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Evaluating working memory capacity and cognitive load in learning from goal based scenario centered 3D multimedia

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Abstract

The purpose of this study is to investigate working memory capacity and cognitive load in learning from Goal Based Scenario centered 3D multimedia learning environment (GBSc3DM) designed based on Cognitive Load Theory (CLT). GBSc3DM was developed in two versions. In the designed of the first version (+CLT) cognitive load principles were applied. In the second version (-CLT), however, the principles were violated. 47 11th grade high school students were selected based on their working memory capacity (WMC). A series of parametric and non parametric statistical techniques were used to analyze the data. The findings are discussed in the following sections.

Keywords: Working memory capacity; cognitive load; goal based scenario; instructional design; multimedia; individual difference.

1. Introduction

Goal based scenario (GBS) offers realistic environments for complex learning tasks. The severe risk of this approach is high task complexity. If learners cannot handle the high task complexity, the learners' limited working memory is overload. Cognitive load theory (CLT) provides valuable guidelines on how to deal with the overload (Van Merriënboer, Kirschner & Kester, 2003). CLT "is concerned with the development of instructional methods that efficiently use people's limited cognitive processing capacity to stimulate their ability to apply acquired knowledge and skills to new situations" (Paas, Tuovinen, Tabbers &:Van Gerven, 2003, p. 63). There are three types of cognitive load which are *intrinsic, extraneous and germane*. *Extraneous cognitive load* is the result of implementing "instructional techniques that require students to engage in activities that are not directed at schema acquisition" (Sweller 1994: p299). It is the effort required by the learner to process poorly designed instruction (Kirschner, 2002). In present study, the powerful CLT-training formats reducing extraneous cognitive load *split attention, redundancy, signaling and modality principle* (Bannert, 2002), and *multimedia and coherence principle* proposed in cognitive theory of multimedia learning (CTML) by Mayer (2001) were investigated. *Multimedia* presentation refers to any presentation that contains printed/spoken text and static/dynamic illustrations (Clark & Mayer, 2003; Mayer &Moreno, 2002). *Modality* refers to placing material into spoken forms of words rather than

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printed word whenever the graphic and/or animation is the focus of the words and both are given simultaneously (Clark & Mayer, 2003; Sweller,Van Merriënboer & Paas, 1998). *Redundancy* refers to presenting words in both text and audio narration which hinder learning. *Spilt attention* refers to presenting words and pictures separately. Learners must use their limited cognitive resource to use mentally organize and integrate the materials when they are separated from each other on the screen. On the contrary, if they are integrated, learners can combine them in their working memory and make meaningful connection between them. *Coherence* refers to presenting irrelevant sound, picture and graphics which can hurt learning in learning materials. In line with the coherence principle, extraneous picture and word should be eliminated (Clark & Mayer, 2003; Mayer and Moreno, 2002). *Signaling* refers to adding non content information, visually or auditory, to the content in order to focus attention to those aspects which is important while watching dynamic display (Sweller et al., 1998).

CLT and CTML based their assumption on limited working memory model proposed by Baddeley and Hitch (1974). Working memory "refers to a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive task as language comprehension, learning and reasoning"(Baddeley, 1992, p. 256). Working memory consists of three subcomponents which are *central executive, phonological loop and visuospatial sketchpad.* Phonological loop and visuospatial sketchpad are two slave system of working memory (Baddeley, 1992). Central executive which is most crucial component of working memory is responsible for coordinating information from two-slave system and manipulation of information for higher order cognitive skills. Since the function of this system are related to the higher order cognitive skills like reading and comprehension while keeping information in a short period, the variation of individual on working memory should be consistent with the performance on cognitive tasks (Unsworth & Engle, 2007).

Although the central assumptions of cognitive theories are based on limited WMC, there is not enough research to investigate the effects of WMC and its relation to cognitive load in multimedia. The effects of WMC might be much more important than before since theories recently try to find out new instructional formats that impose germane cognitive load which is related to the construction of meaningful schemas. However, most research in cognitive theories focus on dual task paradigm to investigate the effects of two slave system and the principles in multimedia (Mayer & Sims, 1994; Gyselinck, Cornaldi, Dubois, De Beni & Ehrlich, 2002; Pujari, 2007) and their realtion to cognitive load (Pujari, 2007). The effect of WMC has been investigated for elderly people (Van Gerven, Paas, Van Marrienboer & Schmidt, 2000; Van Gerven, Paas, Van Marrienboer, Hendrick & Schmidt, 2003; Van Gerven, Paas, Van Marrienboer & Schmidt, 2006). Van Gerven et al (2000) propose some instructional formats that aim to help elderly people because of decline in their WMC and reduced ability to distinguish between relevant and irrelevant information. Van Gerven et al (2003) found that both young and elderly groups benefit most from bimodal condition of instructional format and invested less mental effort, particularly; elderly participants benefit more from bimodal condition. In a recent study, there was no significant difference between modality and variability of worked example for elderly participants and they invested less mental effort in both conditions (Van Gerven et al., 2006).

Goal based scenario requires students to perform complex cognitive task by combining and maintaining verbal and visual information. Therefore, rather than two slave systme, WMC was taken into account for this study. That is, WMC is the measurement of central executive (Unsworth, Heitz, Schrock & Engle, 2005) and it is known that the function of central executive is coordinating two slave systems and maintaining information, hence, to investigate WMC as an individual difference for such a complex learning environment assumed to be much more appropriate for the present study. The following research questions were quided this study:

1. To what extent cognitive load could explain the possible difference on learning outcome from goal based scenario designed multimedia for the learners with different working memory capacity.

1.1. Is there a significant difference between high WMC, medium WMC and low WMC learners on learning outcomes from the second version (-CLT)?

1.2. Is there a significant difference between high WMC, medium WMC and low WMC learners on learning outcomes from the first version (+CLT)?

1.3. Is there a significant difference between the first version (+CLT) and the second version (-CLT) on learning outcome?

1.4. Is there an interaction effect between learners' working memory capacity and two version of GBSc3DM on learning outcome?

2. Method

2.1. *Design*

2 x 3 factorial design was used in this study. The independent variables were the two versions of multimedia (the first (+CLT) and the second (+CLT) versions of GBSc3DM), and X Working Memory Capacity (high WMC, medium WMC and low WMC). The dependent variables were the students' log files, achievement test scores as a pre-test and post-test, and mental effort. Pre-test scores were analyzed across independent variables, and the result was taken into consideration as a covariance when there was a significant difference.

2.2. *Participants*

47 11th grade students (25 females and 22 males) were selected based on their working memory capacity from from one of the Anatolian High Schools participated in this study. Students from high WMC and low WMC were randomly assigned to either of (+CLT or –CLT) multimedia learning environments.

2.3. Software development

The GBSc3DM was developed as a game based learning environment. The goal was to restart the mitosis and meiosis process which did not take place because of viruses' attacks to cells. To achieve the goal, the students had to sequence the main phases of mitosis and meiosis in the correct order, and then should complete the sub phases. The GBSc3DM included library of resources about the topic to provide support for the students. In the first version (+CLT), the multimedia was developed based on "split attention, multimedia, modality, coherence, signaling and redundancy" principles that reduce extraneous cognitive load. In the second version (-CLT), however, the multimedia was developed without these principles. Other than the implementation or violation of the principles, the remaining design and the content were the same in both versions. The information on implementation and violation of the principles in the two versions of the multimedia is provided in Table 1.

Table 1. The design issues in the first (+CLT) and the second version (-CLT) of multimedia

	VERSIONS	
PRINCIPLE	First version (+CLT)	Second version (-CLT)
Split Attention	• The explanation for each button on the main screen was placed next to the related button • Each hyperlink was opened in the same window in library	• The explanation for each button on the main screen placed at the lower side of the screen • Each hyperlink in the library was opened in a different window in the second version.
Multimedia	• Picture and text were presented together to order main phase • Pictures and text were given together in library design	• Only text was presented to order main phases • Text was given in library design
Modality	• Explanations of 3D animation for mitosis and meiosis and all sub phases were given in audio format	• Explanations of 3D animation for mitosis and meiosis and all sub phases were given in text format
Redundancy	• Both text and narration were given, however, choice of switching off the text or the audio explanations of animations were given	• Text was given with animation and no narration and switch off options were given. Since background music was incorporated, the audio explanation was excluded.
Signaling	• Key concepts in library were highlighted	• Key concepts in library were not highlighted
Coherence	• Irrelevant background music was eliminated	• Irrelevant background music (without word) was incorporated

2.4. Instruments

2.4.1. Automated opretaion digit span task (AOSPAN)

Automated operation span task ***(AOSPAN)*** was mouse driven, and the participants only need to click on the mouse to complete the task. They also can complete the task independently of the researcher (Unsworth, Heitz, Schrock & Engle, 2005). The participants were instructed to solve some mathematical problems, and then try to recall the letters appeared among math operations in the correct order. AOSPAN has both good internal consistency (alpha 0.78) and test–retest reliability (0.83) in the original study. The scores gained from the task range from 0 to 75

2.4.2. Cell achievement test

A cell achievement test having 20 multiple choice questions with four options were used as the pre-test and the post-test. The content validity of the test was ensured with subject area teachers. The reliability of the test was 0.73 for Cronbach's alpha and 0.75 for Kuder Richardson-20 (Atilboz, 2004).

2.4.2. Log files

Log files were created and updated automatically as participants proceeded through the program. Seven variables had been recorded. These were the scores gained from multimedia, total time spent in the environment, time spent in sequencing the main phases, the number of errors made in sequencing the main and the sub phases, the frequency of library use. Students earned 10 points for each right answer, and lost 10 point for each wrong answer. The score was computed by subtracting total points of wrong answers from total points of right answers.

2.4.3. Subjective rating scale

Participants expressed their mental efforts with 9-point mental effort rating scale ranging from 1 (very, very low mental effort) to 9 (very, very high mental effort). The validity and reliability of this scale was tested in Turkish context by Kilic and Karadeniz (2004). The reliability of this scale was found to be 0.78 (Cronbach's alpha).

2.5. Procedure

The study lasted two classroom hours. Before the study started, AOSPAN were administered to find out participants' working memory capacity. Among 118 participants , 47 of them were selected for the present study. Firstly, cell achievement test was administrated to the selected participants. Then, the students were required to use the multimedia (+CLT and –CLT), and log files were kept, and mental effort was measured. At the end of the study, students were required to complete the cell achievement test as a posttest.

2.6. Data analysis

Analysis of Covariance (ANCOVA), Analysis of Variance (ANOVA), and Kruskall Wallis non parametric test were used to the analyze data. If the assumption of two way ANCOVA was not meet, two way ANOVA was used, and then if the assumption of two way ANOVA was not meet then Kruskal Wallis was used to analyze data. For all statistical tests a significance level of .05 was maintained.

3. Result

3.1. Prior knowledge

A cell achievement test was administrated to find out the students' prior knowledge in the beginning of the study. The result of two way ANOVA showed that there was no significant difference in students' prior knowledge between two versions of multimedia, working memory capacity, and interaction between the two versions of multimedia and working memory capacity, $F(1, 41) = .815$, $p=.37$; $F(2, 41)= 2.968$, $p=.06$; $F(2, 41)= 2.678$, $p= .08$. Although there was no significant difference with regard to the prior knowledge, the p value for WMC and interaction between WMC and the two versions of multimedia was very close to significance level. Hence, the researchers decided to take students' prior knowledge as a covariance.

3.2. Variables measured for the whole process

Two way ANVOCA was used to analyze the effects of multimedia versions and WMC on ***mental effort, post test (cell achievement test), learning time and library use.*** No main effect was found for multimedia versions (F (1, 40) = 0.36, MSE = 1.94, p = .55), working memory capacity (F (2, 40) = 1.16, MSE = 6.29, p = .32), and no interaction effect was found for working memory capacity and multimedia versions ((F (2, 40) = 1.22, MSE = 0.55, p = .30) on **post-test**. No main effect was found for multimedia versions (F (1, 40) = 0.65, MSE = 1.98, p =.42), working memory capacity (F (2, 40) = 0.08, MSE = 0.26, p = .91), and no interaction effect was found for working memory capacity and multimedia versions (F (2, 40) = .86, MSE = 2.62, p = 42) on invested **mental effort.** No main effect was found for multimedia versions (F (1, 40) = 0.15, MSE = *70440.47*, p = 69), working memory capacity (F (2, 40)

= 0.81, *MSE* = 364568, 97, *p* =.42), and no interaction effect was found for working memory capacity and multimedia versions (*F* (2, 40) = 1.39, *MSE* = 627939, 25, *p* = .26) on **learning time**. No main effect was found for versions of multimedia (*F* (1, 40) = 0.52, *MSE* = 45.90, *p* = .47), working memory capacity (*F* (2, 40) = 1.36, *MSE* = 119.92, *p* = .26), and no interaction effect was found for working memory capacity and multimedia versions (*F* (2, 40) = 2.32, *MSE* = 204.37, *p* = .11) on the frequency of **library use.**

Two ways ANOVA was used to analyze data for **score** gained from multimedia. Main effect was found for multimedia versions (F (1, 41) = 4.26, p= 0.04, *η2 p=.09*. The strength of relationship between multimedia versions and score was medium. Students' score in the first version (+CLT) was higher (M=602.31 SD= 36.12) than that in the second version (-CLT) of multimedia program (M=498.37, SD= 35.04). No main effect was found for working memory capacity (F (2, 41) = 0.84, p= 0.43, *η2 p=.04,* and no interaction effect was found for working memory capacity and multimedia versions (F (2, 41) = 0.04, p= 0.95, *η2 p=.0.002* on score gained from multimedia.

3.3. Mitosis findings

A Kruskal-Wallis test was used to compare the six conditions on **main phase time** and **the number of errors made in sequencing main phases.** No effects of confition was found for **main phase time** H (5) = 6.95, *p*=.22 and **for *main phase error,*** H (1)= 2.79, p=.09. Two ways ANCOVA was used to analyze the data for **each phase error.** A main effect was found for multimedia versions (*F* (1, 40) = 4.53, *MSE = 1764.98*, *p* = .03, *η*2p = .10). The strength of relationship between multimedia versions and each phase error was medium. The adjusted mean for each phase error rate was found significantly lower (M= 15.40) in the first version compared to second version (M= 27.90) of multimedia. However, no main effect was found for working memory capacity (*F* (2, 40) = 1.97, *MSE* = 789.98, *p* =.15), and interaction effect for working memory capacity and multimedia versions (*F* (2, 40) = .05, *MSE* = 21, 88, *p* = .94) on each phase error.

3.4. Meiosis findings

A Kruskal-Wallis test was used to compare the six conditions on **main phase time** and **the number of errors made for each phase**. No effects of condition was found for **main phase time**, H (5) = 8.62, *p*=.12. On the other hand, a significant effect of condition was found, H (5) = 8.62, *p*=.12. Multiple comparisons among groups were conducted with Mann Whitney U test. The test result comparing high WMC/first version and high WMC/second version were significant, z= -2.893, p=0.002 and showed a significantly lower error rate for high WMC/first version (mean rank= 3.92) than high WMC/second version (mean rank= 10.72). The test comparing high WMC/first version and low WMC/second version were found significant, z=-2.152, p=0.03 and showed a significantly lower error rate for high WMC/first version (mean rank= 4.50) than low WMC/second version (mean rank= 9.14). Two ways ANCOVA was used to analyze the data for **main phase error**. No main effect was found for multimedia versions (*F* (1, 40) = 0.5, *MSE* = 15.70, *p* = .46), working memory capacity (*F* (2, 40) = 0.97, *MSE* = 27.79, *p* = .39) and no interaction effect was found for working memory capacity and multimedia versions ((*F* (2, 40) = 0.18, *MSE* = 5.38, *p* = .332) on **main phase error**.

4. Discussion

The effect of WMC was only obtained in each phase error rate in meiosis. The possible reason for this finding might be related to the task itself. Meiosis had 8 sub phases and each subphase has several sub items needs to be sequenced correctly. This task is relatively difficult than the other task in multimedia and the task demanded more attention to maintain task goal. In previous research, the difference between high WMC and low WMC can only observed when task demanded more attention to complete the task (Kane & Engle, 2003). In another study, performance difference between high and low WMC students found out in anti saccade task than the pro saccade task (Kane, Bleckley, Conway & Engle, 2001). In conclusion, the task characteristic requiring demanded attention is an important factor that reveals performance difference between high WMC and low WMC participants.

Both high and low WMC students in the first version (+CLT) made significantly lower error in sequencing each phase of meiosis than the high and low WMC students in the second version (-CLT). It is assumed that high WMC students are able to adjust their attention by zooming out and zooming in based on the task demand. Therefore, it is expected that high WMC students in second version (-CLT) performed relatively similar as the performance of high WMC students in the first version (-CLT). Contrary to this prediction, the result of this study showed that high WMC students performed better when cognitive load principles applied in learning environment. Therefore, it can be concluded that working memory capacity act as enhancer for high WMC students (Hambrick & Engle, 2002) and increase the effects of cognitive load principles on performance.

Low WMC students in the first version (-CLT) made lower error than the high WMC and low WMC students in the second version (-CLT). It is assumed that the low WMC students performed better in the first version (+CLT) compared to the second version (-CLT) because the low WMC learners has more capacity to store and process the information. The result is consistent with this assumption. However, the low WMC students in the first version (+CLT) made lower error than the high WMC student in the second version (-CLT). The reason for this result might be related to the task purposes and individual characteristics. The learning environment was designed as a game based learning environment and so the low WMC learner tried to maintain and coordinate their attention in order to complete the given task in the first version (+CLT). As pointed out by Cankaya (2007), low WMC students in game condition reading purposes make significantly more evaluative judgment than the test condition in verbal protocol task. Furthermore, low WMC readers produced more predictive inferences than the high WMC group in verbal protocol task and free recall. In addition, the participants' characteristics such as age play an important role in findings in that in a previous research it is found that low WMC adults made lower predictive judgment than high WMC adults' participants (Linderholm & Van den Broek, 2002. The target group is also adolescents in the current study therefore it can be expected that the young-low WMC students performed differently than adult-low WMC participants.

5. Conclusion and recommendation

In conlusion, the present study shows that the principles reducing extraneous cognitive load increased learning gains of the students in learning from multimedia. It is also found that students having high and low working memory capacity in the first version (+CLT) of multimedia performed better than the high and low WMC students in the second version of (-CLT) multimedia. Therefore, it can be conluded that the principles aiming to reduce extranous cognitive load free up students' working memory capacity, and so allow them to use their capacity for effective learning. However, further studies in different subject areas and at different grade levels are needed to make strong conclusions.

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