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Pilot study on applying various research methodologies to investigate the effectiveness of e-learning materials

The COVID-19 pandemic had a major impact on higher education. Students were required to adopt a more independent way of learning, and instructors had to redesign courses to fit the digital space. Increasingly frequent e-learning research provides substantial support for the expansion of online education. The aim of this article is to investigate the effectiveness of e-learning materials among university students using a variety of research methodologies (Groningen Sleep Quality Scale, psychomotor vigilance task, verbal fluency and digit span tests, NASA Task Load indeX and eye tracking). In a pilot study conducted in a laboratory environment, 15 participants were divided into three groups and assigned to study from prepared course pages using content-equivalent e-learning materials. The results demonstrated that the applied research methodologies were appropriate for investigating the issue, allowing the pilot study to reveal a set of criteria encompassing the preferences of students for course structures and e-learning materials.

Keywords: *e-learning, learning effectiveness, learning materials, pilot research*

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1. Introduction

The COVID-19 epidemic and the restrictive measures taken to slow it down necessitated a rapid transition in educational institutions around the world (Batdı, Doğan and Talan 2021), and also presented an opportunity to explore the potential of digital education and adapt the learning environments to meet the current needs. Due to the temporary cessation of classical forms of classroom training, instructors, with the active participation and feedback of students, have laid the foundations for a modern, innovative, and new training system for the 21st century, in which the tools of online education have become an integral part of their daily lives. Students were required to adapt to more independent learning and an agenda based on it, and instructors were required to rethink and redesign course content and the manner in which it was conveyed.

When designing e-learning materials, it is important to consider aspects of knowledge transfer that are otherwise self-evident or natural. These include, but are not limited to, aspects such as enhancing learning experiences and knowledge acquisition effectiveness. Nedeva and Dineva (2013) highlighted the role of the instructor, whereas Steen (2008) emphasised the platform development capabilities necessary for effective e-learning. Important and appropriate instructions play an important role in the learning process as well. Clark and Mayer's theory of e-learning course development and their collection of multimedia principles serve as an essential foundation for all previous e-learning development (Clark and Mayer 2016).

Angeliki, Asimina and Eleni (2005) outlined the general characteristics of effective e-learning, which include successful learning achievement, simple accessibility, consistent and accurate messages, ease of use, relevant, entertaining, and memorable content, and reduced training costs. In contemporary and effective e-learning environments, curriculum development and the validation of activity-based teaching methodologies through learning tasks take precedence over content-centricity (Ollé et al. 2016). Increasing student engagement, reducing the risk of dropping out of the teaching-learning process, and the emergence of online teaching methods comparable to the methodology and learning organisation of the face-to-face classroom environment all contributed to the improvement of learning effectiveness (Ollé 2018).

Theories and developments in the field of instructional design have emerged that have assigned a significant role to the direct involvement of the instructor in the design of online courses and e-learning materials (Isaias, Sampson and Ifenthaler 2020; Nilson and Goodson 2021).

The various trends in the use of e-learning (e.g., standard course pages, video-based teaching content, activity-based practical exercises, or modular, object-orientated online courses) in higher education have resulted in solutions of varying quality. As a result, the significance of analysing the path to effective teaching via various e-learning materials has increased.

2. Theoretical background

2.1 Contributing factors of learning effectiveness

We have decades of knowledge and development experience regarding the creation of online courses and digital learning content. Developer practice and applied research conducted during this time period demonstrate that effective e-learning cannot be reduced to the presentation of cutting-edge learning materials using state-of-the-art technology. E-learning success factors are complex systems, in which the curriculum design systems, the trainers, the methodological experts, the institutional quality of service, and, of course, the infrastructure play a significant role (Monda 2014). Compared to the importance of the field, scientific research on the methodological functionality of online courses is grossly underrepresented. The most influential studies examine the relationship between course design and learning effectiveness (Saleh and Salama 2018; Kouis et al. 2020).

The rapidly changing and evolving technological environment has captured efficiency primarily in the learning experience design paradigm and its underlying frameworks in recent years (Hokanson, Clinton and Tracey 2015). By definition, design paradigm integrates educational psychology, teaching methodology, and the development of learning environments (Clark and Mayer 2016). One of its guiding principles is that we cannot plan a student's learning independently of all other factors, but we can design learning experiences, learning tasks, and environments (such as course pages) to make learning more effective and experiential. It is preferable not to plan for the phenomenon of learning but rather to create an environment and process that facilitates knowledge acquisition for the learner.

Learning experience design advances the traditional instructional design model by placing a much greater emphasis on the needs of the learner and the learning environment that can be created. The objective is to create immersive environments where learning tasks and learning activities can increase engagement. According to the findings of Neelen and Kirschner (2020), it is advisable to design learning environments that are effective, efficient, and enjoyable. According to Clark (2021), learning is a process in which emotions, attention, and motivation determine effectiveness and efficiency.

Therefore, learning environment has a significant impact on study motivation and behaviour. Students tend to increase their study motivation and effort during the studying period when they are aware of an upcoming examination. It is crucial to distinguish between the mediated and the direct effects of retrieval and testing on performance. When the retrieval itself has a positive impact on memory performance, but the student does not receive feedback following it, we can speak of direct effects. When a student modifies their behaviour in response to a testing event or receives additional information regarding their performance, mediated effects are observed (Roediger III and Karpicke 2006).

Several studies have investigated the complex relationship between student engagement, student interaction with the online learning environment, and learning performance (Moubayed et al. 2020; Shah and Barkas 2018; Lee, Song and Hong 2019; Rajabalee and Santally 2021; Cole, Lennon and Weber 2021). There are no identical e-learning environments or educational situations. Therefore, research has not identified the most significant factors that determine learning performance. Nevertheless, immersive and interactive e-learning environments have a positive effect on learning effectiveness, according to the findings of all major studies.

To design an effective learning environment, it is necessary to comprehend and model learning, as well as be familiar with the cognitive psychology of the learner. Additionally, it is essential to understand which tasks and online activities can assist the student in learning effectively (Kirschner and Hendrick 2020). Goal, attention, recall, motivation, the learning environment, and assessment of learning performance are key aspects in the design of effective learning (Dirksen 2015).

From students' perspective, expectations regarding the quality of education, including e-learning, are increasing currently (Sushkova et al. 2020), so an effective learning environment is crucial to university student satisfaction as well (Lacka and Wong 2021).

2.2. Mental fatigue

The above-mentioned contributing factors can influence the effectiveness of learning, and mental fatigue is also an important consideration.

Fatigue is a long-studied phenomenon that was originally believed to be a subjective experience. Initial observations have shown that as fatigue increases, blood pressure drops significantly, pacing slows, and response to stimuli increases, which can be explained by a decrease in nerve activity. High levels of fatigue lower motor activity, not only in the currently active (working) but also in the relatively resting organ areas, demonstrating that mental fatigue extends to the motor nerves as well. Fatigue lengthens the reaction time, making it more difficult to reproduce thoughts, thereby seizing control of the peripheral and central nervous systems (Myers 1937).

Nowadays, we can define mental fatigue as reduced alertness during monotonous and repetitive tasks (Roy, Charbonnier and Bonnet 2014), or as experiencing some sort of difficulty in maintaining an adequate level of performance on a task (Zhang, Zheng and Yu 2008). It can also be defined as a psychobiological condition that results from a strenuous, prolonged cognitive activity or occurs as a result of exercise (Trejo et al. 2015).

The most prevalent research methods for measuring mental fatigue are direct and indirect methods. In the case of direct methods, mental work-related fatigue is measured with a task requiring mental performance. Psychophysiological measurements are used to measure mental workload fatigue in indirect methods (for example, by changes in respiration and heart rate, or by changes in the parameters of eye accommodation and eye movements).

There are subjective, behavioural, and psychophysiological manifestations of mental fatigue. It is subjectively experienced as fatigue, lack of motivation, decreased alertness, and energy deficiency. Mental fatigue can be observed objectively in the performance of a given task (e.g., a decrease in accuracy and/or an increase in reaction time).

Psychophysiological tools (such as electroencephalography (EEG) that measures brain activity) can also be used to monitor mental fatigue on a cognitive level, although they do not necessarily involve the subjective, behavioural, and psychophysiological areas. Subjectively, one may experience fatigue, but cognitively and behaviourally it does not manifest if one is able to counteract its effects with a cognitive strategy. Thus, although fatigue can be detected on a behavioural level, the individual does not experience it consciously (Cutsem et al. 2017).

Mental fatigue is a complex phenomenon that is influenced by a variety of factors, including environmental characteristics, a person's health status, vitality, and motivation in a given situation. Fatigue induces numerous alterations in mood, motivation, and information processing. Consequently, attention and interest decrease, and anxiety, frustration, or boredom can occur, making it difficult to continue the task or, in the case of learning, to acquire and record information (Zhang, Zheng and Yu 2008). At the cognitive-behavioural level, reaction time and the effectiveness of performance and decision-making deteriorate. On a subjective level, fatigue and drowsiness may be indicative.

According to studies, mental fatigue is not solely caused by the length of time spent on a particular task. Möckel, Beste and Wascher (2015) assume that the interaction between adaptation and motivational effects in the engagement of a task modulates neurophysiological parameters and also performance.

In psychophysiological characteristics, the effects of mental fatigue can be observed in eye movements and pupillometry, with fewer blinks, dry eyes, and eye muscle fatigue (Williamson and Chamberlain 2005). Examining the relationship between pupil size and task engagement, Hopstaken et al. (2015) found that task engagement was a determining factor. As involvement in the task decreases, the pupil diameter becomes larger. If a participant experiences mental fatigue, we detect slow-wave activity (such as alpha and theta) in the entire cortex using EEG (Dawson, Searle and Paterson 2014).

Throughout high mental workload, pilots and drivers demonstrated an increase in the EEG theta band and a decrease in the alpha band power. In addition, due to the transition between mental workload and mental fatigue, there was an increase in theta, delta, and alpha band EEG power. During drowsiness, increased eye blink rate and decreased heart rate values were observed (Borghini et al. 2014).

Mental fatigue is an incremental and increasing process that can impair information processing (Roy, Charbonnier and Bonnet 2014). However, the effect of mental fatigue on the processes of learning and memory is not so one-sided. According to one study, despite the fact that mental fatigue impairs performance on explicit learning tasks, it can have a positive effect on tasks that do not require cognitive control. Borragán et al. (2016) found that mental fatigue can improve performance in automatic, procedural forms of learning.

It appears that fatigue has no effect on performance of a simple memory task. Mental fatigue can be characterised by a decline in executive control. Executive control is the ability to regulate motor and perceptual processes in order to respond adaptively to novel stimuli or shifting environmental demands (e.g., task requirements) (van der Linden, Frese and Meijman 2003).

2.3. Previous research and relevance

The effectiveness of e-learning has been studied for a very long time. Several studies, employing a variety of research methodologies, have investigated the factors that contribute to the effectiveness of e-learning: Grogan (2015) focused on the role of social and cognitive presence as well as course design utilising content analysis; Hrastinski (2008) investigated the benefits and limitations of asynchronous, synchronous e-learning through interviews and discussion analysis; Chigeza and Halbert (2014) examined educators' knowledge within the context of an e-learning redesign project; Karaksha et al. (2014) conducted a comparative study to evaluate the educational benefits of e-learning tools. Almansoori and Akre (2016) used interviews and questionnaires to summarise the factors influencing the effectiveness of blended learning, including student, faculty, and course characteristics, as well as social aspects. Since the COVID-19 pandemic, this field has become even more popular (Alqahtani and Rajkhan 2020; Maatuk et al. 2021). Due to the constant and rapid changes of learning environments, additional research is necessary.

3. Aim of the research and methodology

The aim of the recent study was to investigate the effectiveness of different e-learning materials using a variety of research methodologies (Figure 1), while taking mental fatigue into account. For this purpose, a pilot study was conducted within the framework of a comparative series of eye tracking experiments (Figure 1).

Eye tracking technology is now widely used because it enables the measurement of unconscious responses to visual stimuli, allowing for a comprehensive understanding of an individual's learning behaviour. There are numerous types of eye movement, with fixations and saccades being the most significant in terms of eye tracking technology. Fixations are typically 200–600 ms-long eye movements during which actual information acquisition and cognitive processing of visual input stimuli take place (Holmqvist et al. 2011). Saccades are rapid, ballistic eye movements that occur between fixations during which the visual system does not acquire new information (Szabó 2020). This information can be represented visually in a variety of ways (Duchowski 2017), the most common of which is the heatmap visualisation, in which all eye movements are displayed collectively. The most frequently observed points are marked in red, while the least watched areas are marked in a cooler, greener colour. This enabled us to obtain useful information regarding the precise direction of the gaze in the learning environments (see Figures 2 and 5–6).

3.1. Preliminary data collection

Before the learning phase, we used a variety of research methodologies to ensure that the 15 participants in the three groups did not differ significantly in health, demographics, or basic working memory processes (see Section 3.4) that could fundamentally influence learning. The following research methodologies were applied for the collection of preliminary data (Figure 1):

- **Health and demographics:** We gathered demographic and health-related information first in order to exclude participants with neurological or psychiatric disorders. There were no participants to exclude.
- **Groningen Sleep Quality Scale:** We measured daily subjective sleep quality using the Groningen Sleep Quality Scale (GSQS) (Simor et al. 2009). In the 15-item questionnaire, participants self-evaluate the quality of their previous night's sleep. The range of scores is 0 to 14 (where the higher score indicates poorer quality of sleep).
- **Digit span tests:** We used the forward (digit span forwards (DSF)) and backward (digit span backwards (DSB)) versions of the digit span test (Leung et al. 2011). Participants were required to recite the sequence following the verbal presentation of the digits. If the participant recited a trial correctly, the subsequent trial would begin. If at least three of the four trials in a certain span were correctly recalled, the next span's digits were presented; otherwise, the task ended (Racsmány et al. 2005).
- **Fluency tasks:** We applied phonological (PFT), semantic (SFT), and verbal fluency tasks (VFT) to evaluate the participant's verbal functioning (Passos et al. 2014). We selected these tasks because they can be administered and scored quickly (Rofes et al. 2019). In the PFT, participants were asked to generate as many words as possible beginning with 'K' in one minute. In the SFT, participants were instructed to generate fruit names, while in the VFT, they were to generate verbs. In each task, proper nouns such as city names and the same word with a different suffix were considered errors, as were intrusions, perseverations, and derivations.

3.2. Psychomotor vigilance task (PVT)

The Psychology Experiment Building Language (PEBL) version of the PVT was used before and after the learning phase to determine whether learning caused mental fatigue (Figure 1) (Basner and Dinges 2011). PVT is an adequate method to detect behavioural alertness as it measures the exact reaction time of the participants. In the PVT, participants were instructed to immediately press the 'space bar' in response to a red circle. We reduced the number of trials to 12, so we used a shorter version of the PVT.

3.3. Post data collection

After the experiments, we implemented additional research methodologies to quantitatively and qualitatively evaluate the learning phase. The following research methodologies were used for post data collection (Figure 1):

Task Load Index: At the end of the experiment, the NASA Task Load indeX (TLX) was applied to provide information on the amount of workload experienced during a given task along several sub-dimensions (Febiyani, Febriani and Ma'Sum 2021). From the points given to these workload dimensions on a scale of 0 to 100 and based on the subjective comparison of the dimensions to each other, we derived a percentage TLX value expressing the participants' perception of their workload (Afifah 2021).

Knowledge Test: After the experiment, learning level was measured in accordance with course objectives using a knowledge test, allowing for an objective comparison of the learning outcomes of the three groups.

Interview: The experiment concluded with a personal interview exploring the insights of various digital learning materials, students' educational habits, and the causes of fatigue or any learning difficulties.

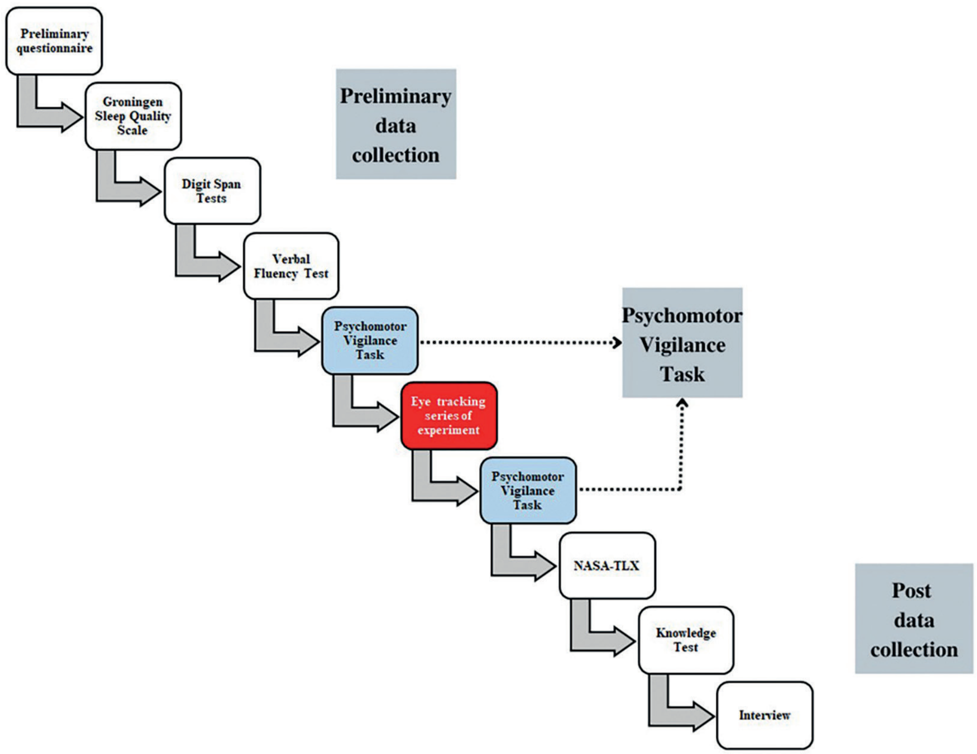

Figure 1. Research plan (own edition)

3.4. Research set-up

In e-learning materials for course pages, supporting students' learning activity is a fundamental developmental task in addition to visual appearance (Martin and Betrus 2019). The general principles and known educational-psychological solutions for providing learning activity do not offer clear development schemes in terms of the target group of students and the educational content, allowing them to be linked to individual developments in each case. Consequently, the development of the same curriculum using different methodological approaches and a comparative analysis of learning outcomes are essential. Content-equivalent but methodologically different courses ensure the comparability of fatigue and learning effectiveness in different learning environments.

In the present research, participants (n=15) were divided into three groups using different course pages designed with different methodological approaches, but with equivalent content: this was ensured by similar or equally effective learning tasks, practice tests with self-checking options, learning methodology descriptions for students, and methodological guidelines (Table 1). The first course page (for Group 1) concentrated on textual content, activity modules, practice tasks, and self-evaluation questions. The second design (for Group 2) featured standard e-learning material: the content was edited based on a screen-script that could be navigated, and was partially interactively displayed. The key component of the third solution (for Group 3) was a voice-narrated teacher presentation.

	Group 1: Modular object-oriented course page	**Group 2: Standard e-learning course page**	**Group 3: Video-based course page**
Learning methodology guidelines for the course	✓	✓	✓
Learning methodology guidelines for the module	✓	✓	✓
Curriculum with illustrative images	✓ Non-interactive Text-based Static	✓ Semi-interactive Text-based Navigable	✓ Semi-interactive Video-based Navigable
Multiple choice question	✓		
Interactive task (e.g. matching)	✓	✓	✓
Question with feedback report	✓		
Practice test with self-checking option	✓	✓	✓

Table 1. Methodological characteristics of the course pages (own edition)

Students' potential learning time was nearly equivalent to 35 minutes, based on preliminary trial learning. The experiment was conducted in a laboratory setting, where participants were required to master e-learning content after locating the assigned Product Experience course using the Moodle e-learning framework. The Product Experience course was selected due to its popularity among students at Budapest University of Technology and Economics (BME). The primary objective of the course was to provide insights into product experiences and their (interdisciplinary) scientific background. After presenting the fundamental psychological knowledge of the topic, the subject discussed unique aspects of the product experience from the product's and a human's perspectives. In the context of the present study, participants learned about various psychological school approaches.

3.5. Sample group

After a preliminary screening, students from BME and the Corvinus University of Budapest (BCE) who were interested in the Product Experience course and had no prior knowledge were recruited for the study. Five men and 10 women participated in the research; seven were BCE students and eight were BME students from entirely different fields. The participants were between the ages of 19 and 25, had an average age of 21.5, and had studied for an average of 15 years (Table 2).

Group	ID	Gender	Age	Education experience (in years)	University	Major
1	P01	Male	24	18	BME	Engineering and Management
	P02	Female	20	13	BCE	Finance and Accounting
	P08	Male	22	14	BCE	Management and Administration
	P12	Female	22	16	BME	Engineering and Management
	P15	Female	21	14	BCE	Business Informatics
2	P05	Female	22	16	BME	Mechanical Engineering
	P07	Male	19	13	BCE	Business Informatics
	P10	Male	25	19	BCE	Engineering and Management
	P13	Female	20	14	BCE	Trade and Marketing Management
	P14	Female	22	15	BME	Engineering and Management

3	P03	Female	19	13	BCE	Trade and Marketing Management
	P04	Female	19	13	BCE	Finance and Accounting
	P06	Female	23	16	BME	Engineering and Management
	P09	Male	23	16	BME	Engineering and Management
	P11	Female	22	16	BME	Engineering and Management

Table 2. Information on interviewees (own edition)

It can also be said that the grade point average (GPA) of the participants' completed semesters was 4.099 (σ=0.471) on average (on a 5-point Likert scale). Their result on the DSF test was 5.2 (σ=1.014), while it was 4.0 (σ=1.195) on DSB. For this sample, the scores on the fluency tests were 18 (σ=4.088) on PFT, 18.6 (σ=4.239) on SFT and 22.8 (σ=4.632) on VFT for the present sample (Table 3).

Group	ID	GPA	DSF	DSB	PFT	SFT	VFT
1	P01	3.29	6	4	17	14	13
	P02	4.6	4	4	18	22	24
	P08	4.55	7	4	15	18	28
	P12	4.59	3	4	11	17	21
	P15	4.33	5	3	17	24	24
2	P05	4.58	7	7	16	20	22
	P07	4.32	6	6	18	19	22
	P10	3.32	5	3	19	29	22
	P13	3.94	5	3	28	11	28
	P14	3.81	5	3	15	16	19
3	P03	4.43	5	5	25	18	27
	P04	4.43	5	3	18	17	22
	P06	3.91	5	3	19	20	26
	P09	3.44	5	4	19	18	29
	P11	3.95	5	4	15	16	15

Table 3. Preliminary results related to the participants (own edition)

Participants were assigned to the three groups based on the results of the digit span test and VFTs, as well as their GPA, so that there were no significant differences between them along these indicators (i.e., the p-values in Table 4 are greater than 0.05 in all cases). Due to the low number of items, values between groups were comparable using the Mann-Whitney U test as a non-parametric alternative to an independent sample t-test.

Groups	1 vs 2	1 vs 3	2 vs 3
GPA	U=7; W=22; Z=-1.15; p=0.25	U=7; W=22; Z=-1.15; p=0.25	U=11; W=26; Z=-0.31; p=0.75
DSF	U=9.5; W=24.5; Z=-0.65; p=0.52	U=12.5; W=27.5; Z=0; p=1	U=7.5; W=22.5; Z=-1.49; p=0.14
DSB	U=11.5; W=26.5; Z=-0.22; p=0.82	U=12; W=27; Z=-0,12; p=0.9	U=12; W=27; Z=-0.11; p=0.091
PFT	U=7; W=22; Z=-1.16; p=0.25	U=4; W=19; Z=-1.8; p=0.07	U=11; W=26; Z=-0.32; p=0.75
SFT	U=12; W=27; Z=-0.1; p=0.92	U=10.5; W=25.5; Z=-0.42; p=0.67	U=11; W=26; Z=-0.32; p=0.75
VFT	U=11.5; W=26.5; Z=-0.21; p=0.83	U=9; W=24; Z=-0.73; p=0.463	U=9,5; W=24,5; Z=-0.65; p=0.52

Table 4. Mann-Whitney test statistics on group differences (own edition)

3.6. Hypotheses

Before the test, six hypotheses regarding the effectiveness of e-learning materials were formulated. The following are examples:

Hypothesis 1: The type of e-learning material has an impact on students' motivation.

Hypothesis 2: The type of e-learning material has an impact on fatigue.

Hypothesis 3: The type of e-learning material has an impact on workload.

Hypothesis 4: The type of e-learning material has an impact on knowledge test scores.

Hypothesis 5: The type of e-learning material has an impact on reaction time.

Hypothesis 6: The knowledge test score is dependent on the GSQS, the GPA, and the time required to complete the test.

4. Results

4.1. Results of the hypothesis tests

For the purpose of examining the hypotheses, the GPA, the GSQS, the motivation points derived from the interviews, the number of fatigue key presses, the TLX value, the time required to complete the test in seconds, the percentage on the knowledge test, and the average reaction time on the PVT tests were collected (Table 5).

Group	ID	GPA	GSQS	Motivation	Number of fatigue key presses	TLX [%]	Time required to complete the test [sec]	Knowledge test [%]	PVT1	PVT2
1	P01	3.29	3	8	3	46	229	40	302.14	291
	P02	4.6	2	6	0	32	470	60	350.59	315.93
	P08	4.55	2	5	2	69	615	80	300.81	287.93
	P12	4.59	3	5	6	66	611	72	409.75	429.31
	P15	4.33	2	10	2	57	358	92	359.36	353.22
2	P05	4.58	2	7	3	64	311	68	365.99	390.76
	P07	4.32	9	9	3	39	424	84	314.11	302.92
	P10	3.32	9	5	0	27	352	88	336.77	379.47
	P13	3.94	3	8	2	50	410	84	324.11	318.12
	P14	3.81	5	8	3	41	340	52	356.59	345.37
3	P03	4.43	3	8	4	68	565	64	297.75	301.29
	P04	4.43	2	8	2	50	295	72	342.43	364.23
	P06	3.91	9	6	1	57	502	68	368.91	360.08
	P09	3.44	0	10	0	57	285	80	318.53	294.16
	P11	3.95	5	7	1	63	500	60	292.92	299.81

Table 5. Results related to hypothesis testing (own edition)

The data for Hypothesis 1 was gathered through interviews. On a 10-point Likert scale, participants were required to rate their subjective perception of their motivation during learning. The participants' subjective assessment of their motivation indicates an upward trend: for Group 1 the average was 6.8 (σ=2.168), for Group 2 it was 7.4 (σ =1.517), and for Group 3 it was 7.8 (σ =1.483). However, the Mann-Whitney U test reveals that there is no significant difference between the three groups (U=10, W=25, Z=-0.535, p=0.592; U=8, W=23, Z=-0.961, p=.337; U=11.5, W=26.5, Z=-0.216, p=0.829). Thus, Hypothesis 1 is rejected, so the current sample does not prove that the type of e-learning material has an impact on students' motivation.

Similarly, in the case of Hypothesis 2, the number of fatigue key presses shows a decreasing trend regarding the groups: 2.6 (σ=2.19), 2.2 (σ=1.3), and 1.6 (σ=1.52). Hypothesis 2 is also rejected because the difference between the groups is not significant (U=12, W=27, Z=-0.110, p=0.913; U=8.5, W=23.5, Z=-0.851, p=0.395; U=9, W=24, Z=-0.747, p=0.548). Therefore, the present sample does not demonstrate that the type of e-learning material has an impact on fatigue.

The examination of Hypothesis 3 was based on the TLX values, which are the highest for Group 3 (on average 59%, σ=6.749). This value was lower for the remaining two course pages: 54% (σ=15.17) for Group 1 and 44.33% (σ=13.65) for Group 2. Since the difference is not statistically significant (U=7, W=22, Z=-1.149, p=0.251; U=11, W=26, Z=0.317, p=0.751; U=4.5, W=19.5, Z=-1.681, p=0.093), Hypothesis 3 was also rejected. The present sample does not prove that the type of e-learning material has an impact on workload.

In relation to Hypothesis 4, it can also be said that the results of the knowledge test demonstrate an increasing trend in the averages: 69% (σ=19.88), 74% (σ=12.20), and 79% (σ=9.55). Hypothesis 4 cannot be accepted because the difference between the groups is not statistically significant (U=10, W=25, Z=-0.524, p=0.6; U=11.5, W=26.5, Z=-0.211, p=0.833; U=7.5, W=22.5, Z=-1.051, p=0.293). The current sample does not provide evidence that the type of e-learning material has an impact on knowledge test scores.

The Wilcoxon signed-rank test can be used to examine Hypothesis 5 due to the line-by-line comparison of PVT times for the participants. Due to the small sample size, we utilised this method as a non-parametric alternative to a paired-sample t-test. Despite the fact that PVT times decreased in four cases in Group 1, three cases in Group 2, and only two cases in Group 3, the difference between the groups is not statistically significant (Z=-0.944, p=0.345, Z=-0.405, p=0.686; Z=-0.135, p=0.893). This also indicates that the hypothesis is rejected in the current sample, so it cannot be demonstrated that the type of e-learning material has an effect on reaction time.

Hypothesis 6 can be examined by Spearman correlation as the knowledge test percentage, time required to complete the test, GSQS, and GPA variables do not all follow normal distribution based on the Kolmogorov-Smirnov tests. Since the correlation coefficients differ significantly from 0 in both instances (ρ=0.065, p=0.819; ρ=0.069, p=-0.806; ρ=0.003, p=0.992), Hypothesis 6 was also rejected. This means that the knowledge test score is not dependent on GSQS, GPA, or the time required to complete the test.

4.2. Eye tracking results

The heatmap of Group 1 demonstrates that the main course page was viewed in accordance with the nature of the learning environment: the text boxes were hardly viewed by the participants, while they focused primarily on the given points, which they had to master step-by-step. Based on the findings, we can conclude that on text-oriented course pages, written content received more attention than images (Figure 2).

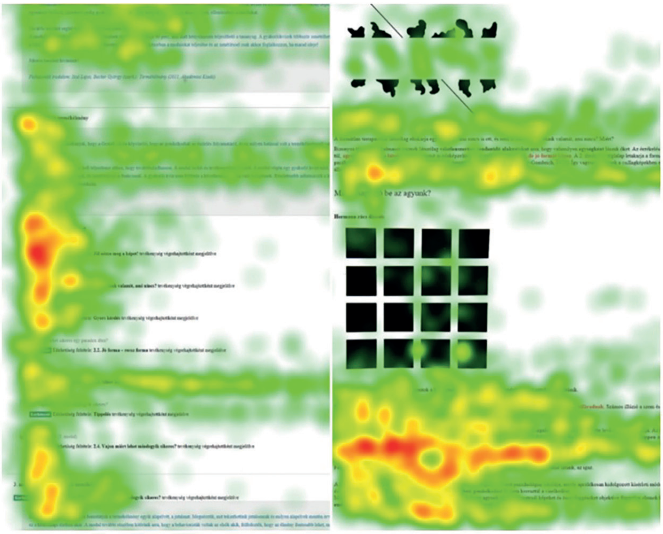

Figure 2. The heatmaps in Group 1: main course page (left) and a subpage example (right) (own edition, created in Tobii Studio)

The eye tracking software enables the selection of various areas of interest (AOIs) (Figure 3), thereby enabling the quantification of which parts of the course pages were the most significant to the participants. The most often used indicators for AOI analysis are the number of fixations and the number of visits (return to the selected AOIs), as they represent the subjective importance of the AOIs (Hámornik et al. 2013).

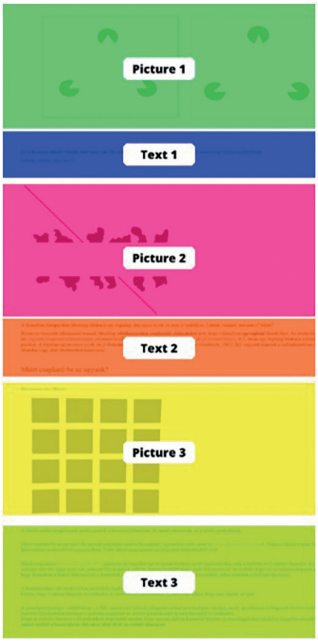

Figure 3. Defining AOIs in Group 1 (own edition, created in Tobii Studio)

On the basis of the data retrieved for the selected AOIs in Figure 3, it is possible to conclude that the total numbers of fixations and visits are higher for all participants when viewing text content (Table 6).

Group 1	Number of fixations							
	Picture 1	**Picture 2**	**Picture 3**	**Total**	**Text 1**	**Text 2**	**Text 3**	**Total**
P01	8	45	17	**70**	50	106	392	**548**
P02	4	12	14	**30**	21	71	208	**300**
P08	9	31	30	**70**	23	135	317	**475**
P12	91	159	60	**310**	26	90	503	**619**
P15	6	45	71	**122**	42	117	315	**474**
Group 1	**Number of visits**							
	Picture 1	**Picture 2**	**Picture 3**	**Total**	**Text 1**	**Text 2**	**Text 3**	**Total**
P01	6	37	14	**57**	39	61	215	**315**
P02	3	4	11	**18**	8	21	77	**106**
P08	5	12	15	**32**	10	31	44	**85**
P12	42	69	31	**142**	15	50	144	**209**
P15	4	13	24	**41**	7	20	40	**67**

Table 6. Quantitative information for the selected AOIs (own edition)

The Wilcoxon signed-rank test enables line-by-line comparisons of these data. Accordingly, the number of fixations and number of visits indicators differ significantly ($Z=-2.023$, $p=0.043$ in both instances). Thus, it can be concluded that text content received greater attention in Group 1 than images.

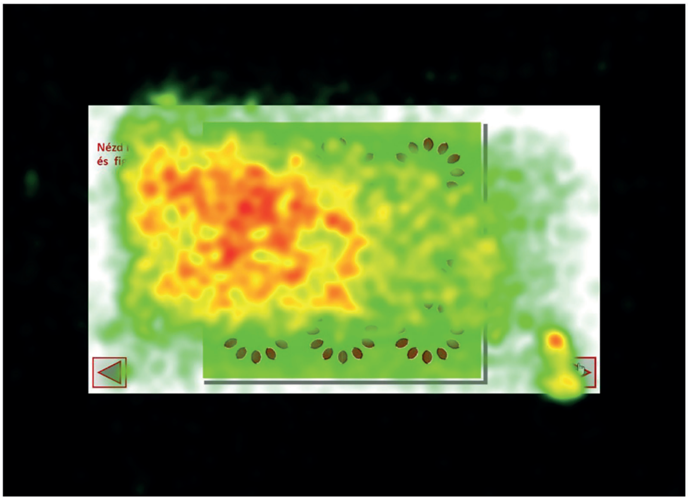

Figure 4. The heatmap in Group 2 for the whole e-learning material (own edition, created in Tobii Studio)

In Group 2, images and texts appeared together in the e-learning material, so the gaze remained predominantly within the learning area, as demonstrated by the resulting heatmap (Figure 4). This demonstrates that the participants were able to focus on the e-learning material sufficiently (with an average number of visits of 50.7 for the learning area with a standard deviation value of 40.577).

In Group 3, in addition to the e-learning content, the academic received appropriate attention during the learning process, as the resulting heatmap demonstrates (Figure 5). The participants' eyes returned an average of 125.8 times (σ=48,215) to the lower right corner, where the university professor was present, indicating the significance of this region. During the interviews, the participants in this group emphasised that the credibility of the instructor in the video was of primary importance.

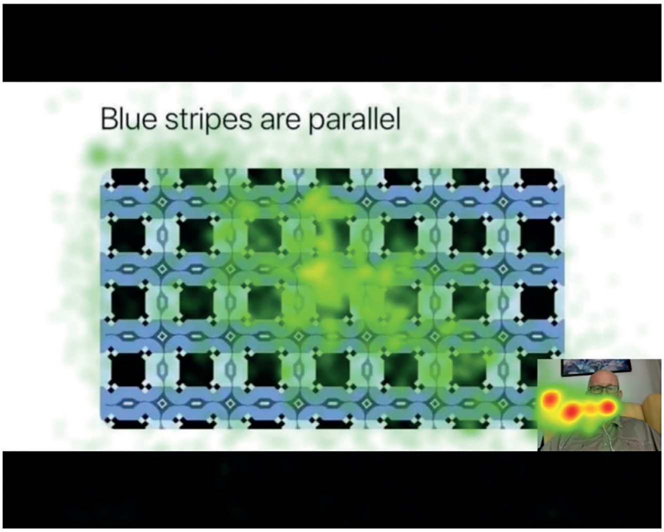

Figure 5. Heatmap example of participants in Group 3
(own edition, created in Tobii Studio)

4.3 Results of the interviews

The vast majority of students can learn effectively in complete silence, according to data collected regarding their learning environments and habits. Only two of the respondents mentioned background music. The interviews also revealed that most students like to study in the evening/night, and only one of them marked dawn as an ideal time to learn. Some justified their late-night studying by mentioning procrastination or the fact that their work schedules allow them to do it. In terms of posture, some students prefer to study in front of a computer or while sitting on the bed, while others prefer to study while lying on the bed or walking. The interviewees also mentioned adequate lighting, a clean environment, sufficient space, and the presence of plants in several instances. Regarding location, a family environment, an apartment, and a dormitory with their own room were highlighted.

In terms of learning strategy, in addition to repeatedly re-reading digital content, the majority of students learn from the notes they take during comprehending the material. Some also facilitate note-taking visually (e.g. using highlighters). Several interviewees remarked that they like video-based e-learning content because they can process it at their own pace (they can stop it, speed it up, etc.). Some of the interviewees stated that completing practice tests and previous exams also facilitates the acquisition of new information.

Most students realised that they were becoming tired when they could no longer 'grasp the material' after reading it multiple times, when their attention wandered, or when they felt drowsy all of a sudden. According to the interviewees, physical symptoms also indicate that they are already exhausted: headaches, back pain, numbness in the neck, and eye fatigue were cited. Many of the students used the phrase 'that's enough' to describe how they feel when they have studied for too long. Symptoms of fatigue experienced during the current experiment included the above-mentioned responses for those participants who pressed the fatigue indicator button.

Students have varying strategies for what to do if they become tired while studying. Most of them take breaks during which they consume coffee, water, or soft drinks. Some revitalise themselves by moving (standing up, walking, exercising, yoga), while others interact with the ones surrounding them (mostly in the form of conversation). Several students mentioned using their cell phones, browsing the Internet, and playing video games as a method of relieving fatigue.

Students expect online learning materials to be concise above all else. Importantly, the materials and course pages as a whole should be engaging, well-organised, aesthetically pleasing, and filled with practical examples.

Comments on the teaching material to be acquired within the framework of the experiment were evaluated separately along with the three groups. Four of the five participants in Group 1 enjoyed the provided e-learning content. In addition to processing difficulties and 'boring' sections, the undeveloped and poorly structured modular, object-oriented course page with a large amount of text was cited as a problem.

Participants in Group 2 overwhelmingly rated the standard, navigable e-learning material as 'good' and 'interesting'. It was easy to navigate and understand, but they disliked the excessive image sizes and dated design ('where an image floated across the entire screen was very confusing').

All five students in Group 3 liked the video-based teaching materials because the professor was always visible, making the learning experience more personal. Four of them also enjoyed using the course page, while one had a technical issue and could not comment positively. The poor design of the slides behind the video, the illegibility of the reversed texts, and the lack of text contrast contributed to their dislike.

5. Conclusion

We used both qualitative and quantitative research methods within the scope of this study. Multiple tests, eye tracking, and interviews complemented each other, demonstrating the methodological soundness of the research plan. Due to the small sample size of the current pilot study, the hypotheses had to be rejected because no significant results were obtained. However, trends can almost always be observed; these indicate that, as the number of respondents increases, the differences between the groups will also be statistically confirmed. Despite the increasing/decreasing averages predicting differences between groups in the pilot study, it appears that the type of instructional material has an effect on the effectiveness of e-learning. The values for motivation and knowledge test scores increased between groups, whereas the subjective perception of fatigue decreased. Only the change in workload values shows no trend. Moreover, based on the changes in reaction time observed in the current pilot study, it appears that video-based course pages are the most effective form of learning materials. Moreover, interviews provide a complete picture of student preferences regarding effective e-learning materials. On the basis of the results, it is recommended to upload brief, concise video content that should be supplemented with additional materials (e.g. a slide show). Regarding professors' personalities, authenticity was emphasised, whereas written materials must be concise and interesting. The students also emphasised the importance of a large number of practice tests as a necessity for an engaging course page.

5.1. Limitations and future work

Due to the coronavirus pandemic, the study could not be conducted before the middle of the summer break. As a result, it was significantly more difficult to recruit students, which may have affected their motivation and attitude. In the pilot study, the hypotheses had to be rejected because no significant results were obtained due to the small number of items used. However, trends can almost always be observed; these indicate that it would be worthwhile to continue research by increasing the number of respondents in order to statistically confirm the differences between the groups. In addition, mental fatigue can be monitored objectively through the use of eye tracking data. According to eye tracking studies, a number of fatigue-correlated metrics, including pupil diameter, blinking, constriction velocity and amplitude, and saccadic metrics, have been identified (Benedetto et al. 2011; Morad et al. 2000). In cognitively demanding tasks, the correlation between saccadic parameters (e.g., velocity) and fatigue has been studied extensively. Researchers found that as fatigue increases, saccade velocity decreases in a variety of task settings (Stasi et al. 2013, 2015); therefore, we intend to evaluate this indicator in the near future.

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