Motivational Evaluation of a Virtual Reality Simulator to Teach Disk-Scheduling Algorithms for Solid-State Drives (SSDs)

Alex Sandro Rodrigues Ancioto[1], Luiz Felipe Santos Freitas[1], Diego Roberto Colombo Dias[2], Valéria Farinazzo Martins[3], Alexandre Fonseca Brandão[4], and Marcelo de Paiva Guimarães[1,5(✉)]

[1] Computer Science Master Program, UNIFACCAMP, Campo Limpo Paulista, Brazil
alexancioto@gmail.com, luiz.freitas@ifms.edu.br, marcelodepaiva@gmail.com
[2] Computer Science Department (UFSJ), São João del Rei, Brazil
diegocolombo.dias@gmail.com
[3] Faculty of Computing and Informatics, Mackenzie Presbyterian University, São Paulo, Brazil
valfarinazzo@hotmail.com
[4] Institito de Física Gleb Wataghin (UNICAMP), Campinas, Brazil
abrandao@ifi.unicamp.br
[5] Núcleo de Ensino a Distância (UAB/Reitoria), UNIFESP, São Paulo, Brazil

Abstract. The literature already shows diverse gains in the adoption of virtual reality environments, such as the possibility of safely repeating experiments without increasing the costs. However, it is unclear the advantages of the adoption of two-dimensional (2D) simulators in comparison to three-dimensional (3D) simulators based on virtual reality. We present a motivational analysis of a virtual reality simulator for teaching disk-scheduling algorithms for solid-state drives (SSDs). For this, we developed a fully immersive and interactive simulator. A case study was carried out with 38 students in which it compared the simulator being executed in a 2D environment (desktop) with a 3D environment (Google Cardboard). The results indicate a motivational increase in the 3D environment in some aspects.

Keywords: SSD · Scheduling algorithms · Virtual reality · Simulation

1 Introduction

Computer science major demands innovative training strategies able to adapt to all technological changes that are happening. For example, in order to improve factors such as resistance against mechanical shocks, energy consumption, and performance, in recent years it has become common to adopt solid-state drives (SSDs) instead of the traditional hard disk drives (HDDs) as computer non-volatile storage devices [1, 2].

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The Operating Systems class, which is essential for any computer science major, should treat the specific disk-scheduling algorithms for SSDs to take full advantage of them. Learning these algorithms SSDs is a challenging task for students, who must learn how the hardware works as well as reorder the input/output (I/O) requests. Operating System classes are traditionally taught using conventional material such as slideshows and blackboards and, rarely, bi-dimensional (2D) or command line simulators [3–6]. This way, the virtual reality simulators are a possibility as new instructional resources.

Virtual reality allows users to be immersed in virtual worlds in real time and interact with the three-dimensional (3D) objects [7]. This technology has proven to be effective in many teaching situations, especially in which users manipulate real objects, such as driving a car [8–11] or riding a motorcycle [12, 13]. However, there are still barriers to be overcome, especially when referring to abstract subjects, which are not directly related to a 3D space, as is the case of the disk-scheduling algorithms for SSDs. Virtual reality simulators can be a feasible option to assist in teaching these algorithms since it allows, for example, the conversion of abstract content into concrete elements, the execution of a task rather than just an observation, the simulation of unreal situations, and free simulation replay without cost increase [14–16]. Moreover, the use of a virtual reality simulator can generate motivational stimuli [17–19], which are important for sustaining learners' curiosities and interests and for creating an effective motivational environment.

This paper aims to present a motivational analysis of a simulator for teaching disk-scheduling algorithms for SSDs. For this, we developed a fully immersive and interactive simulator. It supports disk-scheduling algorithms for SSDs such as NOOP [20] and Parallel Issue Queuing (PIQ) [20], and it also shows the hardware architecture details of an SSD. A case study was carried out with 38 students in which it compared the same simulator being executed in a 2D environment (desktop) with a 3D environment (Google Cardboard). The results indicate a motivational increase in the 3D environment in some aspects.

The remainder of the paper is organized as follows: Sect. 2 explains the disk-scheduling simulator's architecture and provides details of its implementation. Section 3 presents the motivational aspects evaluation. Section 4 shows the experiment setup. Section 5 presents the results, and Sect. 6 shows conclusions and plans for future works.

2 Disk-Scheduling Simulator

SSDs are built using flash microcontrollers to enhance their reliability as well as their speed without mechanical elements [21–24]. They have specific disk-scheduling algorithms which are different from those traditionally used to manage the I/O requests for HDDs. SSDs tend to be adopted by the computers as an efficient storage device solution, and this requires specific computer science skills and expertise to design improvements.

The main purpose of the virtual reality SSD simulator developed is to assist students in learning about the main disk-scheduling algorithms and the hardware details, understanding their advantages and disadvantages. This simulator takes the students to a place where they cannot physically go. It was designed to add new disk-scheduling algorithms easily, requiring only a new routine associated with the 3D models to be added. The simulator was developed using the Unity[1] game engine, which is used to develop games for desktop platforms, mobile devices, browser-based applications, and consoles. During the simulation, each student enters in a laboratory room and visualizes, manipulates, and exploits the algorithms and the associated hardware, pursuing the lecture objectives at their own pace. There is a bench for each algorithm.

For now, the following disk-scheduling algorithms are available [20]:

- NOOP: this algorithm schedules the I/O requests in the order of first in, first out (FIFO).
- PIQ: it orders the I/O requests without conflicts into the same batch and I/O requests with conflicts into different batches. This design allows the multiple I/O requests in one batch to be fulfilled simultaneously by exploiting the SSD parallelism.

The algorithm execution can be visualized in a 3D model. We create metaphors to represent all elements involved in the simulation. For example, the I/O requests are represented as animated cubes. The simulator presents the following features:

- Immersion: it supports hardware, such as head mounted displays (HMDs) (i.e., Google Cardboard, Samsung Gear VR), that allows the users to be isolated from the rest of the world.
- Interaction: it refers to the capacity of the students to move within the virtual world and to interact with the objects, for example, pressing a button. The simulator supports interactions via remote control, joystick, keyboard, and mouse. Interaction contributes to users' feeling of immersion.
- Navigation: it refers to the possibility of the user getting from one location in the environment to another. In the simulator the student can move from one bench to another. Each bench depicts the simulation of an algorithm. Animations are presented when the avatar gets closer. It also displays messages and/or allows students to listen to descriptions of the current activity.

Figure 1 depicts the bench which simulates the NOOP algorithm. The student can visualize the pending queue (reading (R) and writing (W) requisitions) and hardware elements such as host interface, flash translation layer (FTL), and the flash controller. The animation occurs according with the pending queue and the algorithm simulated.

[1] https://unity3d.com/.



Fig. 1. Bench for simulation of the NOOP disk-scheduling algorithm.

Figure 2 depicts the algorithm PIQ running in a Google Cardboard (left and right eyes). During our tests, we interacted using a joystick with Bluetooth connection. The simulation represents the separation of the I/O requests into batches where there is no conflict in each batch. After the separation, the request batches are proposed to group requests without conflicts into batches. The conflict detection is based on the location vectors of I/O requests, considering the waiting and outstanding requests in the I/O queue.

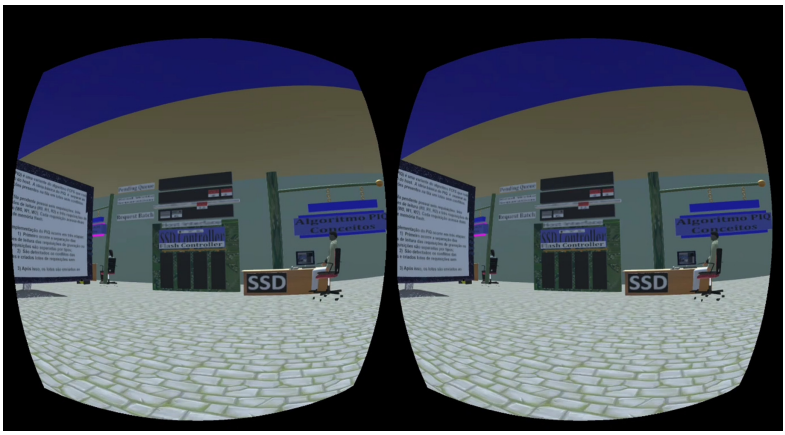

Fig. 2. Bench for the PIQ scheduling algorithm (left and right eyes).

3 Motivational Evaluation

The evaluation aimed to compare students' motivation when using the 3D version of the simulator (Google Cardboard) and the 2D (desktop). We created a questionnaire (Table 1) based on the based on the ARCS motivation model [25], which considers the following factors [26]:

- Attention: it refers to the learners' interest in the activity performed. It is essential to get and keep the learners' interest and attention.
- Relevance: it refers to increasing students' interest by connecting their prior experience to the content provided.
- Confidence: when the students believe that they can meet the objectives and that the cost (time or effort) is adequate, their motivation increases.
- Satisfaction: it refers to how much the students are proud and satisfied of what they have achieved during the learning process.

The questionnaire (Table 1) was also created based on level two of the model proposed by Kirkpatrick [27]. This model aims to analyze and evaluate the results of training and educational programs according to four levels. His model also allows identification of the criteria that influence each level. As you move from one level to another, the process becomes more complex and time-consuming, but it delivers more valuable results. In our research, we focus on the first level. The levels are [27]:

- Reaction: it aims to evaluate how the students liked the training, if they found it favorable, engaging, useful, and easy to apply.
- Learning: it aims to determine which expertise, knowledge, or mindsets the students have developed and that these are directly attributable to the training.
- Behavior: it refers in how they apply what they have learned during the activity after completing the training.
- Results: it aims to verify if the targeted outcomes occur as a result of the training.

Table 1 shows the questionnaire created based on the ARCS and Kirkpatrick models to perform the motivational evaluation of our disk-scheduling simulator. These questions were analyzed according with each category. The categories were rated using the Likert scale [28].

Table 1. Motivational questionnaire

Questions	Categories
ARC model [25, 26]	
1. The simulator interface design is attractive	Attention
2. The simulator graphical interface is pleasant	Attention
3. The simulator teaches surprising or unexpected content	Satisfaction
4. The simulator content is relevant to my goals	Relevance
5. The simulator stimulated my interest in knowing more about the subject presented	Relevance

(*continued*)

Table 1. (*continued*)

Questions	Categories
6. The simulator presents abstract content in a practical way	Confidence
7. I felt that I was making progress while using the simulator	Satisfaction
8. The simulator kept me motivated to continue using it	Attention
9. I would like to use this simulator again	Confidence
Training model [27]	
10. I can remember the content presented by the simulator	Learning
11. I can understand the content presented by the simulator	Learning
12. I can apply the content presented by the simulator	Learning

4 Experimental Setup

This section describes the randomized experiment we carried out to evaluate the motivation of using a simulator to assist the learning of disk-scheduling algorithms for SSDs. The study took place in the second semester of 2018 at the Federal Institute of São Paulo, located in the city of Pirituba, Brazil, in Computer Science courses. Formally, we set out to answer the following research question:

Research question: Is a 3D simulator a better motivator to teach disk-scheduling algorithms than a 2D simulator?

The aforementioned research question outlines the issue that this study is intended to investigate. Throughout the rest of the paper, we refer to the approach based on desktop (2D interface) as DESKTOP and the immersive (3D interface) approach as HMD.

To evaluate our conjecture, 38 subjects were assigned to the two different treatments at random: 19 subjects were assigned to DESKTOP, and 19 subjects were assigned to HMD. The main dependent variable is the scores of the subjects in the questionnaire. More specifically, this dependent variable is defined in terms of rating each question.

The experiment was broken down into four steps. These steps are listed in chronological order in Table 2.

Table 2. Motivational evaluation stages

Step	Description	Time
Division of class	The students were divided into two groups of nineteen (19) students randomly	Free
Simulator	Group 1: this group went to the laboratory and was taught with the DESKTOP simulator. The tests were taught in classrooms with one desktop per student Group 2: this group went to the laboratory and was taught with the HMD simulator. The tests were taught in classrooms with one Google Cardboard per student	10 min
Test	All students answered the questionnaire	15 min

5 Results and Discussion

The Likert scale [28] has been adopted (1-Strongly disagree, 2-Disagree, 3-Neither agree nor disagree, 4-Agree, 5-Strongly agree). Table 3 depicts the results obtained. In general, the results were better for the HMD and the standard deviation was lower, indicating that its use can improve the learning process.

Table 3. Motivational evaluation results

	DESKTOP	HMD
Median	3.71	3.76
Mean	3.62	3.82
Std	0.29	0.25
Max	3.95	4.37
Min	3.21	3.42

Figure 3 depicts the results obtained (DESKTOP X HMD). The HMD simulator received the highest grade from most of the students.

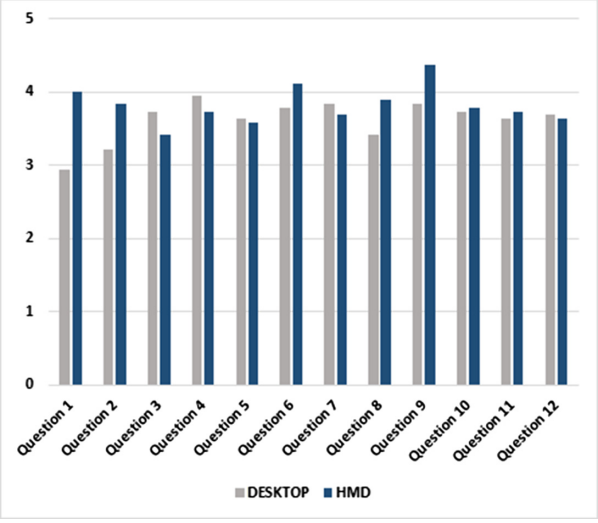

Fig. 3. Motivational evaluation (DESKTOP X HMD)

HMD received the best grades in 7 questions, while DESKTOP was better in 5 questions. According to the categories presented in the questionnaire (Table 1), the results obtained were:

- Attention (questions 1, 2, and 8): the HMD version was better evaluated in all questions. However, it can be observed that the simulator interface, mainly the desktop version, requires improvements. For example, the hardware elements modeled must be improved.
- Satisfaction (questions 3 and 7): Although the grades were similar, the DESKTOP version was better evaluated in both questions. We believe that these results are related to the quality of the 3D model, which should be improved.
- Relevance (questions 4 and 5): the grades were again better for the DESKTOP. These questions are related to student interest in the subject; it was expected that the HMD solution would receive the better grade because virtual reality immerses the student in what he/she is learning. However, this category requires computational experience of the students because it treats their involvement with the content. Thus, we believe that the simulator presented is a tool that can increase this interest, showing the content in practice.
- Confidence (questions 6 and 9): In both questions HMD received higher grades. This result could be because the HMD solution is a novelty to most of the students, and the algorithm animations run in real time and can be seen from different points of view.
- Learning (questions 10, 11, and 12): HMD received higher grades in questions 10 and 11, and DESKTOP was better in question 12. Virtual reality simulators seem to be the natural next step for the evolution of education because of their pillars (immersion, interaction, and imagination). Although the results indicate higher grades to the HMD environment, we understand that further investigation is necessary.

Table 4 depicts the simulator approach that had the better performance according to the questionnaire categories.

Table 4. Categories results

Categories	Best performance
Attention	HMD
Satisfaction	DESKTOP
Relevance	DESKTOP
Confidence	HMD
Learning	Similar

6 Conclusions

Creating a motivational environment for learners is one of the goals of an educational institution, which aim to create a modern and successful teaching/learning process. In recent years, there is growing interest in using simulators based on virtual reality technology to facilitate the teaching/learning process in diverse areas. However, it is not clear their efficiency considering some aspects, for example, learning, motivation, and confidence when compared with traditional simulators such as 2D and command

line based. This paper aimed to investigate the motivation aspect, comparing the same simulator in two versions (2D and 3D interface) for teaching disk-scheduling algorithms for SSDs.

SSDs are being increasingly adopted as a storage solution. These devices work differently when compared with magnetic disks. Therefore, the Operating System class needs updated content considering this new scenario. The simulator developed can help students understand how SSDs work, including the algorithms and the hardware involved. For now, NOOP and PIQ algorithms are available, but it has the flexibility to incorporate additional algorithms and other features, such as details about the I/O controllers.

Motivational evaluation is very important for choosing material to assist the class because it can make the learning process more engaging. The results presented indicate that motivation increases in the 3D environment in some aspects; it also shows that further investigation is necessary. It was also noticed that the 3D version kept the student focused in his/her class. During the test, the HMD group showed higher levels of participation.

In the future, we plan to improve the simulator by adding new algorithms and investigating collaborative enterprise learning needs and data analytics. We also plan to improve the 3D models and conduct experiments to determine the simulator's effect on student learning.

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