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The effect of design tasks on the cognitive load level of instructional designers in 3D MUVEs

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Abstract
This study aims to investigate the effects of different design tasks on the cognitive load level of instructional designers during the process of designing a learning activity in a 3D multi-user virtual environment (MUVE). The sample consisted of 16 undergraduate students who were experienced in the areas of instructional design, computer programming and graphic design. The designers were assigned to the design teams with 5 or 6 members and conducted a collaborative instructional design project to develop a solution to an ill-structured problem on the OpenSimulator platform for 8 weeks. Following the implementation, the designers were administered the Mental Effort Rating Scale regarding the 11 design tasks in the 3D MUVE. The results showed that the designers were cognitively overloaded while performing the design tasks in this environment. When the cognitive load scores were examined, it was found that the preparation of the learning scenario, uploading user-created 3D models, content creation, modelling of the draft view of the designed environment and 3D model design tasks were found as the most challenging tasks in terms of cognitive effort. On the other hand, it was found that the tasks of making animation, creating non-player characters and designing an interactive menu led to relatively less cognitive load.

Keywords Three-dimensional multi-user virtual environments · Cognitive load · Instructional design · OpenSimulator

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Introduction

Three-dimensional (3D) multi-user virtual environments (MUVEs) are virtual spaces that are usually simulations of physical environments in authentic life where users are represented through 3D characters (avatars) and interact with objects and other characters in the environment (Doğan et al. 2018). Second Life, OpenSimulator, Active Worlds, Instant Messaging Virtual Universe (IMVU), There and Online Universe (Onverse) are just a few of the popular 3D virtual platforms that allow users to come together for various purposes including education, business, design, creativity, entertainment and socialization. In such environments, users generally navigate a virtual environment modeled in a similar way to the physical world, manipulate the environment, interact with objects and communicate with other users in the environment.

3D virtual environments can hold new tendencies and opportunities in many education levels, especially in higher education. Dalgarno and Lee (2010) stated that, compared to their 2D counterparts, 3D MUVEs have superior pedagogical benefits such as advanced spatial information presentation (or high representational fidelity), enhanced experiential learning opportunities, student motivation and participation, improved contextuality and more effective collaborative learning. 3D environments receive growing attention in the field of education, as they support activities and interactions that cannot be performed in face-to-face lessons (Thackray et al. 2010). 3D simulations, games and other virtual environments offer learners the opportunity to manifest metaphorical representations of their ideas through the objects in the environment. 3D MUVEs may also allow conducting time-consuming experiments outside of school. These environments in this respect can act as a bridge between formal and informal learning.

3D MUVEs can enable users to experience authentic activities that are difficult to perform in real life for reasons such as risk factors and resources including time, cost and infrastructure (Cho and Lim 2017; Ioannis et al. 2016). 3D virtual environments were reported to provide learning conditions that are as effective as real-world arrangements for kinesthetic skill development and subject area learning (Winkelmann et al. 2020). These environments also increase opportunities for collaborative learning and problem-solving via authentic tasks across different disciplines, thus support building common knowledge in situated contexts (Ketelhut et al. 2010). However, it is crucial for knowledge construction to provide learners with the opportunity to navigate, explore and manipulate within 3D virtual environments (Dickey 2003; Tüzün and Doğan 2019). 3D MUVEs may produce results that are similar to those in physical spaces in terms of spatial knowledge acquisition (Tüzün and Özdinç 2016). Moreover, many studies reported that these virtual worlds successfully create the perception of reality and the feeling of immersion and presence in users (Liaw et al. 2019; Tüzün and Özdinç 2016). In particular, with the help of head-mounted displays, the recent improvement of the immersive effect of 3D graphics has resulted in enhancement of users' perceptions of reality and presence in the virtual environment (Güleç et al. 2019).

Findings on instructional practices carried out in 3D MUVEs are widespread in the literature. However, very little is discussed about how instructional design processes are carried out in such environments used in an educational context, and what awaits designers with regard to the design of the environments technologically and pedagogically. Moreover, many different factors involved in the design and development of such environments may cause processes of instructional design to turn into a chaotic effort (Kapp and O'Driscoll 2009). 3D virtual spaces, which are not considered interesting and impressive by users and made up of similar structures and objects, probably become desolate (Tüzün et al. 2019). Similarly, it should not be forgotten that, if one fails to piece together pedagogical elements with objects in a 3D MUVE within the scope of a proper instructional scenario, and the appearance and appeal of the environment surpasses its learning tasks, users' navigation and movements in the environment may miss the pedagogical benefits.

The process of designing 3D MUVEs that are designed to be learning environments and appeal to learners with different personal characteristics requires achievement of complex tasks. The design process of such environments involves instructional design, as well as virtual environment design. Pedagogical approaches that lead the design process also gain importance in this process. This process requires the collaboration of many people, especially visual design specialists who design 2D/3D graphics and animations, subject matter experts who develop content, software developers, instructional designers, educational measurement and evaluation specialists, producers who organize videos introducing the environment and vocal artists who voice characters (Doğan 2019). Instructional designers, in particular, have an important role in both the virtual environment design and instructional design process. In this process, it is also important to understand learners' cognitive processes to be able to improve the effectiveness of educational environments (Singh and Kalyuga 2016).

Even though it also depends on 3D development platforms to some extent, real-time inclusion of both the third dimension information of object locations and enhanced reality into the human–computer interaction are major features that make 3D MUVEs different from other learning settings in terms of cognitive processing (Nelson and Erlandson 2012). These increased representational details that contribute to the sense of immersion impose an additional load on cognitive processes (Bower 2017). The complex and versatile design nature of 3D virtual learning environments may cause cognitive overload problems among designers and users. Cognitive load refers to the capacity of information that can be stored in the working memory through a range of cognitive processes such as comprehension, schema formation, schema modification and problem-solving (Ginns and Leppink 2019). Cognitive load problems surface when users need to simultaneously split their attention between certain tasks on a screen. Moreover, the presence of too much information causes cognitive overload (Tengku Wook et al. 2016). Sweller et al. (1998) classified cognitive load into three groups: intrinsic load, extraneous load and germane load. Accordingly, intrinsic load refers to the level of complexity of content or material. Because some tasks are more complex than others, individuals also have diverse intrinsic loads while struggling with them. Extraneous load is the presentation of information—that is unrelated to the learning process—with learning materials or content. An intrinsic load is associated with anything that has been or needs to be learned, whereas an extraneous load is associated with the instructional design. Germane load is related to the way information is presented to learners and instructional activities that the learners need, but it also involves processes for formation and modification of schemas. Germane load refers to resources in the working memory struggling to cope with an intrinsic load rather than an extraneous cognitive load (Sweller et al. 2019). An intrinsic load is about one's previous experiences, whereas a germane load is a result of functional cognitive processes such as abstraction and elaboration. An extraneous cognitive load is a result of instructional techniques used in the learning settings (Dan and Reiner 2017). The learning process has not been completed if the sum of intrinsic load, extraneous load and germane load exceed the capacity of the working memory, or in other words, if there is cognitive overload (Paas et al. 2003).

In this context, answers to the following question were sought in this study: "What are the effects of different design tasks on instructional designers' cognitive load levels in the process of preparation of learning activities in 3D MUVEs?"

Method

Research method

In this study, a case study approach was adopted as the research method. A case study is often used to study a certain phenomenon within its authentic conditions. It is a research method that is used in cases where the boundaries between the phenomenon and its content where the phenomenon exists are not clear, and there are multiple evidence or data sources available (Yin 1984). Case studies are used when a researcher has to investigate a program, an activity, a process, an event or one or more people in an in-depth manner (Cresswell 2003). As part of the study, the participants in the role of instructional designers were given a problem status in order to establish an authentic design condition in 3D MUVEs, and they were then asked to design a learning activity collaboratively on OpenSimulator, an open-source platform for developing 3D virtual environments.

Participants

In this study, the purposive sampling method—a non-random sampling technique—was utilized. The purposive sampling technique is a sampling method in which only participants with certain characteristics are included in a study to improve the representativeness of the sample to collect data necessary for the study (Fraenkel and Wallen 2006). In this context, the participants were composed of 21 undergraduate students that had experience in instructional design, programming and graphic design, who came together within the scope of an elective course. After the implementation, five participants did not prefer to participate in the data collection stage. All five participants were male. This caused imbalance in the distribution of the participants by gender. As a result, the sample was composed of 16 students. The demographic characteristics of the participants, who are referred to as the designers (instructional designers) in the subsequent sections of the study, are presented in Table 1. Among the designers, 11 were female (69%), and 5 were male (31%). The average age of the designers was 23. The majority of them (69%) did not have experience in using 3D MUVEs.

Data collection instruments

This study utilized the Mental Effort Rating Scale, a demographic questionnaire, personal web pages (PWPs) of the designers and reflection reports, which conveyed student impressions and experiences related to the course and the instructional design process carried out in a 3D virtual environment.

Mental effort rating scale

In this study, the Mental Effort Rating Scale was administered to the participants at the end of the semester. The scale consisted of 11 items with 9-point Likert-type options on how

Table 1 Demographic information about the instructional designers

Variables	Frequency (f)	Percentage (%)
Gender		
Male	5	31
Female	11	69
Age		
21–25 years	13	81
26–30 years	2	13
31–35 years	1	6
Experience in using computers		
7–9 years	7	44
10 years and above	9	56
Experience in using 3D MUVEs		
No experience	11	69
1–3 years	4	25
4–6 years	1	6

much cognitive effort the participants exerted while performing their design tasks. The scale was prepared using a subjective rating scale which was originally published by Paas and Van Merriënboer (1993) and adapted into the Turkish language by Kılıç and Karadeniz (2004). The Mental Effort Rating Scale is actually a one-item scale for determining the cognitive effort spent during the fulfillment of a specific task. The scale is a modified form of the Perceived Task Difficulty Scale developed by Bratfisch et al. (1972). The mental effort, which can be considered as an indicator of cognitive workload, is rated on a scale of 1-9. When the scale is scored, a score of 1-4 points on each item is considered an indicator of low mental effort, and a score of 5-9 is considered indicative of high mental effort. The internal consistency coefficients (Cronbach Alpha) of the original and adapted form of the scale were calculated to be .90 and .78, respectively (Kılıç and Karadeniz 2004). It is advised that students are given more than one task for calculation of the reliability coefficient of the scale (Paas and Van Merriënboer 1993). In this study, 11 tasks were given to the designers as a framework for the instructional activity in 3D environments. These tasks were related to instructional design processes (3 items), 2D/3D design and modelling (3 items) and user interactions (5 items). The instructional designers were asked to evaluate themselves by using this scale about the tasks they fulfilled throughout the process. The reliability coefficient of the scale in this study was calculated to be .83. The clarity of the scale in terms of language and expressions were checked by two faculty members who are experts in the field.

Demographic questionnaire

This questionnaire was a personal information form consisting of 4 items to determine the designers' gender, age, experience in using computers and experience in using 3D MUVEs.

Personal web pages

The designers were asked to prepare a personal web page at the beginning of the implementation process to better know each other. The web pages were also created to know each other's working styles and qualifications in terms of technical design/instructional design, in addition to their personality. These web pages hosted information such as profile photos, contact information, courses taken, programming experience and level, objectives and goals for the course, other personal characteristics (outstanding characteristics, favorable/unfavorable behaviors, principles and so forth) and expectations from teamwork and team members.

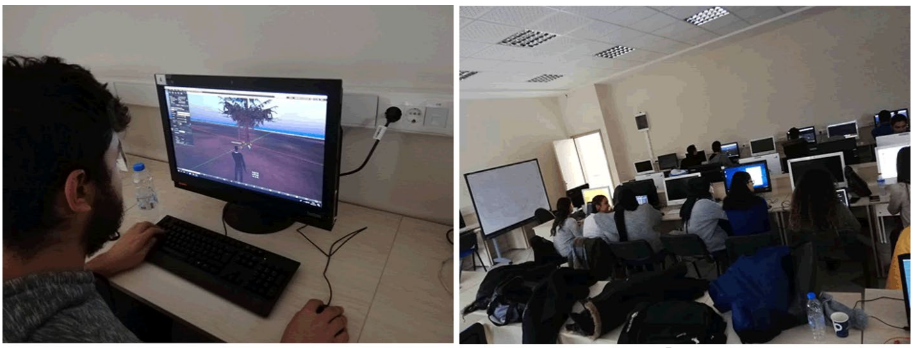
Reflection reports

At the end of the implementation, the designers' reflections about their overall impressions with regard to the course given were collected. Additionally, their thoughts about what worked and what did not during the design of the educational implementation were also inquired. The reflection reports were extensive and made up of a total of 35 items about what they experienced throughout the course. Of these items, only the ones inquiring about the difficulties and obstacles in the design process were included in the content analysis.

Implementation process

The data were collected as part of an undergraduate-level course that aimed to help the students learn about 3D MUVEs, make educational content and carry out instructional designs in such environments (Fig. 1). In the first 8 weeks of the implementation process, which lasted a total of 16 weeks, the participants were given training on practical information about the design of 3D MUVEs and were presented with implementation examples. Additionally, weekly assignments were given for them to become more familiar with the 3D development environment. These course sessions constituted the theoretically heavy part of the implementation and were held for 3 h a week.

The designers worked in OpenSimulator, an open-source server platform that can be used as both a design/development environment and a navigation environment. OpenSimulator, just like Second Life, has an archipelago model system in which land pieces are articulated to each other by means of physical routes (tunnels, bridges, roads) or teleportation links. OpenSimulator provides designers with more flexibility to customize virtual worlds in comparison to many commercial 3D development environments (for example, Second Life) (Nakapan and Gu 2011). At the beginning of the implementation



a b

Fig. 1 Images of individual (**a**) and collaborative (**b**) work performed during the 3D MUVE design process

process, the designers were given an ill-structured problem scenario. They were told that there was a problem in terms of the lack of adequate recognition of the ecosystem and the lack of awareness of tree diversity on campus by students. The designers were asked to solve this problem through 3D authentic environments and learning tasks that they would construct based on the framework of a scenario they would design. Following the theoretically heavy part of the implementation, the participants were divided into teams and continued their work collaboratively in the second 8 weeks of the implementation. In this process, each team was provided an independent free space on the OpenSimulator server as an island to create 3D virtual spaces. In these spaces, the designers had the opportunity to build structures (including object creation/uploading and land arrangements), edit avatar appearances and actions, construct interactions and run scripts without any restrictions. The number of members in each team varied between 5 and 6 individuals. The design teams were formed by considering the participants' gender and prerequisite skills (instructional design, computer programming and graphic design experience). Table 2 shows the basic activities (tasks) performed by the designers in the 3D MUVE during the implementation process.

During weeks 9–16 of the implementation process, the designers held regular weekly meetings with an expert from the field of biology (botany). In addition to the face-to-face interviews, the designers were also offered the opportunity to communicate asynchronously through e-mail with a subject matter expert. The subject matter expert provided the designers with information about general vegetation cover, tree species, characteristics of trees, their habitats and the soil (land) structures in which trees grew. The exchange of ideas with the subject matter expert enabled the construction of 3D trees and land models in an authentic manner.

The roles of the researchers

One of the researchers was involved in the design process in the role of the technical support assistant and the course instructor. The two other researchers participated in the study as non-participant observers.

Table 2 The list of design tasks in 3D MUVE according to task types

Task type	Tasks
2D/3D design and modelling	Modelling the draft view of the environment on paper
	Designing 3D models
	Uploading 3D models
Instructional design	Preparing a learning scenario
	Creating and editing content (audio, video, text, photo and so forth)
	Evaluating users
Interaction	Preparing animations
	Creating head up display (HUD) menu
	Preparing interactions
	Creating non-player characters (NPCs)
	Writing script (coding)

Data analysis

The IBM SPSS (v.21) and NVivo (v.10) software packages were used to analyze the mental effort and reflection report data, respectively. The data obtained from the demographic questionnaire were digitized to be presented as frequency and percentage values. The designers' mental effort scores were analyzed through mean and standard deviation values. Their mean score differences depending on the types of tasks were analyzed through a Friedman test, the nonparametric equivalent of one-way repeated-measures analysis of variance. Kruskal–Wallis H test was also used to determine whether the mental effort levels of the designers differed between the design teams. The statistical threshold value was accepted to be .05. If the Friedman test results were statistically significant, Wilcoxon signed-rank tests were carried out for pairwise comparisons among the task types. Statistical significance in the pairwise comparisons was determined by using Bonferroni correction. The data obtained from the reflection reports were analyzed with the ground-up approach. A data stack of 19,788 words consisting of 130,980 characters not including spaces was obtained from the reflection reports. When these data were transferred to the MS Word software using the Times New Roman font type with 12 points font size, a document consisting of 48 normal-size pages was obtained. The reflection reports were then transferred to the NVivo software. Qualitative data analysis began with free coding. When the code saturation was achieved, the process continued with axial coding. In other words, free codes were associated with each other, resulting in categories and themes. The coding resulted in 37 free codes and 6 themes. These themes were instructional design, technical design (infrastructure), 3D object design (modelling, uploading and placement), teamwork, interaction elements and time management.

Findings

Within the scope of the study, the designers engaged in a total of 11 tasks of three different types: instructional design, 3D design and modelling, and environment-user interactions. After the designers were presented with the problem scenario, they began to create instructional scenarios first. They then tried to model draft drawings on paper about the 3D virtual learning environment being planned to be developed. Figure 2 features drawings of the 2D environment prepared by one of the design teams.

In this sense, the preparation of instructional scenarios may be considered as the first stage of the design of 3D virtual learning environments. Instructional scenarios are a major component that guides other stages of 3D virtual environment design. The designers also considered elements such as roles, stages, tasks, difficulty levels of tasks, flow, user–user and user–environment interactions and evaluation of users in instructional scenarios. Figure 3 demonstrates the bird's eye view and normal view of a number of 3D virtual environments designed by a design team.

> **Sample project:** The project name is Alchemist. According to this project, the mother of the virtual character (player) suffers from a fatal illness. Their mother needs a magic potion to recover. The player learns from the doctor that there is a wizard in the temple, and only he can prepare the potion. The player then sets out. While the player searches for the materials the wizard wants the player to bring to him in 5 different regions (Andrea, Aestus, Quanah, Gionel and Polus), the player

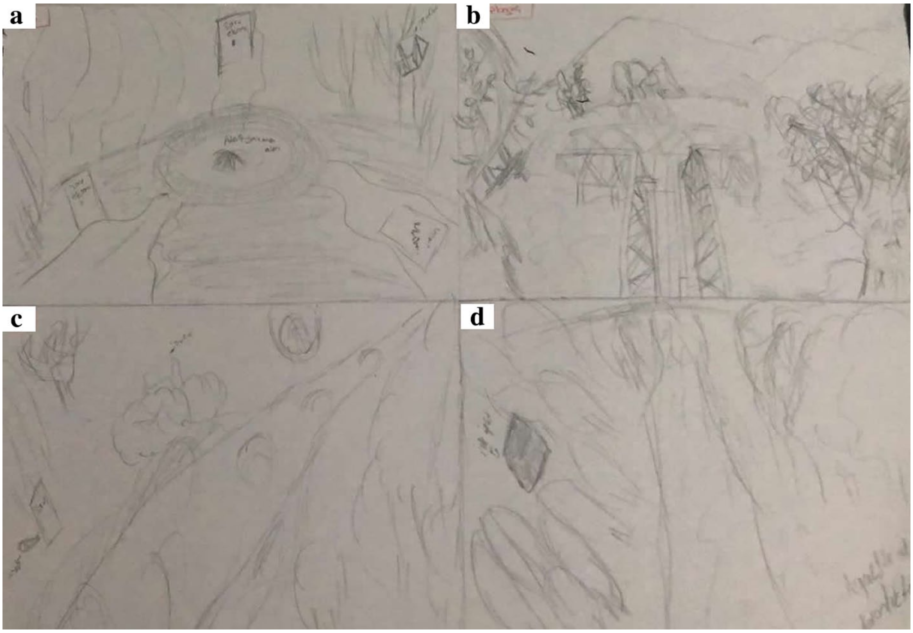


Fig. 2 Modelling of 3D virtual environments on paper. The sketches of the bird's eye (**a**, **b**) and normal views (**c**, **d**) regarding envisioned 3D virtual environments. The drawing depicts the settlement where the story begins (**b**) and a crossroad point (**a**) and forestlands (**c**, **d**)

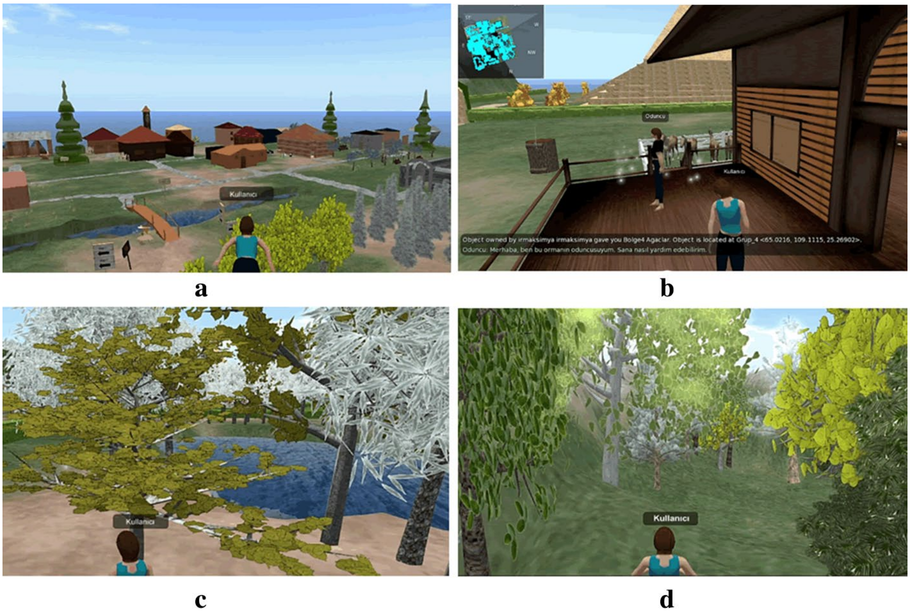


Fig. 3 Bird's eye view (**a**) and normal view (**b**–**d**) of 3D MUVEs prepared by the designers

chooses one of the easy/medium/hard game modes based on their own knowledge and begins their learning adventure. Players try to collect the herbal samples they need by talking to other players and local people (non-player characters) that they encounter, by collecting data from the environment and from these people and by analyzing these data. In the meantime, they have the opportunity to learn concepts such as the names of tree species, trunk and leaf characteristics, the terrain and climatic conditions in which trees grow. They also experience scientific processes such as gathering, analyzing and evaluating data as much as experiencing the relationships in the ecosystem.

Table 3 shows the mean mental effort scores of the designers in relation to the design tasks. The results showed that the designers were cognitively overloaded while carrying out the tasks in the 3D virtual environment. In this respect, the following tasks caused a high cognitive workload on the designers: preparing learning scenarios, uploading 3D models, creating educational content, modelling the draft view of the environment, designing 3D models, preparing user evaluation, designing interactions, writing scripts and preparing Head-Up Display (HUD) menus. However, creating Non-Player Characters (NPCs) and preparing animations were not found cognitively challenging by the designers.

It was found that the levels of the mental workload of the designers varied significantly depending on the task types ($\chi^2(2)=11.580$, $p=0.003$). As seen in Table 4, the environment-user interaction tasks led to a relatively low mental workload.

For pairwise comparisons between the types of tasks, Wilcoxon signed-rank test was employed (Table 5). In order to reduce the Type 1 error rate in these analyses, Bonferroni correction was utilized, and the statistical significance threshold value was lowered to 0.017 (p value/pairwise count comparison). In this respect, the designers were found to employ themselves in significantly higher mental workload in the tasks related to instructional design (Median = 6.33) and 2D/3D design and modelling (Median = 6.67) in comparison to the tasks associated with environment-user interaction (Median = 5.80; $p<0.017$). Although it provided very limited information due to the small sample size, whether the cognitive effort levels of the designers differentiated according to the teams was also examined to determine to what extent the results were affected by the in-team dynamics. The results showed that there was no significant difference between the teams

Table 3 Mental effort scores of the designers based on the design tasks

Tasks	Mean	SD
Preparing a learning scenario	7.00	1.55
Uploading 3D models	7.00	1.63
Creating and editing content (audio, video, text, photo, and so forth)	6.94	1.73
Modelling the draft view of the environment on paper	6.69	1.49
Designing 3D models	6.25	2.14
Preparing user evaluation components	5.69	2.18
Preparing interactions	5.56	2.45
Writing script (coding)	5.31	2.60
Creating HUD menus	5.06	2.64
Creating non-player characters (NPCs)	4.94	2.41
Preparing animations	4.25	2.38

Table 4 The comparison of the effects of types of design tasks in 3D MUVEs on the designers' mental effort levels according to Friedman test results

Mean ranks			Test statistics			
2D/3D Design and Modelling	Instructional design	Environment-user interactions	n	Chi square	df	Asymp. sig.
2.47	2.19	1.34	16	11.508	2	0.003*

*p value is smaller than .01

Table 5 Post-hoc analysis of cognitive effort levels based on task types through the Wilcoxon signed-rank test

Test statistics	Pairwise comparisons		
	Interaction—3D design and modelling	Interaction—Instructional design	Instructional design—3D design and modelling
Z-value	−2.869	−2.663	−0.729
Significance value	.004*	.008*	.466

Test statistics are presented based on positive ranks

*Statistical significance at the level of .01

in terms of task types [$\chi^2(3)=3.25$, $p=.35>.05$; $\chi^2(3)=1.12$, $p=.77>.05$; $\chi^2(3)=.68$, $p=.88>.05$ for 2D/3D design and modelling, instructional design and interaction tasks, respectively]. Nevertheless, unpredictable in-team dynamics might have had an impact on the results of the study.

The results from the reflection reports were also in parallel with the mental effort scores. When the reflection reports were examined, the designers were found to have difficulty preparing the learning scenarios, in particular, during the instructional design phase. It is considered that this situation was caused by the need to dynamically change the learning scenarios throughout the process because of the technical problems or limitations they faced in the development environment. Troubles faced while conveying designs that were prepared in various 3D modelling tools to the OpenSimulator environment also led to changes in the instructional design plans from time to time. The technical competencies of the designers and the characteristics of the 3D virtual development environment were also observed to steer the instructional design.

> D9: Additionally, we prepared the scenario without being aware of our skills, which led us to modify the scenario.
> D11: The environment we employed didn't support every kind of design. I had trouble likening the trees and then uploading them into the environment. This is why there were times when we had to modify the scenario.

The designers indicated that, during the 3D design and modelling activities, they had to take into account too many details to make the objects look authentic. Moreover, positioning objects and topographically arranging some of the objects (lakes, mountains, land (soil) and so forth) while creating designs in the 3D virtual environment were also found to be quite challenging for the designers.

D6: First, I created a lake. Then, I wanted to modify certain parts, but the environment was completely flooded, and I couldn't save it back. We re-arranged the land, and then, the lake was added by D4.
D11: I couldn't cope with the design elements that were too detailed. So, I had problems in struggling with similar details while designing trees.
D13: I attempted to build a lake or a mountain four times. The environment was flooded in all four times, and the mountains vanished.

The designers faced too many errors while uploading the 3D objects into the virtual environment. They had also difficulties in finding the objects that were pre-placed in the 3D virtual environment, modifying the existing objects and restoring some of the deleted objects. Another issue was that, while removing certain 3D objects from the environment, other objects of the same kind were removed accidentally. The designers had trouble transferring ready-made 3D items as well as the objects they designed in other 3D design tools into the environment. Striving to design most objects in the 3D virtual environment was, therefore, another difficulty for the designers. The designers reported that they had a real hard time in creating unique and creative models.

D6: It was really difficult for us to be unable to bring back the objects that vanished out of the environment because there were objects that we accidentally selected, and when we deleted items, the selected objects were also gone.
D15: I had difficulties in adding three-dimensional objects from the outside to the environment. This is why I created all my objects myself.
D16: I think I have weaknesses in the design phase, and my imagination is also weak. I couldn't think of anything unique.

The work carried out on the server led to an increase in the designers' concerns about making mistakes. This restricted some of the designers' attempts to modify the 3D virtual environment from time to time. Moreover, certain privileges (permissions) in the server environment at times restricted the designers from viewing and modifying certain objects in the common workspace.

D2: It was hard working on the server. I didn't dare try things because I was too afraid to make mistakes.

Technical troubles and errors often affected the design processes negatively in the 3D virtual environment. The designers who attempted to develop different technical solutions had to modify their instructional design plans from time to time. Additionally, it was frequently reported that the hardware capacities of personal computers also impeded the design processes in the virtual environment.

D10: I was restricted when I was trying to do what I wanted to do. Tree[d] [a free program used to design 3D tree models] caused a problem that I thought was unrelated to my computer specifications.

Although preparation of user interactions in the environment required a lower level of mental effort than other design tasks according to the scale results, it was another issue that challenged the designers. In comparison to the other task types, the interaction tasks required the designers to work more collaboratively. The errors that the designers faced increased, especially in the coding of the interaction tasks.

D11: I've had difficulties while creating interactions. These problems may be due to the possibility that we're not competent enough for both technical and planned work.

D4: Coding stages. We tried the codes we wrote and encountered errors many times.

Discussion and recommendations

The process of developing 3D virtual learning environments comprises the components of instructional design, graphic design (modelling, designing and placing of 3D objects) and interaction design. Pedagogical approaches that would form the basis for learning activities are also important in this process. Instructional designers have an important role in both the environment design process and the instructional design process. However, the complex and versatile design nature of 3D MUVEs may cause instructional designers to be cognitively overloaded. In this context, answers to the following question were sought in this study: “What are the effects of different design tasks on instructional designers’ levels of mental load in the process of preparation of learning activities in 3D MUVEs?”

The results showed that the designers were cognitively overloaded while fulfilling the design tasks in the 3D virtual environment. An examination of the mental effort scores revealed that preparing instructional scenarios, uploading 3D models, preparing educational content (text, pictures, audio, video and so forth), modelling the draft view of the environment on paper and designing 3D models were the most challenging tasks with regard to mental workload. On the other hand, the tasks of preparing animations, NPCs and HUD menus were determined to lead to relatively less cognitive workload.

When the mental effort scores were examined with regard to the task types, the designers were found to be cognitively overloaded more in the tasks related to instructional design and 2D/3D design and modelling, and relatively less in the tasks related to environment-user interactions. It was indicated, based on the analysis of the data in the reflection reports, that this was due to the modifications that had to be made in the instructional design process depending on the limitations of the technical design tools. In addition, this was thought to be caused by the fact that 3D models had more details, and the topographic properties of these objects and the spatial layouts in the virtual environment required complex operations.

Virtual worlds allow people to discover new and different environments (e.g. rain forests, lakes, mountainous areas, deserts, historical and cultural places) and experience situated interactions with the help of authentic settings (Dalgarno and Lee 2010). While doing this, it is important to create artifacts (objects, buildings and structures) in the 3D virtual environment that comply with real-world restrictions as much as making them similar to their physical counterparts. For example, avatars should not be able to pass through walls. Certain restrictions provided by 3D development platforms may steer the process of designing 3D objects. From time to time, this may cause deviations in the representations of real-world conditions or properties that are being simulated, in 3D object and building (artifact) design, in actions of avatars and eventually in instructional scenarios (De Lucia et al. 2009). Such a dynamic- and inter-connectedness between technical and instructional design poses difficulties in application development processes.

Virtual worlds support collaborative, empathetic, reflective and inquiry-based learnings such as role-playing, game-based learning and gamification, interdisciplinary interaction, discussion and project-based learning activities (Cho and Lim 2017). In this study, the design teams utilized quests (inquiry-based activities) in the 3D environments and scenarios, which they prepared by adhering to the problem-based learning approach. Exploring 3D virtual environments and finding hides (hidden places) in such environments or searching for quests is an exciting activity for users (Tüzün 2006). One of the most significant features of 3D virtual worlds is their ability to tell stories. To use this ability for instructional purposes, it is necessary to equip 3D environments with interesting and rich scenarios. During preparation of scenarios, the target student audience, cultural values, subject matter and the pedagogical approach should be considered, and 3D interfaces/objects appropriate for scenarios should be created. For this reason, the impact of quests based on learning scenarios on cognitive endeavors/efforts in tasks of instructional design and 3D object/environment design should not be neglected.

From the point of view of social-constructivist learning theories, learning is a tool-dependent and social phenomenon that can be acquired by using cultural artifacts (elements) and socially constructing interpersonal knowledge (Keskitalo et al. 2011). Avatar interactions in 3D virtual worlds play a vital role in users' acquisition of a common understanding of the subject or phenomenon that the users master, and therefore, in their social construction of knowledge. It has been reported in studies that student autonomy in collaborative endeavors (problem-solving processes, in particular) carried out in 3D virtual learning environments improves intrinsic motivation, which in turn enhances learning outcomes (acquisition of knowledge) (Cho and Lim 2017). For this reason, the learning process in 3D MUVEs is associated with perceptions of belonging to a learning community, awareness, presence and communication, in addition to instructional content and activities (De Lucia et al. 2009; Tüzün et al. 2019). Moreover, creating a learning community in a 3D virtual world necessitates additional interaction and communication opportunities among users through planned and unplanned social encounters (Kreijns et al. 2007). In 3D virtual learning environments, formation of the senses of community and presence depends on the authenticity of user–user and user–environment interactions. In a sense, it depends on integration of contextual factors and spatial arrangements (related to learning) in a natural and harmonious way within the framework of instructional scenarios. In this study, the designers were observed to focus heavily on creating user–environment interaction elements (non-player characters, dialog boxes and chat messages, HUD menus and so forth). 3D MUVEs are spaces where users navigate freely to experience the feeling of being a part of (presence in) the virtual world, interacting intuitively with objects and other people (Schmeil et al. 2012). Users might not know how to benefit from the environment without suitable interaction scenarios, choreographies, scripts, affordances or hints. The designers in this study used visual clues (lighting/highlighting), signs and other affordances to offer guidance and support to users. Such guidance/support elements prevent users from getting lost in a virtual environment, thus contributing to maximizing the benefit from the virtual world. It was observed that the designers did not sufficiently introduce interaction scenarios/patterns to the virtual worlds that would promote collaboration between users. It is considered that this could have affected the mental effort the designers exerted in the tasks of interaction design. However, this may have been caused by the expectation that user interactions would occur spontaneously in the virtual world within the instructional contexts.

The cognitive load theory emphasizes limited information processing capacity in the working memory, offering clues about the effective use of cognitive resources (Mayer and Moreno 2003). The theory is highly functional in directing learning processes to make cognitive efforts more effective in complex learning tasks such as design and problem-solving. The results from this study highlighted the complex and multifaceted nature of instructional design processes in 3D MUVEs. Therefore, it is recommended that design teams that are gathered to prepare learning activities in such environments are composed of individuals with different technical qualifications in addition to subject matter experts and instructional designers.

The mental effort measurements were carried out following the project delivery, as the time intervals between the start and end of the design tasks varied according to the design teams. This caused a limitation that might have affected the mental effort levels perceived by the designers who gained experience in the implementation process due to the maturation effect. Additionally, the cognitive effort data that were collected based on self-reporting. The recall effect, which decreases as a natural result of progressive design processes, was neglected in this study. The relatively small sample size in this study and the diversity of data collection instruments constituted a limitation. For future studies, data sources such as field notes (design diaries or designer's logbooks), focus group interviews, log records on 3D development platforms might contribute to capturing different insights regarding design processes on these 3D environments. The low experience levels of the designers in developing 3D virtual environments should also be taken into account in interpreting the results. Studies to be conducted with designers of different experience levels may provide different results.

Conclusion

Instructional environments and technologies vary to a great extent following developments in Information and Communication Technologies (Vicent et al. 2015). 3D virtual environments have begun to attract the attention of many academicians in recent years (Hu et al. 2011). 3D virtual environments offer unique opportunities for creating manipulative instructional processes in almost every field, from natural sciences to architecture and even art education with the help of realistic and complex visualizations they offer (Shin and Park 2019). In many disciplines, it is difficult to create authentic and manipulative conditions appropriate for design tasks. 3D MUVEs offer manipulative environments that support individual and collaborative work, especially in designing materials and instruction in educational sciences. 3D MUVEs support every designer to have an independent perspective. Moreover, designers navigating the same virtual environment can manipulate environments and objects in 3D worlds by completing synchronous/asynchronous collaborative design and learning tasks (De Lucia et al. 2009). Nevertheless, authentic modelling and representation of physical world conditions in a virtual environment is not an easy task. Additionally, it may be challenging for instructional designers to create contextual features of learning, subject-specific content, user evaluations and user interaction/communication opportunities for avatars that would share a common area spatially and temporally. The literature reports mostly pedagogical outcomes and benefits of 3D MUVEs in education, primarily knowledge gain, social interaction and communication, engagement and motivation. Unlike the literature, this study examined the design processes of 3D virtual environments in an authentic context. In this context, a group of undergraduate students in the role of instructional designers was asked to develop 3D virtual learning environments to introduce the tree species within the campus to students, and thus, elevating their awareness of the on-campus biodiversity. In this process, the designers were given a total of 11 design tasks categorized under three different task types—2D/3D modelling and design, instructional design, and user–environment interaction. The results showed that learning scenario building, uploading user-created 3D models, content creation, modelling of the draft view of the environment and 3D model design were the most challenging, while making animations, creating non-player characters and designing an interactive menu were the least challenging design tasks in terms of cognitive effort. Moreover, the 2D/3D modelling and instructional design tasks required significantly higher mental effort in comparison to the user interaction tasks. In particular, the need to change the learning scenarios dynamically due to technical limitations, the problems faced in uploading the 3D object models into the OpenSimulator environment, the details in the object placements and the topographic layout adjustments of the various terrains were some of the challenging issues that demanded high mental effort. This study presented designer points of view beyond end-user–environment interactions. Examination of pedagogical and technical design processes in 3D virtual worlds in terms of cognitive workload is thought to provide guidance on the instructional design strategies and models recommended for such environments.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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