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Determining the Effectiveness of Technology Supported Guided Materials Based on Cognitive Load Theory Principles Related to Solar System[1]

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Abstract

The aim of this study is to investigate the effect of guided materials based on Cognitive Load Theory principles related to solar system on 7th grade students' performance, cognitive load and instructional efficiency. Semi-experimental research design was used in this study. Main application is carried out with 67 7th grade students and one science and technology teacher in Ordu. Data are obtained with; science test, performance test and Cognitive Load Scale. Science test was used as a pretest to determine the equivalency of the groups. Performance test and Cognitive Load Scale were implemented at the end of the learning session. The quantitative data analyzed with independent samples t-test was used to compare the differences of the experimental and control groups. It is determined that guided materials based on Cognitive Load Theory principles made significant meaningful effect on students' performance and cognitive load compared with current instruction program. It was found that; learning environment enriched with animations developed Cognitive Load Theory principles provide the learning environment by having fun, permanent and meaningful learning. Compared to students in the control group, students in the experimental group learned with technology supported guided materials based on Cognitive Load Theory principles have lower cognitive load and it was concluded that they provide more effective learning.

Keywords: Cognitive Load Theory, Cognitive Load, Instructional Efficiency, Animation.

ÖZET

The aim of this study is to investigate the effect of guided materials based on Cognitive Load Theory principles related to solar system on 7th grade students' performance, cognitive load and instructional efficiency. Semi-experimental research design was used in this study. Main application is carried out with 67 7th grade students and one science and technology teacher in in Ordu. Data are obtained with; science test, performance test and Cognitive Load Scale. Science test was used as a pretest to determine the equivalency of the groups. Performance test and Cognitive Load Scale were implemented at the end of the learning session. The quantitative data analyzed with independent samples t-test was used to compare the differences of the experimental and control groups. It is determined that guided materials based on

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Cognitive Load Theory principles made significant meaningful effect on students' performance and cognitive load compared with current instruction program. It was found that; learning environment enriched with animations developed Cognitive Load Theory principles provide the learning environment by having fun, permanent and meaningful learning. Compared to students in the control group, students in the experimental group learned with technology supported guided materials based on Cognitive Load Theory principles have lower cognitive load and it was concluded that they provide more effective learning.

Anahtar Kelimeler: Bilişsel Yük Kuramı, Bilişsel Yük, Öğretim Verimliliği, Animasyon

1. Introduction

Information technology tools are contemporary tools which should be used for the people, institutions and companies to make their jobs more efficient, more qualified and faster (Sağıroğlu, 2001). With the development and progression of technology in all areas, information technology tools have also begun to be used within the process of education. In order to be able to appeal to more sense organs, multimedia should be included in the education process. Multimedia is the integration of different symbol systems such as text, graphic, animation, photograph, video and sound in a way that they complement each other in order to present a specific content (Aldağ and Sezgin, 2002). These symbol systems should be integrated according to specific design principles. To do this, human cognitive architecture, especially the working memory, which is one of the components making up the structure, should be known well. One of the instructional design models which use human cognitive architecture as base is Cognitive Load Theory.

Cognitive Load Theory is an effective theory in the areas of educational psychology and instructional design, which was suggested by John Sweller. According to the Cognitive Load Theory, it is accepted that of the memory types which make up the human cognitive architecture, working memory has a limited capacity to store and process information while long term memory has an unlimited capacity. It is suggested that learning will be negatively affected when working memory is overloaded. Working memory has two sub components as visual and verbal channel with limited capacity (Baddeley, 1992). Verbal expressions are processed in the audio channel of the working memory, while visual expressions are processed in the visual channel. Thus, material which appeals' only to visual or verbal channel will cause the capacity of working memory to exceed and as a result, cognitive overload. Materials which can use both visual and verbal channel distribute the load to two channels, decrease the cognitive load and support learning.

If the capacity of working memory is exceeded during the processing of information, cognitive load will occur. Cognitive load is defined as the pressure a specific learning job forms on the cognitive structure of the students (Sweller, van Merrienboer and Paas, 1988). Three types of cognitive loads are defined. They are intrinsic cognitive load which results from the learning content, extraneous cognitive load which results from instructional design and germane cognitive load which is caused by the processes which enable the formation and organization of mental schemas. Intrinsic and extraneous cognitive loads have an inhibitory effect, while germane cognitive load has a supportive effect on learning. The working memory capacity spent for extraneous cognitive load is decreased with an effective instructional design, the gap that occurs is assigned for germane cognitive load and thus mental structures can be formed more easily. With the formation of mental structures, cognitive load decreases in the next stage (Takır, 2011).

Cognitive Load Theory comes up with instructional design effects which aim to balance the intrinsic cognitive load and to decrease the extraneous cognitive load which results from the learning environment and thus to open up more space for the working load of the students. During the development of Cognitive Load Theory, various cognitive load effects have been put forward as a result of random and controlled experiments. These effects have generally been compared with traditional methods and their efficiency has been proved (Sweller, 2008). Split-attention, modality and redundancy effects were used in the preparation of the materials used in this study.

Split-attention effect emphasizes that cognitive load will increase as a result of the split of attention with the presentation of different information which appeal to the same perception channel of the working memory and states that this situation should be avoided (van Gevren, Paas, van Merienboer and Schmidt, 2006; Sweller and Chandler, 1994; Sweller, 2004). When the information that has to be processed in visual channel exceeds the capacity of the channel, extreme cognitive loading occurs. In order to prevent this, some of the information that needs to be processes should be transferred from visual channel to the audial channel. Studies have shown that verbal presentation of the text instead of written presentation is more effective in learning. This situation is explained as the modality effect (Schnotz, 2005; Mayer, 2009). Studies have shown that verbal presentation of the text instead of written presentation is more effective in learning (Mayer and Anderson, 1991; Mayer, 1997; Moreno, Mayer, Spires and Lester, 2001).

One should avoid presenting a text that explains a visual both in written and verbal presentation. This is called redundancy effect (Chandler and Sweller, 1991). When both animation and written text are presented to students simultaneously, students' attention is split between animation and the text since both components appeal to the visual channel of the working memory. This in turn prevents the effective use of working memory and causes cognitive overload. In order to prevent this, it is recommended to use verbal presentation that appeals to visual channel instead of written text which uses visual channel (Kalyuga, Chandler, & Sweller, 1999).

In order to be able to make effective use of multimedia which has begun to be used frequently in learning process, the concept of cognitive overload, which is the leading problem experienced in these environments, should be understood and this problem should be solved. Mental load, mental effort and performance are three measurable dimensions of cognitive load (Paas & van Merriënboer, 1994). Mental load is the portion of cognitive load that is imposed exclusively by the task and by environmental demands. Mental effort refers to the cognitive capacity actually allocated to the task. Performance is a reflection of mental load, mental effort, and the above-mentioned causal factors (Kablan & Erden, 2008; Kirschner, 2002).

The purpose of this study was to compare the performance, mental load and instructional efficiency between the experimental and the control group. It was expected that the experimental group would require less mental effort and show better performance than the students in the control group. Therefore, it was assumed that instructional efficiency in the experimental group would be higher than the control group.

2. Method

2.1. Participants

The participants were 67 seventh-grade students (30 female, 37 male) from primary school in Ordu. They were attending science classes with the same curriculum. The subject of the experimental instruction was celestial bodies, chosen from the national seventh-grade science curriculum.

In this study, students were randomly selected and allocated to two groups according to the instructional materials. Control group studied the subject from course book and student book (31 students); experimental group studied from guided materials based on the Cognitive Load Theory principles (36 students). The subject of instruction was new to all participants and they were randomly assigned to two groups. The two groups were compared with independent samples t-test analysis according to their pretest performance scores on seventh-grade science test.

Independent samples t-test revealed no significant differences between the experimental and control groups for science test. Means, standard deviations and the p-value are displayed in Table 1. The p-value obtained indicated that the two groups were equal according to their pretest score.

Table 1. Independent samples t-test on pretest scores

Groups	N	$\bar{X}$	Ss	sd	t	p
Experimental	36	8.78	2.929	65	1.375	0.174
Control	31	9.84	3.387			

Note: maximum pretest score = 24.

2.2. Materials

Instructions for control group were carried out course book and student book by teacher and for experimental group instructions were delivered electronically using computer and projector by researcher. Firstly, researchers designed all computer-based instructional materials using "Adobe Flash Professional CS6". The subject of instruction was chosen from the seventh-grade national science curriculum and materials were prepared according to the objectives and content of the curriculum.

Solar system subject are consist of eleven concepts: solar system, eight planets forming the solar system and the moon, galaxy, space and universe. An animation is prepared for each concept. Subject completed by 14 practice animations after studying concept animations.

Computer-based instruction software was prepared to provide tutorial allowing students to learn at their own pace. Students can watch the animation, listen the audio again and again, and the move on to the next screen using the mouse when they want to.

2.3. Performance Testing

According to Cognitive Load Theory, performance is most often measured by a test taken at the end of the lesson or sometimes measured by the time required to complete a lesson or a test (Clark, Nguyen, & Sweller, 2005). In order to measure the performance of the participants, a multiple choice test was used in the study. Reliability of the test was calculated using Kuder-Richardson formula 20 (K-R 20). The K-R 20 reliability of the test was found to be 0.81.

2.4. Subjective Cognitive Load Scale

In order to measure cognitive load that occurs on students' cognitive structure, a nine-point Likert-type scale developed by Paas and van Merriënboer (1993) was used. This scale accepted as a valid method for measuring cognitive load (Paas & van Merriënboer, 1994; Yeung, Jin, & Sweller, 1998; Kalyuga, Chandler, & Sweller, 1998). In this study, participants were asked "How much effort do you spend when studying the concept? Select your answer". The participants selected one of the nine options: "extremely little", "very little", "little", "relatively little", "neither little not much", "relatively much", "much", "very much", "extremely much". A mental load rating ranging from 1 to 9 was therefore collected from each participant. They were asked to rate the instruction they had just finished the subject.

2.5. Instructional Efficiency

Cognitive Load Theory is about instructional efficiency. According to Paas and Merriënboer (1993), it was important to consider the cognitive costs of learning. Efficiency is defined by the theory in terms of two variables: performance and mental effort. Efficiency (E) was calculated by $E = \left(Z_{performance} - Z_{mentaleffort}\right)/\sqrt{2}$ formula where $Z_{performance}$ represents the standardized (Z scores) test scores, and $Z_{mental\, effort}$ the standardized mental effort scores collected after the testing period. When using this formula, if Z scores for performance and mental effort are equal, efficiency is zero$(E = 0)$; if Z scores for performance higher than mental effort, efficiency is positive$(E > 0)$. Otherwise; if Z score for mental effort higher than performance, efficiency is negative$(E < 0)$. Instructions that result in higher learning outcomes with less mental effort are more efficient that instructions that lead to lower outcomes with greater mental effort.

2.6. Efficiency Graph

In order to visually represent the efficiency, efficiency graph is used like the one shown in Figure 1. Efficiency graph is a two-dimensional diagram in which average performance Z scores are plotted on the vertical axis and average mental effort Z scores are plotted on the horizontal axis. Point A indicates high efficiency which means high performance with low mental effort. In contrast Point B indicates low efficiency which means low performance with high mental effort. The upper left quadrant of the graph is considered the high efficiency area of the graph and the lower right quadrant of the graph is called the low efficiency area of the graph. The most efficient instructions are those that fall into the upper left quadrant of the graph, indicating instructions that result in high performance with low mental effort.

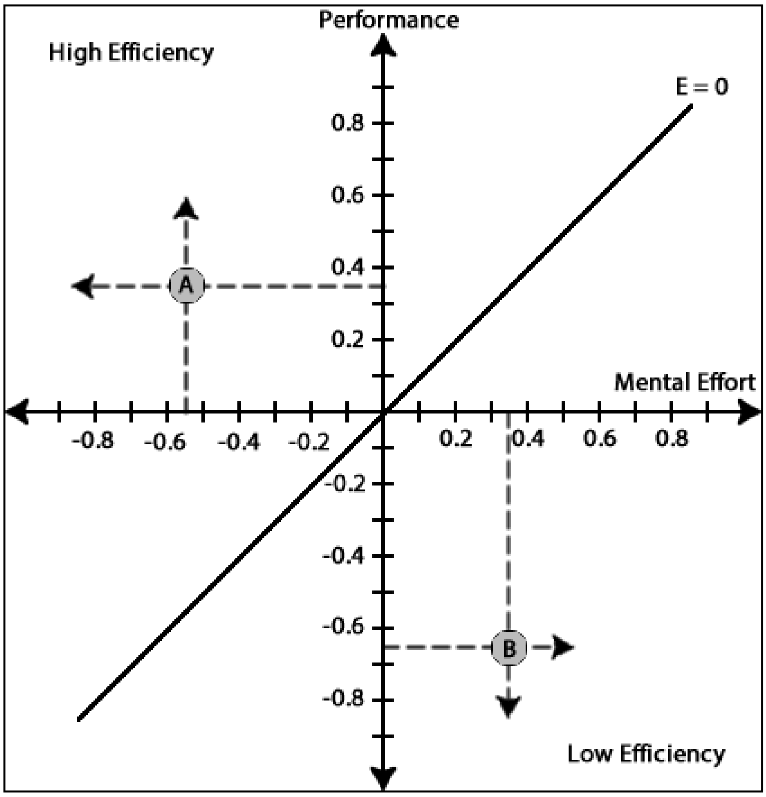


Figure 1. Efficiency graph.

2.7. Design and procedure

The experiment was carried out in the computer lab for experimental group and classroom for the control group. Computer lab contains 25 IBM compatible computers, one projector and sound system. Because of the insufficient number of computers, the experimental group was divided into two groups consisting of 18 students. Rules and how to use computer-based instruction were explained to students before the instruction began. The length of two instruction period was 40 min. After completing the instruction, all students were asked to fill out the subjective cognitive load scale and then an achievement test was administered to measure the performance of the students. All students were tested individually and all tests were conducted in a single session.

3. Results

The obtained data were analyzed using independent samples t-test. The dependent variables were test performance score, subjective rating scale of cognitive load and efficiency. Means and standard deviations of variables are displayed in Table 2.

Table 2. Descriptive statistics on performance, and rating scale.

Variable	Group	N	Mean	Standard deviation	Standard error mean
Performance	Experimental	36	54.56	6.171	1.029
	Control	31	38.97	11.757	2.112
Rating Scale	Experimental	36	2.31	1.283	0.214
	Control	31	5.55	1.312	0.236
Efficiency	Experimental	36	0.935	0.593	0.098
	Control	31	-1.086	0.921	0.165

3.1. Performance Testing

According to Cognitive Load Theory; if cognitive load on learners' working memory can be reduced during instructions then test performance of learners increase. Therefore, the authors expected that the experimental group should outperform the control group. The analysis revealed significant differences in test scores between the groups. The obtained p value indicated that the experimental group outperformed the control group (Table 3).

Table 3. Independent samples t-test results of performance scores.

Variable	Group	N	$\bar{X}$	Sd	df	t	p
Performance	Experimental	36	54.56	6.171	65	-6.929	0.000
	Control	31	38.97	11.757			

3.2. Subjective Rating of Cognitive Load

The authors had hypothesized that the experimental group would require the least mental effort to process the instructional materials. The analysis produced significant differences between instructional formats using subjective rating scale data. The obtained p value indicated that the experimental group required significantly less mental effort than the control group (Table 4).

Table 4. Independent samples t-test results of mental effort scores.

Variable	Group	N	$\bar{X}$	Sd	df	t	p
Mental Effort	Experimental	36	2.31	1.283	65	10.205	0.000
	Control	31	5.55	1.312			

3.3. Instructional Efficiency

Average performance Z scores, average mental effort Z scores and calculated instructional efficiency points are displayed in Table 5.

Table 5. Average performance Z score, average mental effort Z score and instructional efficiency point of groups.

Group	N	Performance Z score	Mental Effort Z score	Instructional Efficiency
Experimental	36	0.600	-0.723	0.935

Control	31	-0.697	0.839	-1.086

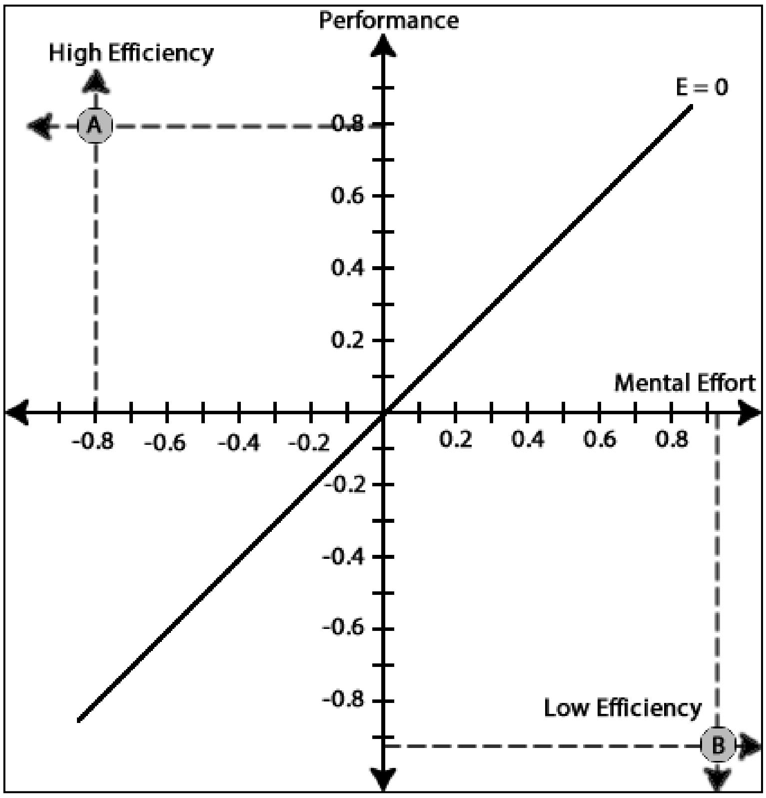
The authors had predicted that instructions that performed for experimental group was high efficient than control group. The independent samples t-test results revealed significant differences in efficiency between the experimental and the control groups. The obtained p value indicated that experimental group learned more efficiently than control group (Table 6).

Table 6. Independent samples t-test of efficiency scores.

Variable	Group	N	$\bar{X}$	Sd	df	t	p
Efficiency	Experimental	36	0.935	0.593	65	-10.830	0.000
	Control	31	-1.086	0.921			

3.4. Efficiency Graph

Figure 2 illustrates the results for instructional efficiency. The efficiency point of experimental group is located in the upper left quadrant of the efficiency graph (higher performance with lower mental effort), whereas the efficiency point of control group is located in the lower right quadrant of the efficiency graph (lower performance with higher mental effort).



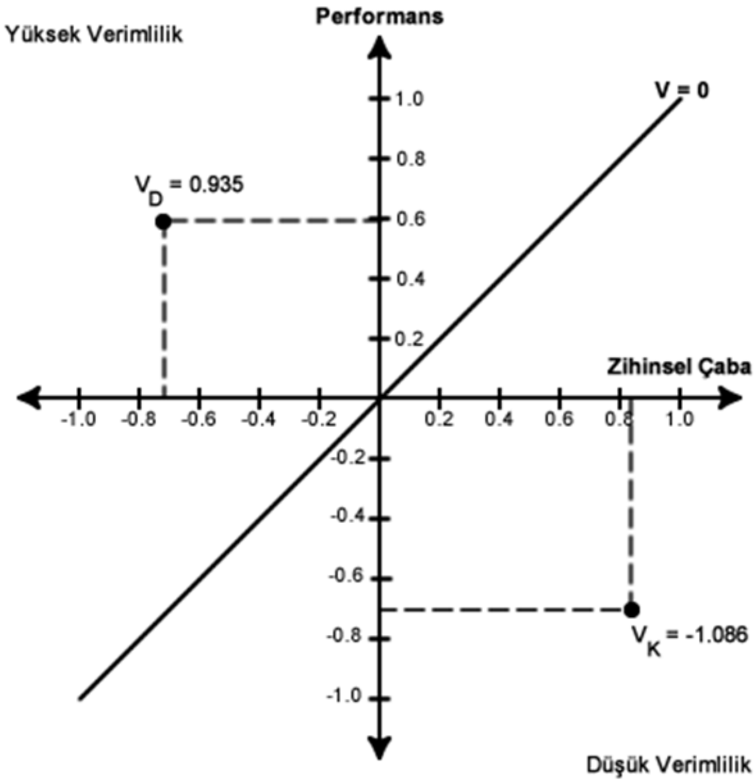


Figure 2. Illustration of efficiency points of groups on efficiency graph (A: Experimental Group, B: Control Group).

4. Discussion

In this study, the effectiveness of technology supported guided materials based on Cognitive Load Theory design principles related to celestial bodies subject on 7th grade students' were compared with respect to performance, mental effort and instructional efficiency between the two groups.

The first result indicated that the performance of the students in the experimental group was better than that of the students in the control group. It had been expected that successful mental integration of two different information sources (visual and verbal) during instruction should decrease extraneous cognitive load on working memory that improve test performance. Therefore, the students in the experimental group should outperform those in the control group. Students' performance was measured using a multiple-choice test, and the results showed that performance scores of the experimental group were significantly higher than those of the control group. Therefore, it is possible to conclude that students learn concepts better with technology supported guided materials based on Cognitive Load Theory design principles in science instructions. This finding is consistent with previous research (Kalyuga, Chandler, & Sweller, 2000; Tindall-Ford, Chandler, & Sweller, 1997).

The second result was that instructions with the experimental group required less mental effort than instructions with the control group. Cognitive processing of visuals and related text, including dynamic visualizations such as animations and simulations, involves the selection and organization of relevant elements of visual and auditory information distributing cognitive load on the two channels of working memory. This finding is consistent with previous research which showed that complex visuals are understood more efficiently when explanatory words are presented in an audio modality than when presented in a written modality. (Mousavi, Low, & Sweller, 1995; Mayer & Moreno, 1998; Moreno & Mayer, 1999)

Finally, the third result was that instructional efficiency in the experimental group was higher than in the control group. Instructions that result in higher learning outcomes or performance with less mental effort are more efficient than instructions that lead to lower outcomes with greater mental effort. The result of this study showed that instructional design principles of Cognitive Load Theory increases instructional efficiency. (van Gog & Paas, 2008).

In this research, we try to develop narrated animations fostered meaningful learning without increasing cognitive load. However, additional research is needed to determine the role of individual differences in visual and verbal learning styles in influencing cognitive load.

Subjective rating scale of cognitive load was used to measure cognitive load in this research. Cognitive load can be measured by various methods. Additional researches would be useful to have direct measures of cognitive load.

In this research, level of learners' expertise was ignored. Using visuals with audio narration of text usually enhanced learning outcomes for students with low prior knowledge levels, but not for those with higher knowledge levels. Further researches would be needed to compare the effectiveness of Cognitive Load Theory design principles between the novel and more knowledgeable learners.

References

Aldağ, H., & Sezgin, M. E. (2002). Multimedia uygulamalarında ikili kodlama kuramı. *Marmara Üniversitesi Atatürk Eğitim Fakültesi Eğitim Bilimleri Dergisi, 15*, 29-44.

Baddeley, A. (1992). Working Memory. *Science, 255*(5044), 556-559.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Istruction, 8*, 293-332.

Clark, R. C., Nguyen, F., & Sweller, J. (2005). *Efficiency in learning: Evidence-based guidelines to manage cognitive load.* Sydney: Pfeiffer.

Kablan, Z., & Erden, M. (2008). Instructional efficiency of integrated and seperated text with animated presentations in computer-based science instruction. *Computers and Education, 51*, 660-668.

Kalyuga, S., Chandler, P., & Sweller, J. (1998). Levels of expertise and instructional design. *Human Factors, 40*, 1-17.

Kalyuga, S., Chandler, P., & Sweller, J. (1999). Managing split-attention and redundancy in multimedia instruction. *Applied Cognitive Psychology, 13*, 351-371.

Kirschner, P. A. (2002). Cognitive load theory: implication of cognitive load theory on the design of learning. *Learning and Instruction, 12*, 1-10.

Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist, 32*, 1-19.

Mayer, R. E. (2009). *Multimedia learning.* New York: Cambridge University Press.

Mayer, R. E., & Anderson, R. B. (1991). Animations need narrations: An experimental test of a dual-coding hypothesis. *Journal of Educational Psychology, 83*, 484-490.

Mayer, R. E., & Moreno, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of Educational Psychology, 90*, 312-320.

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology, 91*, 358-368.

Moreno, R., Mayer, R. E., Spires, H. A., & Lester, J. C. (2001). The case for social agency in computer-based teaching: Do students learn more deeply when they interact with animated pedagogical agents? *Cognition and Instruction, 19*, 177-213.

Mousavi, S. Y., Low, R., & Sweller, J. (1995). Reducing cognitive load by mixing auditory and visual presentation modes. *ournal of Educational Psychology, 87*, 319-334.

Paas, F., & van Merriënboer, J. (1993). The efficiency of instructional conditions: an approach to combine mental effort and performance measures. *Human Factors, 35*, 737-743.

Paas, F., & van Merriënboer, J. (1994). Variability of worked examples and transfer of geometrical problem-solving skills: A cognitive-load approach. *Journal of Educational Psychology, 86*, 122-133.

Sağıroğlu, Ş. (2001). *Etkin bilişim teknolojileri kullanımı.* Ankara: Ufuk Kitabevi.

Schnotz, W. (2005). An integrated model of text and picture comprehension. In R. E. Mayer, *In The Cambridge handbook of multimedia learning* (pp. 49-69). Cambridge: Cambridge University Press.

Sweller, J. (2004). Instructional design consequences of an analogy between evolution by natural selection and human cognitive architecture. *Instructional Science, 32*, 9-31.

Sweller, J. (2008). Instructional implications of David C. Geary's evolutionary educational psychology. *Educational Psychologist, 43*, 214-216.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition and Instruction, 12*(3), 185-233.

Sweller, J., van Merrienboer, J., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.

Takır, A. (2011). *The effect of an instruction designed by cognitive load theory principles on 7th grade students' achievement in algebra topics and cognitive load.* Ankara: Orta Doğu Teknik Üniversitesi.

van Gerven, P. W., Paas, F., van Merriënboer, J., & Schmidt, H. G. (2006). Modality and variability as factors in training the elderly. *Applied Cognitive Psychology, 20*, 311-320.

van Gog, T., & Paas, F. (2008). Instructional efficiency: Revisiting the original construct in educational research. *Educational Psychologist, 43*, 16-26.

Yeung, A. S., Jin, P., & Sweller, J. (1998). Cognitive load and learner expertise: Split-attention and redundancy effects in reading with explanatory notes. *Contemporary Educational Psychology, 23*, 1-21.