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Recency Effect on Problem Solving in Interactive Multimedia Learning

Robert Zheng
Assistant Professor, Department of Psychological Studies in Education (PSE)
College of Education, Temple University, Pennsylvania, USA
robert.Zheng@temple.edu

Bei Zhou
Department of Curriculum, Instruction, and Technology in Education (CITE), College of Education
Temple University, Ritter Hall 472, 1301 Cecil B Moore Ave, Philadelphia, PA 19122, USA
Tel: +1 215 204 6372
zb713@temple.edu

ABSTRACT

This study investigated the impact of recency effect on multiple rule-based problem solving in an interactive multimedia environment. Forty-five college students were recruited and assigned to two groups: synchronized and unsynchronized interactive multimedia groups based on their spatial ability score. Results show that students in the synchronized interactive multimedia group outperformed their counterparts in the unsynchronized interactive multimedia group in terms of response time and test scores. Results also indicated that low spatial ability learners in the synchronized interactive multimedia showed an improvement in problem solving.

Keywords

Multimedia, Problem solving, Recency effect, Rule-based reasoning, Working memory

Introduction

Problem-solving skill is highly valued. In the last five decades, many theorists and educational institutions have placed a heavy emphasis on this ability. For example, the movement of "discovery learning" (e.g., Bruner, 1961) was spawned, at least in part, by the perceived importance of fostering problem-solving skills. This emphasis on problem solving was not associated, however, with the knowledge of cognitive resources involved in the problem solving process. That is, it focused on procedures of problem solving rather than investigating the relationship between procedures of problem solving and cognitive resources that affect such procedures (Sweller & Low, 1992; Hanley, 1987). In the last twenty years, this state of affairs has begun to change with our knowledge of relevant mechanism (e.g., working memory, cognitive load, etc.) increasing markedly. This study investigated the recency effect – a phenomenon in working memory that affects learners' holding of information during problem solving - and how such phenomenon may affect learners' multiple rule-based reasoning in particular, and problem solving skills in general.

Literature Review

Working Memory and Cognitive Load

Cognitive scientists believe that the input information such as auditory, visual, and kinesthetic, etc. is processed through a temporary storage before it gets coded into the long term memory (Baddeley & Logie, 1992; Logie, 1995). This temporary storage, also called the working memory, comprises two major components. One is the executive controlling mechanism that is believed to be related to cognitive activities such as reasoning and problem-solving. The other is the visuo-spatial sketchpad (VSS) that is believed to process and manipulate visuo-spatial images (Logie, 1995; Pearson & Logie, 2000). For example, the ability to mentally manipulate 3D images by rotating them in mind is largely determined by the VSS function. The two components are closely related and interacted with each other in the process of problem solving (Bollaert, 2000; Mayer & Moreno, 2003).

Studies show that the working memory is very limited in both duration and capacity. Van Merrienboer and Sweller (2005) observe that the working memory stores about seven elements but normally operates on only two or three elements. They also find that the working memory can deal with information "for no more than a few seconds with almost all information lost after about 20 seconds unless it is refreshed by rehearsal" (p. 148). When the working memory becomes overloaded with information, learning can be adversely affected (Paas, Tuovinen, Tabbers, & Gerven, 2003; Sweller & Chandler, 1994; Marcus, Cooper, & Sweller, 1996). Sweller and

Chandler (1991) studied the relationship between the cognitive load and the learning effectiveness and found that learning became improved when the extraneous cognitive load was reduced. According to Cognitive Load Theory (CLT), three types of cognitive load exist: *intrinsic load*, *extraneous* or *ineffective load*, and *germane* or *effective load*. The *intrinsic cognitive load* refers to cognitive load that is induced by the structure and complexity of the instructional material. Usually, teachers or instructional designers can do little to influence the intrinsic cognitive load. The *extraneous cognitive load* is referred to the cognitive load caused by the format and manner in which information is presented. For example, teachers may unwittingly increase learner's extraneous cognitive load by presenting materials that "require students to mentally integrate mutually referring, disparate sources of information" (Sweller et al., 1991, p.353). Finally, the *germane cognitive load* refers to cognitive load that is induced by learners' efforts to process and comprehend the material. The goal of CLT is to increase this type of cognitive load so that the learner can have more cognitive resources available to solve problems (Brunken, Plass, & Leutner, 2003; Marcus, et al., 1996).

Cognitive Load Theory has been recently introduced into multimedia studies where researchers try to find out whether the use of multimedia can improve learning by reducing extraneous cognitive load. Tabbers, Martens and Van Merrienboer (2004) studied the effects of modality and cueing on learning in terms of cognitive load theory and found that adding visual cues to the pictures enhanced learners' retention scores. Mayer and his colleagues (Mayer, 1997; Mayer et al., 2003) conducted a series of studies on the effect of text and image on problem solving. They noticed that when learners were presented with synchronized texts and images, they were able to better recall and answer transfer questions. However when learners were presented with unsynchronized instructional material, i.e., the text was presented first followed by an image (a filled delay phenomenon), learners' ability to recall and answer transfer questions decreased. Mayer (1997) concluded that the synchronized multimedia could alleviate the extraneous cognitive load and provide extra cognitive resources for problem solving whereas the unsynchronized multimedia could cause cognitive overload, thus decreased performance in learning. Although the CLT theory provides insights on problem solving in terms of cognitive load, cautions must be taken in interpreting learners' ability to solve problems. Studies show that factors such as recency effect, problem types, etc. are related to learners' problem-solving skills (Delisle, 1997; Logie, 1995).

Recency Effect and Cognitive Load

While the process of problem solving draws on resources from both long-term and short-term memories, it is believed to rely heavily on the working memory for the working information during the problem-solving process (Baddeley et al., 1992; Logie, 1995). When this temporary holding of information in the working memory is interrupted, the ability to solve problems can be affected. Capitani, Della Sala, Logie, and Spinner (as cited in Logie, 1995) conducted a study on the working memory. They found a high recall by subjects immediately after the items have been presented. However if there was a filled delay before the recall was required, only the first few items on the list could be recalled. Logie (1995) described the former phenomenon as the recency effect and the latter as the primary effect. He believed that "recency reflected the operation of a short-term or primary memory system" (p. 5) which was critical to problem solving process. It is essential to distinguish between cognitive load and recency effect since both involve cognitive resources in working memory pertaining to learning. The notion of cognitive load refers to the load imposed on the learner's working memory while performing a particular task whereas the recency effect refers to the information, specifically the most recent information that can be recalled within working memory. The cognitive load study is focused on working memory architecture and its limitations relating to the design of instruction (Van Merrienboer et al., 2005; Paas et al., 2003; Tabbers et al., 2004). The recency effect is, however, focused on the state of recalling and maintaining much needed information during problem solving process.

Of particular interest to researchers is the issue of effective time period in recency effect. Studies on effective time period in recency effect have so far produced mixed results. For example, studies by Posner, Boies, Eichelman and Taylor (1969, cited from Baddeley, 1997) suggest that the information resulting from a visual trace has a 2-second decay rate. However, Glanzer and Cunitz (1966, cited from Haberlandt, 1999) observed that the recency effect was wiped out when recall was delayed by 30 seconds. Contrary to the findings of Posner et al. (1969) and Glanzer et al. (1966), Bjork and Whitten (1974, cited from Haberlandt, 1999) showed that the recency effect could survive a delay. They had subjects learn a word list in a free-recall experiment. After a 30-second interval of backward counting that should have resulted in a loss of the most recent items from the short-term memory, they found the subjects were still able to recall the most recent items in the list. Obviously, the inconsistency in the above findings raises the question of whether the effective time period should be used to measure the impact of recency effect on problem solving. Richardson (1996) states that "working memory is not a general system with unitary capacity. Rather, the capacity of working memory will vary as a function of how efficient the individual is at the specific processes demanded by the task to which working memory is being applied" (p. 12) which means the measurement of the impact of recency effect on problem solving should focus on the effectiveness that learners make use of the limited working memory capacity in information processing (Perfetti & Goldman, 1976). In other words, the recency effect should be measured in terms of learner efficiency in problem solving, that is, the ability to achieve optimal results in problem solving with minimum amount of time possible.

Problem Types

Delisle (1997) states that problem types are related to thinking procedures in problem-solving process. For example, causal relationship problems require a linear thinking procedure that has a strong linear direction emphasizing the cause and effect whereas multiple rule-based problems involve simultaneously weighing several conditions/rules in mind in order to make a decision (Frye, Zelazo, & Palfai, 1995; Price & Yates, 1995). Zheng, Miller, Snelbecker, & Cohen (2005) assert that different types of problem may require different levels of working information in problem solving process. For instance, the multiple rule-based problem solving may require more working information than does causal relationship problem solving or single rule-based problem solving. The single rule-based problem solving, according to Frye et al. (1995), requires a straight-forward deductive thinking such as applying the rule of card sorting to the action of sorting a deck of cards whereas the multiple rule-based problem solving involves a more complex, nonlinear thinking where the learner reaches a solution by engaging in a series of cognitive thinking activities such as analyzing, synthesizing, evaluating, and so forth while holding several conditions and rules in mind within a short time framework provided by the working memory (Johnson, Boyd, & Magnani, 1994; Price et al., 1995). Obviously, multiple rule-based problem solving is likely to increase intrinsic cognitive load more than other two types of problem solving.

Studies showed that the interactive multimedia can enhance students' recalling and maintaining of working information in multiple rule-based problem solving (Zheng et al., 2005). According to the dual coding theory (Paivio, 1986), learning is more effective with two sensory channels (i.e., visual and verbal) than one channel alone. When information is processed through multiple sensory channels, learners' ability to hold such information is improved (Zheng et al., 2005). However, this ability is also determined by the types of problem and thinking procedures during the problem solving process.

Learner Characteristics

One of the issues that frequently surfaced in multimedia problem-solving research is whether demographic factors such as age, education, ethnicity, etc. would affect learners' problem solving (Forcier & Descy, 2005). Hall and Cooper (1991) report a gender difference in computer use. Passig and Levin (2000) concur that gender preferences exist in multimedia related problem solving. Another issue of interest is individual differences in multimedia problem solving. Fink and Neubaurer (2005) observed that individuals differ in speed of information processing and working memory. Mayer and Sims (1994) conducted a study on spatial ability and problem solving with multimedia and concluded that the spatial ability was critical to problem solving and "appears to enhance coordinated visual and verbal instruction" (p. 399).

Hypotheses

Based on the above discussion, the following hypotheses were proposed that formed the basis for this study:

Hypothesis 1

Participants in the synchronized interactive multimedia group will outperform their counterparts in the unsynchronized interactive multimedia group in multiple rule-based problem-solving.

Hypothesis 2

Different interactive multimedia such as synchronized and unsynchronized multimedia can significantly affect learners' spatial ability and their performance relating to such ability.

Hypothesis 3

Learners' ability to solve problems can be affected by demographic factors such as education, ethnicity, gender, and hobbies.

Methodology

Participants & Design

Participants consisted of 45 students recruited from a large comprehensive research university on the east coast of the United States in the fall 2004. Of 45 participants, 89% (n = 40) were undergraduate teacher education majors who received course credit for participating in the study and 11% (n = 5) were graduate students who volunteered to participate in this study. Approximately 65 % (n = 29) of the participants were Caucasian, 22% (n = 10) were African-American, and 13% (n = 6) were Asian or Asian American. The average age of the participants was 21 with a range from 19 to 31.

Two levels of interactive multimedia (synchronized vs. unsynchronized) were crossed with two levels of spatial ability (high vs. low) to form a 2 x 2 between subjects factorial design. Participants were blocked by spatial ability and then randomly assigned to one of the multimedia groups. The independent variables included multimedia learning (synchronized vs. unsynchronized) and spatial ability (high vs. low) with two dependent variables: response time and test scores. In this study, demographic information such as age, education, ethnicity, and hobbies was collected and served as covariates in MANCOVA analysis. All statistical tests were performed with alpha at .05.

Measures

Two instruments were used to assess students' spatial ability and problem-solving skills.

Guilford-Zimmerman Aptitude Survey Test 5: Spatial Orientation (Guilford-Zimmerman, 1956). The Guilford-Zimmerman spatial orientation test requires participants to observe the position of the bow of a boat relative to the horizon and then to correctly identify the change in the boat's orientation by the change in horizon relative to the bow. The purpose of the Guilford-Zimmerman test is to assess participant's ability to mentally maneuver objects in terms of the special relationship which is consistent with the reasoning tasks set up in this study, that is, the participant came up with a solution by maneuvering the figures and determining the spatial relationship between the figures based on the conditions and rules set in the tasks. The Guildford-Zimmerman spatial orientation test has reported a high reliability (alpha = .88) (Price & Eliot, 1975).

Interactive Multimedia Problem-Solving Test. The interactive multimedia problem-solving test was developed by the first author using Flash MX and Microsoft Active Server Page. The test comprised five sub-tests that included air traffic control, Tower of Hanoi, sailing boat, taking pictures, and office inspection. Sub-test 1 *Air Traffic Control* had a set of conditions that restricted the order and parking positions of airplanes. The subject had to consider all the conditions and decided which flight would park at which gate without violating the conditions (Figure 1). Sub-test 2 *Tower of Hanoi* had a set of rules restricting the movement of disks. The subject was required to move three disks from one stack to another without violating the rules. Sub-test 3 *Sailing Boat* described six boats anchoring at four different directions. The subject was to find out the spatial relationship between the boats based on the conditions given. Sub-test 4 *Taking Pictures* had a set of rules that determined who could stand next to each other in the line. The subject was required to come up with a list of persons who would take the pictures in an order that did not violate the rules set by the task. Finally, Sub-test 5 *Office Inspection* was about office inspections by five people who conflicted with each other in terms of the schedule and the order of inspection. The subject had to consider these conflicting conditions and decided who got assigned to inspect which office without violating the conditions/rules. For each sub-test, there was a problem (text) and an interactive multimedia with which the subject could move the figures around to help solve the problem. Two versions of tests were created: synchronized and unsynchronized. The synchronized interactive multimedia test displayed both text and interactive multimedia at the same time on the same page whereas the unsynchronized interactive multimedia test separated the text from the interactive multimedia by presenting the text first followed by an interactive multimedia.

The problem-solving test consisted of five sub-tests, each contained three parts: the problem with the text format, interactive multimedia, and two problem-solving questions that measured participants' multiple rule-based reasoning skills. Each sub-test had a timer recording the start and the end of the response time (Figure 1).

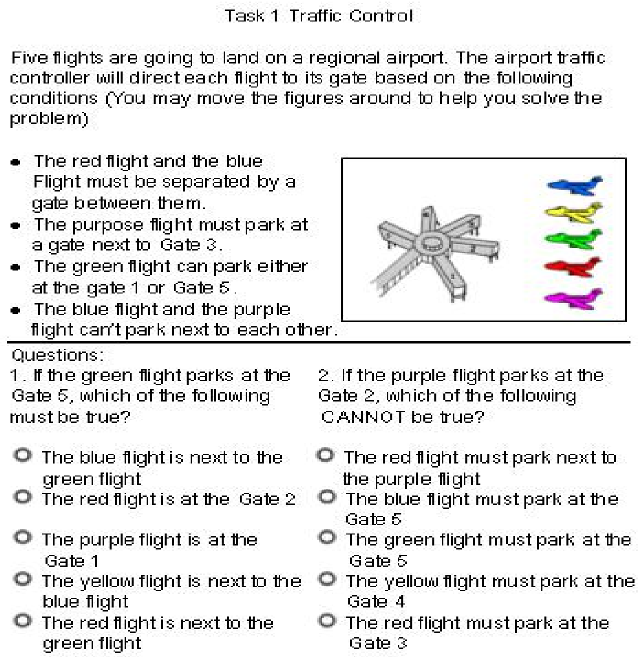

Figure 1. Sample of Multiple Rule-Based Problem-Solving Tasks

To ensure the content validity, the instrument was reviewed by a panel of instructors and a selected group of graduate students whose feedback was carefully reviewed and changes were made based on the feedback. Next, a pilot test was conducted to a group of undergraduates (n = 10). Further changes were made based on the results of the pilot test and comments from instructors. A reliability analysis was done on test items. The Pearson correlation analysis showed that nine items had a significant correlation between sub-items (Table 1). The item reliability analysis using Cronbach alpha showed a moderate coefficient of .71.

Table 1. Pearson Correlation Matrix

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Question 1	1									
Question 2	-	1								
Question 3	-	-	1							
Question 4	**	-	-	1						
Question 5	-	-	-	-	1					
Question 6	*	-	-	**	-	1				
Question 7	-	-	-	-	-	-	1			
Question 8	-	**	-	-	-	**	-	1		
Question 9	-	-	**	-	-	-	-	**	1	
Question 10	-	-	-	**	-	-	-	-	*	1

** Correlation is significant at .01 level (2-tailed)
* Correlation is significant at .05 level (2-tailed)

Procedure

Using a blocked random sampling procedure, participants were first given the Guilford-Zimmerman Aptitude Survey Test 5: Spatial Orientation (Guilford & Zimmerman, 1956). The middle value of the distribution (median = 7.25) was determined and chosen as the cut score for defining subjects' high and low spatial ability. Subjects were then blocked into high and low spatial ability groups based on their spatial ability test score. Subjects were randomly drawn from each of the blocked groups (i.e., high and low spatial ability) to form two separate groups: the synchronized interactive multimedia group and the unsynchronized interactive multimedia group. A paired samples *t*-test was performed on the synchronized and unsynchronized multimedia groups. The result indicated no significant difference between two groups, $t_{(1, 21)} = 1.00$ (2-tailed), $p = .329$, ns.

Participants were given a test number and assigned to one of the interactive multimedia groups based on the result of randomization. They were provided a URL to take the problem solving test online in a computer classroom proctored by the investigator. The participants were required to fill out a demographic information sheet online which included age, education, ethnicity, hobbies, etc. After completing the demographic information, participants began to take the problem solving test. Participants were first presented a problem that included a scenario with some conditions and rules. They were then told to use the interactive multimedia to help solve the problem by moving images or figures around to simulate various solutions until the correct solution was reached. The total score equaled 10 points. If an error was made by the participant, a point would be deducted from the total score. All participants were given a consent form to sign for their participation in the study.

Results

Descriptive Statistics

The means and standard deviations are reported in Table 2.

Table 2. Descriptive Statistics for Response Time and Test Scores

	Multimedia Group	Spatial Ability	Mean	Standard Deviation	N
Response Time	Synchronized	High	15.89	.84	12
		Low	17.95	1.46	11
		Total	16.87	1.56	23
	Unsynchronized	High	18.64	1.39	10
		Low	17.27	2.45	12
		Total	17.89	2.11	22
	Total	High	17.14	1.78	22
		Low	17.59	2.02	23
		Total	17.37	2.11	45
Test Scores	Synchronized	High	6.17	1.26	12
		Low	4.64	1.50	11
		Total	5.43	1.56	23
	Unsynchronized	High	4.90	.56	10
		Low	4.00	1.47	12
		Total	4.41	1.22	22
	Total	High	5.59	1.18	22
		Low	4.30	1.49	23
		Total	4.93	1.48	45

With regard to the response time the synchronized group ($Mean_{sync} = 16.87$) spent less time than the unsynchronized group ($Mean_{unsync} = 18.89$) in problem solving test. Further, high spatial ability subjects in the synchronized group ($Mean_{sync} = 15.89$) spent less response time than their counterparts in the unsynchronized group ($Mean_{unsync} = 18.64$). However, low spatial ability subjects in the synchronized group ($Mean_{sync} = 17.95$)

seemed to spend more response time than their counterparts in the unsynchronized group ($Mean_{unsync} = 17.25$). With regard to test scores the synchronized group ($Mean_{sync} = 5.43$) scored higher on problem-solving test than the unsynchronized group ($Mean_{unsync} = 4.41$). Both high and low spatial ability subjects in the synchronized group outperformed their counterparts in problem-solving test.

MANCOVA Tests

A multivariate analysis of covariance (MANOVA) was conducted with spatial ability and interactive multimedia group as independent variables, the response time and the test score as dependent variables, and education, gender, ethnicity, and hobby as covariates. The Wilks' Lambda estimate was used to determine the main effects. The results indicated that there was a main effect for multimedia group (Wilks' Lambda = 5.642; p = .007) and for spatial ability (Wilks' Lambda = 5.397; p = .008). There was also an overall interaction between the multimedia group and the spatial ability (Wilks' Lambda = 6.480; p = .004). The covariance analysis indicated that none of the covariates were significant: education (Wilk's Lambda = 1.824, p = .176), gender (Wilk's Lambda = 2.167, p = .129), Ethnicity (Wilk's Lambda = .736, p = .486), and hobby (Wilk's Lambda = .944, p = .398) (Table 3).

Table 3. MANOVA Tests

Effect		Value	F	Sig.	Partial Eta Squared
Education	Philai's Trace	.092	1.824	.176	.092
	Wilks' Lambda	.908	1.824	.176	.092
	Hotelling's Trace	.101	1.824	.176	.092
Gender	Philai's Trace	.107	2.167	.129	.107
	Wilks' Lambda	.893	2.167	.129	.107
	Hotelling's Trace	.120	2.167	.129	.107
Ethnicity	Philai's Trace	.039	.736	.486	.039
	Wilks' Lambda	.961	.736	.486	.039
	Hotelling's Trace	.041	.736	.486	.039
Hobby	Philai's Trace	.050	.944	.398	.050
	Wilks' Lambda	.950	.944	.398	.050
	Hotelling's Trace	.052	.944	.398	.050
Group	Philai's Trace	.220	5.642	.007	.220
	Wilks' Lambda	.780	5.642	.007	.220
	Hotelling's Trace	.282	5.642	.007	.220
Spatial	Philai's Trace	.212	5.397	.008	.212
	Wilks' Lambda	.788	5.397	.008	.212
	Hotelling's Trace	.270	5.397	.008	.212
Group * Spatial	Philai's Trace	.245	6.480	.004	.245
	Wilks' Lambda	.755	6.480	.004	.245
	Hotelling's Trace	.324	6.480	.004	.245

* Design: Intercept+Education+Gender+Ethnicity+Hobby+Group+Spatial+ Group * Spatial

The between-subjects analysis showed that there was a significant difference between the synchronized and the unsynchronized groups in terms of the response time ($F_{(1, 44)} = 4.345$; p = .043) and test scores ($F_{(1, 44)} = 6.187$; p = .017). There was a significant difference between the high and the low spatial ability people for test scores ($F_{(1, 44)} = 10.091$; p = .003) but no significance was found for the response time ($F_{(1, 44)} = .482$; p = .491). With regard to the multimedia group and spatial ability interaction, there was an overall interaction for the response time ($F_{(1, 44)} = 11.979$; p = .001). But no interaction was found for test scores ($F_{(1, 44)} = .679$; p = .415) (Table 4).

Efficiency Scores

The efficiency score is the total test score divided by the total response time in seconds. The total test score was calculated by adding up the correct scores from each task and the total response time was calculated by summing up the response time of all tasks. An efficient problem solver is defined as a person who achieved higher test scores with less response time. Descriptive data (Table 5) and the results of univariate analysis of variance (Table 6) are reported as follows.

Table 4. Tests of Between-Subjects Effects

Source	Dependent Variable	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power
Group	Response Time	1	11.988	4.345	.043 *	.096	.530
	Test Scores	1	10.128	6.187	.017 *	.131	.680
Spatial	Response Time	1	1.330	.482	.491	.012	.104
	Test Scores	1	16.518	10.091	.003 *	.198	.873
Group * Spatial	Response Time	1	33.053	11.979	.001*	.226	.922
	Test Scores	1	1.111	.679	.415	.016	.127
Total	Response Time	45					
	Test Scores	45					

* Significant at alpha = .05.

Table 5. Descriptive Statistics for Efficiency Scores

Multimedia Group	Spatial Ability	Mean	Std Deviation	N
Synchronized Multimedia Group	Higher	.387	.087	12
	Low	.260	.097	11
	Total	.326	.110	23
Unsynchronized Multimedia Group	Higher	.262	.036	10
	Low	.225	.070	12
	Total	.242	.059	22
Total	Higher	.330	.092	22
	Low	.242	.084	23
	Total	.285	.098	45

Table 6. Univariate Analysis of Variance

Source	df	F	Sig.	Partial Eta Squared	Observed Power
Multimedia Group	1	11.99	.001*	.226	.922
Spatial Ability	1	12.60	.001*	.235	.934
Multimedia Group * Spatial Ability	1	3.78	.059	.084	.476
Total	45				

* Significant at alpha = .01

Discussions

The discussion of the results will focus on three hypotheses proposed earlier with an emphasis on (a) the impact of recency effect on problem-solving, (b) multimedia and spatial ability, and (c) demographic factors as covariates.

Hypothesis 1

Hypothesis 1 tried to investigate whether the use of different interactive multimedia (synchronized vs. unsynchronized) would affect learners' performance in problem solving. The results of the study showed a main effect for multimedia groups as well as an overall interaction between multimedia groups and the spatial ability, which means learners' performance in problem solving was affected by the type of media employed. This was supported by the mean difference in test scores between the synchronized group ($Mean_{sync} = 5.43$) and the unsynchronized group ($Mean_{unsync} = 4.41$) (Table 1). The between-subjects tests indicated a statistical significance between two groups ($F_{(1, 44)} = 6.187$; $p < .05$) (Table 4). However, when learners' performance was measured by the response time instead of test scores, low spatial ability subjects in the synchronized group performed less well than high spatial ability subjects in the unsynchronized group (Table 2). There was a marginal significance between two groups (synchronized vs. unsynchronized) in terms of response time ($F_{(1, 44)} = 4.345$; $p = .043$). Nonetheless, such difference was compromised by a small effect size ($\eta^2 = .096$) and weak statistical power (.530) (Table 4), which means the difference may have little practical significance in reality.

Results also show that when provided with the synchronized interactive multimedia, higher spatial ability learners had a higher efficiency score than their counterparts in the unsynchronized interactive multimedia (Table 5). There was a significant difference between multimedia groups ($F_{(1, 44)} = 11.99$, $p < .05$) (Table 6). Since the efficiency score indicates learners' ability to solve problems in terms of the ratio between total test scores and total response time (in seconds), it would be reasonable to assume that learners who solved more problems with less response time had more cognitive resources during problem solving process. It would also imply that such learners were more effective in recalling and maintaining critical working information while solving problems since recalling and maintaining working information is critical to problem solving (Loggie, 1995).

The results of MANCOVA and univariate analysis of variance have consistently shown that the synchronized interactive multimedia facilitated learners' ability to solve problems due to a prompt recall and retrieval of working information whereas the unsynchronized interactive multimedia decreased the learners' ability to solve problems due to a filled delay phenomenon caused by scrolling back and forth between pages. Evidently, the synchronized interactive multimedia facilitates the recall of on-demand working information – a recency effect - and enables learners to solve problems more efficiently in a short time framework provided by the working memory. The findings of this study concurred with previous studies (e.g., Mayer et al., 1994; 2003) that the synchronized multimedia enhanced students' problem solving whereas the unsynchronized multimedia could affect students' ability to recall and maintain working information in the working memory due to a filled delay phenomenon.

Hypothesis 2

Hypothesis 2 tried to find out whether different interactive multimedia such as synchronized and unsynchronized multimedia would affect learners' spatial ability and their performance. The MANCOVA analysis revealed an interaction between multimedia group and spatial ability (Wilks' Lambda = 6.480; $p = .004$). Overall, high and low spatial ability subjects in the synchronized group outperformed their counterparts in the unsynchronized group ($F_{(1, 44)} = 10.091$, $p < .05$). It should be noted that with synchronized interactive multimedia low spatial ability subjects outperformed their counterparts and did almost as well as the high spatial ability subjects in the unsynchronized group. This is perhaps for low spatial learners who are known for linear and abstract thinking (McGrew & Flanagan, 1998), multiple sensory inputs from the synchronized interactive multimedia can provide extra cognitive resources that enable them to recall and maintain on-demand working information while engaging in multiple rule-based reasoning. This suggests that media attributes like synchronized interactive multimedia can compensate learner's deficit in spatial ability such as visualization (Reiser, 1994; Salomon, 1979).

The efficiency analysis showed that the synchronized interactive multimedia facilitated learning for both high and low spatial ability learners. High spatial ability learners in the synchronized group (Mean = .387) outperformed all three groups including low spatial ability learners in the synchronized group, high and low spatial ability learners in the unsynchronized group. The mean score of low spatial ability learners in the synchronized group (Mean = .260) was higher than its counterparts (Mean = .226) and almost the same as the high spatial ability learners in the unsynchronized group (Mean = .262) (Table 5). There was a significant difference between spatial groups in terms of efficiency ($F_{(1, 44)} = 12.60$, $p < .05$). This suggests that with the synchronized interactive multimedia both high and low spatial ability learners were able to perform well in problem solving.

Hypothesis 3

Hypothesis 3 tried to determine if demographic factors such as education, ethnicity, gender, and hobbies would affect learners' ability to solve problems. Although studies (Forcier et al., 2005; Hall et al., 1991; Passig et al., 2000) showed that demographic factors could influence learners' attitude, motivation, and their way of learning, the results of this study showed that none of the demographic factors that is, education, ethnicity, gender, and hobbies, were significant (Table 3), which suggested that in this particular study main effects for multimedia group and spatial ability were accounted for by the differences between multimedia groups, not affected by any of the covariates mentioned above.

Conclusion

As it was mentioned elsewhere in this paper, the ability to hold information in one's working memory is critical to multiple rule-based reasoning problem solving. This study indicated that the recency effect, which is related to learners' ability to recall and maintain working information in working memory, is related to the media employed in problem solving. The analysis of efficiency scores revealed that the synchronized interactive multimedia could facilitate recalling and maintaining on-demand information in working memory - a recency effect, thus enabled learners to solve problems more efficiently whereas the unsynchronized interactive multimedia hinders immediate information retrieval due to a filled delay phenomenon. This was supported by the observation we made in which subjects in the synchronized group were more focused on problem solving whereas subjects in the unsynchronized group frequently scrolled back and forth between the pages trying to update the information in working memory while working on the problems.

This study concurred with previous studies that spatial ability is related to multimedia problem solving (Mayer et al., 1994). However, it went further to conclude that the synchronized interactive multimedia could compensate low spatial ability learners for lacking visualization in problem solving. Contrary to the findings of previous studies (Forcier et al., 2005; Hall et al., 1991; Passig et al., 2000; Fink et al., 2005), this study did not find any significant relationship between demographic factors and learners' ability to problem-solving.

Overall, we can derive some useful theoretical and practical implications from this study. On the theoretical side, the results have extended the exiting studies on multimedia such as cognitive load theory and called attention to an important cognitive phenomenon – recency effect - in the interactive multimedia problem solving. The study provides a better understanding of the relationship between spatial ability and media as well as the relationship between recency effect and multimedia presentation mode, which promotes further research on the constructs of working memory, complex reasoning such as multiple rule-based reasoning, and interactive multimedia. On the practical side, our work reveals that differences in multimedia design can result in different cognitive consequences. Therefore, teachers and other professional educators need to be aware of such issues as media attributes, problem types, and learner characteristics in the process of designing multimedia problem solving, especially in designing multiple rule-based problems.

The importance of teaching problem solving to students has been widely recognized by teachers, administrators, and other educational stakeholders. The advent of computer technology, particularly multimedia learning, has changed the landscape of problem-solving instruction. Computer-based problem simulations, for example, begin to replace the traditional paper and pencil approach with more vivid, interactive approach that provides both auditory and visual information to problem solving. The psychological and cognitive benefits of using multimedia to teach problem solving are palpable: the multimedia motivates students to learn, promotes deep understanding, and engages them in problem solving (Fulford, 2001; Mayer et al., 2003; Rieber & Hannafin, 1988). This study has provided initial results on the impact of recency effect on multimedia problem solving.

Further research is needed to investigate the relationship between cognitive load and recency effect and perhaps include cognitive load as a possible covariate to determine the impact of recency effect on problem solving. Research in the future should include a larger, more diverse population in terms of ethnicity, age, education, social and economic status. It is suggested that a broader research agenda is needed to address the whole range of issues in the study of recency effect that includes the relationship between recency effect and its related cognitive constructs such as learner aptitudes, learning styles, mental synthesis, etc. in the context of working memory and multimedia learning.

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