Measuring Cognitive Load of E-learning Students for Improving Efficiency of Learning

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Abstract: *Cognitive Load Theory helps for evaluating cognitive tasks to detect the level of the information at the beginning of learning process. Paas and Merrienboer are the pioneers in the cognitive load measurement technique. In this study, the efficiency of the learning environment of the History of Civilizations' e-class was calculated with the Cognitive Load measurement method of Paas and Merrienboer, and interpreted according to concerned variables. Results were cross checked by the ANOVA method. Suggestions for improving the efficiency of the e-learning environment were discussed in the last section.*

Key words: *Cognitive Load Theory, Efficiency of the e-learning environment, Cognitive overload, cognitive capacity*

INTRODUCTION

Nowadays, human cognitive structures and processes have increasingly interested from learning and instructional designers; this also has introduced a new line of research on instructional design principles. Cognitive Load Theory (CLT) is probably the extensively accepted theory in evaluating such principles. It considers both structure of information and the learners' human cognitive architecture to understand the information processing mechanism of human being. To minimize the cognitive load to increase the learning efficiency, it focuses on advancing in instructional design to eliminate the learning complexity and cognitive overloads of the learners [1]. In this study, the assumptions of CLT were accepted as the general framework. This research aims to analyze the efficiency of the e-learning environment of the History of Civilizations class that was taught in 2009 spring period in e-learning environment.

In the first part of the study, CLT, its basic assumptions and measurement techniques were briefly summarized. After then, which data collected during the 2009 spring semester History of Civilizations class was concisely introduced, and the efficiency status of 36 regularly attended students were interpreted according to their genders, sections and faculties. Results under these headings were also crosschecked by using ANOVA test. Finally, based on the findings of these interpretations, suggestions for improving the efficiency of the learning environment of the e-class were discussed in the conclusion section [6].

COGNITIVE LOAD THEORY

CLT is focuses on understanding complex cognitive tasks that derived from the amount and interaction of the information which is needed to be managed at the beginning of the learning processes. This theory puts forward a framework for understanding cognitive processes and learning models. Also, it has aims to developing new instructional methods to increasing the learners' cognitive capacity or minimizing learning loads base on the learners' skills and competency [1].

Cognitive Load theorists assume that there are two types of memory that works within the learning processes of the individuals; working memory and long-term memory. Working memory is only enough for limited number of information, of possibly no more than seven novel interacting elements at a time. Long-term memory, on the other hand, is unlimited and stores the mental schemas, cognitive constructs, of the individuals [1-2]. They allow us to organize the problem states that face with to choose most appropriate solutions. It reveals the actual mental power of human beings.

The long-term and the working memory work simultaneously in an active learning process. While information transmitted from an instructor is being analyzed in the working memory, information that is stored in schemas is transmitted to the working memory in

order to guide them. In order for efficient learning to occur, cognitive load theorists believe that the information that is needed to be processed and constructed in the working memory. The cognitive load imposed on the working memory, should be moderated and facilitated. Cognitive load, in other words, is the data loaded to the memory that is being used during a learning process.

CLT supports three different types of cognitive load: i)intrinsic cognitive load, ii)extraneous or ineffective cognitive load, and iii)germane or effective cognitive load. Intrinsic Cognitive Load is the number of elements that are needed to be processed simultaneously in working memory, and cannot be influenced by instructional designs. Extraneous or ineffective cognitive load *"is the extra load beyond the intrinsic cognitive load resulting from mainly poorly designed instruction"* [2]. Finally, germane cognitive load is the one that contributes to the construction, as well as the automation of schemas. In order for efficient learning to occur, instructional designs should focus decreasing the amount of extraneous cognitive load, increasing germane cognitive load, and commanding intrinsic load by breaking down complex tasks into a series of perquisite tasks and by supporting knowledge.

Measuring the cognitive load

The mostly proposed method to measure cognitive load was developed by Paas and Merrienboer, which takes both performance and mental efforts of the individuals into account in determining the efficiency of the learning environments in question.

$$E = \frac{z_{Performance} - z_{Mental\ Effort}}{\sqrt{2}} \quad (1)$$

The formula 1 computes the E value to represent the efficiency of the learning environment. The √2 represents the measurement of the distance between two points. Evaluation of the results can be made by the efficiency table, which was developed by Paas and Merrienboer.

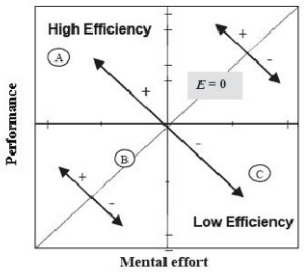


Fig. 1. Graph of efficiency

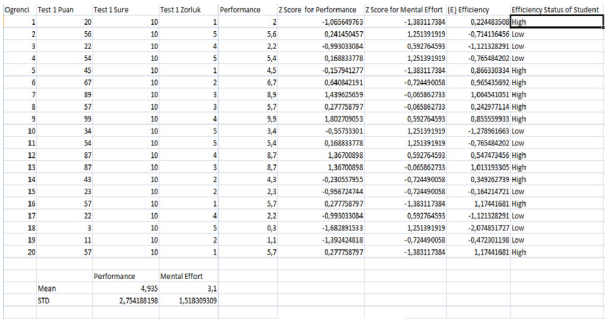
As mentioned earlier, because of this method integrates mental effort and performance, it is the most efficient and valuable method to employ to measure cognitive load. In this regard, while measuring the environmental efficiency of the History of Civilization class, the aforementioned formula was used, and the results were interpreted in the light of the efficiency graph given in Fig. 1.

MATERIALS AND METHODS

The History of Civilization class in Bahçeşehir University, Faculty of Engineering was taken as an example for measuring the efficiency of the learning environment with Paas and Merrienboer's method of measurement. Under the aforementioned class, which lasts 14 weeks and was based on movie screening every 2 weeks, in order to evaluate the efficiency of the learning environment and the overall success of the class, students were

asked to participate in quizzes with 10 questions and to rank the difficulty of these questions. A total of 7 quizzes were made during the semester. Within 15 minutes time period, students both answered the questions and ranked the difficulty of them, from 1 to 5. One corresponds to the easiest question, where five corresponds to the most difficult one. It operated for 4 sections in 2009 spring semester.

Data about the questions and its degree of difficulty was collected and transformed into z-performance and z-mental effort scores, as well as the scores of efficiency. While calculating z-performance scores, the total of correct answers of the students in each quiz were divided to the total number of quizzes. The z-mental effort, on the other hand was calculated in the light of the data on the difficulty levels of the questions as given in Fig.2. Based on these two data sets, efficiency was calculated through the formula 1 and given in Fig.3. As number of students that attend to the classes differed from one week to another, a group of 36 students who attended to all quizzes and all e-lectures were selected for the interpretation of the overall learning environment of the History of Civilizations course.



Ogrenci	Test 1 Puan	Test 1 Sure	Test 1 Zorluk	Performance	Z Score for Performance	Z Score for Mental Effort	(E) Efficiency	Efficiency Status of Student
1	20	10	1	2	-1,065649763	-1,383117384	0,224483508	High
2	56	10	5	5,6	0,241450457	1,251391919	-0,714136456	Low
3	22	10	4	2,2	-0,993033084	0,592764593	-1,121338291	Low
4	54	10	5	5,4	0,168833778	1,251391919	-0,765844202	Low
5	45	10	1	4,5	-0,157941277	-1,383117384	0,866330334	High
6	67	10	2	6,7	0,640842191	-0,724490058	0,965435692	High
7	89	10	3	8,9	1,439625659	-0,065862733	1,064541051	High
8	57	10	3	5,7	0,277758797	-0,065862733	0,242977114	High
9	99	10	4	9,9	1,802709053	0,592764593	0,855559933	High
10	34	10	5	3,4	-0,55733301	1,251391919	-1,278961663	Low
11	54	10	5	5,4	0,168833778	1,251391919	-0,765844202	Low
12	87	10	4	8,7	1,36700898	0,592764593	0,547472456	High
13	87	10	3	8,7	1,36700898	-0,065862733	1,013193305	High
14	43	10	2	4,3	-0,280557955	-0,724490058	0,349262739	High
15	23	10	2	2,3	-0,956724744	-0,724490058	-0,164214721	Low
16	57	10	1	5,7	0,277758797	-1,383117384	1,17441681	High
17	22	10	4	2,2	-0,993033084	0,592764593	-1,121338291	Low
18	3	10	5	0,3	-1,682891533	1,251391919	-2,674851727	Low
19	11	10	2	1,1	-1,392424818	-0,724490058	-0,472301198	Low
20	57	10	1	5,7	0,277758797	-1,383117384	1,17441681	High
		Performance	Mental Effort					
	Mean	4,935	3,1					
	STD	2,754188198	1,518309309					

Fig.2. Efficiency calculation of twenty randomly-selected students from all sections

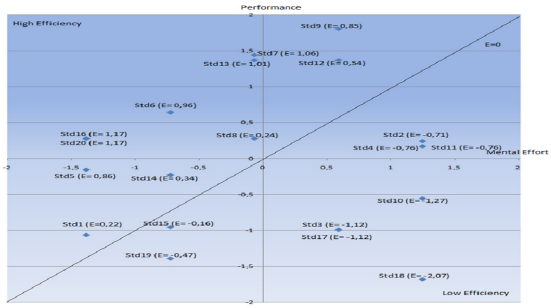
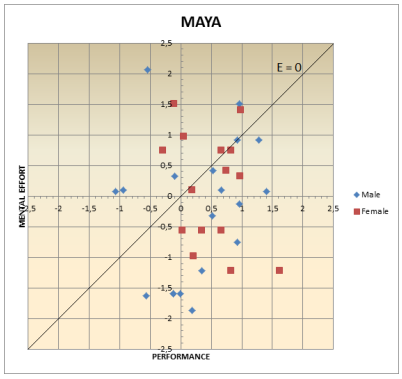


Fig.3. Graph for efficiency

Due to ethical reasons and privacy of the students, the students were enumerated from 1 to 36. Finally, based on the calculated performances and mental efforts of selected 36 students, the efficiency of the learning environment of the History of Civilizations course on students was interpreted through the table in figure 4 under five headings; section-based efficiency of genders, Movie-based efficiency of different faculties, section-based efficiency of different Movies, Movie-based efficiency of genders, and finally, Movie-based efficiency of different sections. The achieved results under each heading were also crosschecked by using ANOVA test method in SPSS tool. Here is an example for the efficiency measurements in Figure 4.



Dependent	Variable	Sum of Squares	df	Mean Square	F	Sig.
Gender	Between Groups	,375	1	,375	1.536	,218
	Within Groups	25,875	106	,244		
	Total	26,250	107			

Fig. 4. (a) efficiency performances of male and female students for Maya; (b) ANOVA test result of Maya for gender variable

FINDINGS

Section based efficiency of genders

When we compared section-based efficiency of male and female students, we see highly diverse results.

Table 1. Number of Students that attended to the lectures and sections

		MOVIES						
		Hannibal	Maya	Columbus	Colonial America	Islam	Galileo	Newton
SECTIONS	Sec. 5	49	56	36	52	36	68	72
	Sec. 6	54	50	31	22	25	47	53
	Sec. 7	68	54	57	46	13	53	42
	Sec. 8	77	53	44	58	19	54	36

In section 5, we observed low efficiency between the genders. The 60% of males that were taking History of Civilizations class in section 5 clustered with low efficiency. Similarly, 80% of female students had low efficiency in the same section. So, it can be concluded that the efficiency of the learning environment of section 5 is very low for the majority of the students regardless of their genders.

Section 6 shows a different picture than section 5. When we take a look at the female population in this section, we see that both girls were highly efficient, whereas majority of the male population was faced with low efficient learning environment. In other words, learning environment for section 6 was more efficient for female students than for male students.

For section 7 offers just the opposite version of the section 6. In this section, the 66% of male students have reached high efficiency, where 66% females have faced with low efficient environment for learning.

Finally, in section 8, it was observed with low efficient learning environment for 62% of male students. As section 8 was only made up of male students, we cannot analyze the efficiency for female students.

Movie based efficiency of genders

When we take a look at the efficiency for different genders in seven different movies, we are commonly faced with opposite efficiency statuses for male and female students. While male and female population showed parallel efficiency levels in three movies (Islam, Maya and Colonial America), the results are highly different for the rest.

The Maya movie was shown in 4th weeks; we observed that efficiency of the learning environment was low for majority of the students, regardless of their genders. Only the 33.3% of the female population archived the high efficiency, whereas this percentage decreased to 28.5% among male population.

The same results were also determined by the ANOVA test. As the calculated value of significance by the ANOVA method is greater than 0.05, it is proven that genders of the participants of the fourth week are not important in determining the efficiency of the learning environment of the class via the quiz.

Like Maya movie, learning environment for the movie Colonial America was inefficient for the most of the students. The 67% of female and male students experienced low efficiency in this movie and its questions. Thus, supported by the findings of the ANOVA test, we can conclude that week 4 and week 6 of the History of the Civilization class provided the least efficient learning environment for both male and female participants via the movies.

Majority of both male and female students were again faced with inefficient learning environment for the class of week 7, where the movie "Islam" was shown. In that week's lecture, only the 47% of female students, the 43% of male students were responded with high efficiency. Again, in line with the efficiency statuses of the students, ANOVA test

proved that gender is not a significant variable for the efficiency of the learning environment of the week concerned.

In weeks where the movies Hannibal, Columbus, Galileo and Newton were screened, differences in genders were also reflected in the efficiency statuses of the male and female students. For example, in terms of the movie Columbus, the 67% of female students were low, where 62% of the male participants were high in efficiency.

The significance of the genders of the students for the movie Columbus is also reflected in the results of the ANOVA test. As the value of significance is smaller than 0.05, it is verified that genders have significant differences for the efficiency of the learning environment of week 5. The same result was also received in the week of Galileo (the 53% of female students and the 43% of male students responded with low efficiency) and in the week of Newton (the 67% of female students, the 43% of male students responded with low efficiency).

Although there were efficiency differences between male and female participants of the weeks where Galileo and Newton were screened, results of the ANOVA test demonstrate that gender has not a significant variable for those weeks in question. These results are highly plausible as the efficiency statuses of genders in the weeks of Galileo and Newton are extremely close to each other.

The only movie where the efficiency of the learning environment was higher for female students when compared to male students was the week of Hannibal. In that week's lecture, the 60% of the female students have high efficiency, where it was decreased to the 38% for male students. The results of the ANOVA test also illustrated the significance of gender differences in determining the efficiency of the learning environment of the first week.

Overall, when we compare the movie-based efficiency of the genders, we con conclude that the efficiency of the learning environment was low for majority of the female students, whereas the learning environment was relatively more efficient for male students.

Section based efficiency of different movies

The section-based analysis of the different movies that were screened throughout the History of Civilization course once again shows an interesting table of results about how efficient the learning environment of the e-class is.

For the students of section 5, the learning environment was most efficient in week 9, where the movie was screened is Galileo. On the other hand, students found the learning environment least efficient during the weeks of the screening of Maya, Colonial and Newton.

The most efficient learning environment that was provided to the students of section 6 was the week that Islam and Newton movies were screened and quizzes performed. Instead, the weeks of Hannibal, Maya, Columbus and Colonial were considered as the least efficient for the students of section 6.

The Newton movie is the most efficient environment for learning in section 6 students. The 67% of students of this section revealed high efficiency statuses during this week for quiz. Contrariwise, students were faced with the least - efficient environment for learning during the screening of Hannibal, Maya, Columbus and Colonial.

Finally, students of section 8 experienced the highest efficiency about the environment of learning during week 5, in which Columbus was the main focus of attention. Conversely, they faced with the least efficient learning environment in week 4, when students of the section 8 were obliged to watch and analyze the movie called Maya.

To sum up, it is clear that the least efficient learning environment was provided to the students in all of the sections during the screening of the movie Maya. On the other hand, Newton movie seems to have an efficient atmosphere that did provide relatively higher

efficiency for students in all of the sections, when compared to the other movies in quizzes.

As the efficiency statuses and the ANOVA check test results indicate that different variables showed different significance levels for separate weeks of the History of Civilizations e-class in Bahçeşehir University in 2009 Spring Semester. For example, while genders of the participants have a significant importance in determining the efficiency of the e-learning environments of most of the weeks. The same could not be argued for the different schools that the students were belong to. For majority of the movies, efficiency statuses show parallel results and for majority of the students that are both from school of Engineering and School of Arts & Sciences, the environment that the movies were shown has low in efficiency.

Like the genders of the students, sections that they belong to were also crucial variables for determining the efficiencies of the learning environments of the weeks of History of Civilizations e-class. For example, as ANOVA tests also indicated that in majority of the weeks, students of section 5 and section 8 have revealed low efficiency statuses, where the learning environment of each week was efficient for the participants of section 6.

Regardless of their genders, sections of schools, however, it is evident that learning environment of the History of Civilizations class was dominantly low for majority of the students. In 252 efficiency results of 36 students for 7 weeks, 144(the 57%) of them revealed low efficiency statuses for the e-learning environment of the class. The main reason of this inefficiency is base on the inadequate skills of the students in English literature.

CONCLUSIONS AND FUTURE SUGGESTIONS TO IMPROVE THE EFFICIENCY OF THE E-LEARNING ENVIRONMENT

According to the various experiments of Kalyuga, Chandler and Sheller (1999), in order for a learning environment to become effective based on the principles of cognitive load theory;

(1) Textual material should be presented in auditory rather than written form;

(2) Textual materials should not be presented in both auditory and written form;

(3) If textual materials must be presented in written form, search for diagrammatic referents should be reduced by using appropriate marker guides such as colour-coding" [3], or cognitive maps can be used.

Similarly, Mayer and Moreno (1999), in their research on reducing excessive cognitive load in learning environments, suggested strategies that were summarized below [4];

- Moving some of the data processing activities from visual channel to auditory channel.
- Allowing time between successive bite-size segments and provide pretraining in names and characteristics of components.
- Eliminating extraneous material and providing cues for how to process the material to reduce processing of extraneous material.
- Avoiding to present identical streams of printed and spoken words, and finally
- Presenting narrations and corresponding animation simultaneously to minimize need to hold representations in memory

So, according to these suggestions of CLT, there are numerous ways to improve the efficiency of the e-learning environment of the History of Civilizations e-class. For example, in line with the second suggestion of Mayer and Moreno, movies that were shown during a e-class time can be divided into parts, and five - minute breaks can be taken between each part. What is more, before the screening, instructor can give brief information about the theme or characters of the movie in quiz by small clips. Also, in order to avoid

extraneous material, instructor can also give students some clues about important points, conversations or scenes of the movies. By this way, students will know the points that they have to pay attention to in order process the material more efficiently [5].

In terms of the strategies proposed by Mayer and Moreno, instructor can increase the efficiency of the class by explaining some of the germane cognitive material along with the visual material to minimize need to hold representations in memory, and to shift some of the processing from visual channel to auditory channel. If these suggestions will be taken into account in future semesters, not just for the History of Civilizations class but for all courses, efficiency of the learning environments, and consequently, performances of the students may increase dramatically.

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The paper has been reviewed.