05 level. (P<.05)

CL comparison between different performance clusters of the control group and the experiment group. There was no significant difference on the students' self-reported CL between different performance clusters of the control and the experiment groups. The results were not illustrated in the paper, either. Tables 8–10 showed the means and standard deviations of students' self-reported CL in high, medium and low performance clusters, respectively.

Table 8: High Performance Students' Self-Reported Cognitive Load in Mid-Term and Final-Term

	Teaching-method	N	Mean	Std. Deviation
Mid-term CL	Control Group	9	4.56	1.51
	Experiment Group	9	4.44	1.88
Final-term CL	Control Group	9	6.44	1.59
	Experiment Group	9	6.11	2.03

Table 9: Medium Performance Students' Self-Reported Cognitive Load in Mid-Term and Final-Term

	Teaching-method	N	Mean	Std. Deviation
Mid-term CL	Control Group	18	5.83	1.58
	Experiment Group	17	5.12	1.96
Final-term CL	Control Group	18	6.72	1.67
	Experiment Group	17	6.59	1.28

Table 10: Low Performance Students' Self-Reported Cognitive Load in Mid-Term and Final-Term

	Teaching-method	N	Mean	Std. Deviation
Mid-term CL	Control Group	9	6.22	1.72
	Experiment Group	9	5.89	1.27
Final-term CL	Control Group	9	7.00	2.29
	Experiment Group	9	6.44	1.51

From Tables 8–10, the following observations could be drawn.

- Though there was no significant difference on CL between the experiment and control groups, all high, medium and low performance students in the experiment group claimed lower CL than those in the control group. It indicated that the experiment-based dynamic math teaching method could help the students to reduce their CL in understanding the math concepts.

- After the first stage teaching, medium performance students showed the maximum mean difference of learning CL among the three different performance clusters. It indicated that the experiment-based dynamic math teaching method was more helpful for the medium performance students to reduce their learning CL in a short term.

- After the second stage teaching, low performance students showed the maximum mean difference of learning CL among the three different performance clusters. It indicated that the experiment-based dynamic math teaching method was more helpful for the low performance students to reduce their learning CL in a long term.

Conclusions

This study showed that there was no significant difference of math achievements between the experiment and control groups. Based on the test scores, the experiment-based dynamic math teaching method had negative effect to the high performance students. The traditional teaching method was more suitable for them. In a short term, the experiment-based dynamic math teaching method was more suitable for the medium and low performance students to improve their learning achievements. In a long term, however, there was no advantage.

This study also showed that there was no significant difference on CL between the experiment and control groups. However, the experiment group reported lower CL than the one reported by the control group. It indicated that the experiment-based dynamic math teaching method could help the students to reduce their CL in understanding the math concepts.

Combining the CL with the students' math achievements, the results showed that in a short term, the medium performance students made a relatively bigger progress in their achievements and claimed a relatively lower CL. Though their achievements were lower in the final test, their scores became higher in the post test. So it could be concluded that the experiment-based dynamic math teaching was more suitable for the medium performance students.

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