

Sortica: A VR Serious Game to Teach Scheduling Algorithms to Undergraduate Students

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Abstract: Scheduling algorithms are an important part of the Computer Science curriculum as these algorithms control how resources are handled and shared within the operating system. Outside the realm of Computer Science, scheduling algorithms are a critical part of project management, enabling the translation of project plans into realistic and efficient operating time tables. Scheduling algorithms are often hard to understand by undergraduate students who struggle to visualise them and understand the practicalities of their implementation. Immersive Serious Games (iSG) have been shown to be an effective approach to visualise abstract concepts and immerse and engage students in practical tasks that require hands-on intervention. This paper presents the case study of “Sortica” a prototype iSG aimed at introducing students unfamiliar with scheduling algorithms to the foundational algorithms of the subject, such as last-in-first-out (LIFO) and first-in-first-out (FIFO). Within “Sortica” students took on the role of a robot worker tasked to rebuild town street buildings using the LIFO and FIFO algorithms. “Sortica” was developed following a human centred iterative approach and was tested through four data collection sessions for a total of 26 undergraduate participants from three modules in programmes that do not teach scheduling algorithms. A pre-test post-test method was used to test knowledge acquisition, the post-test also included questions regarding engagement, perceived learning and the NASA-TLX scale. Additionally, in-game analytics were collected to measure student performance within the iSG. Students were observed during the gameplay and interviewed to collect feedback regarding different aspects of the game. After data cleaning a preliminary data analysis shows that despite a high starting baseline (39% achieved perfect pre-test scores) participants felt that the iSG was highly engaging and helped solidify their understanding of the subject. Preliminary analysis of the NASA-TLX scale shows that the cognitive load was moderately high for the tasks, which could help explain why 4.35% of the valid responses showed a score decrease in the post-test. This work shows that the translation of abstract concepts of scheduling algorithms into mundane tasks makes “Sortica” an engaging tool for introduction and consolidation of basic scheduling algorithms knowledge and understanding. Furthermore, analysis of user friction reveals critical design considerations regarding diegetic interfaces, false affordances, and cognitive load in educational VR

Keywords: Virtual reality, Immersive serious games, Education, Scheduling algorithms, Embodied learning

1. Introduction

Scheduling algorithms govern many aspects of project planning and computer sciences applications. These algorithms are related to data structures, such as stacks (LIFO) and queues (FIFO), that students often find hard to grasp and implement. Despite the importance of the subject, data structures and algorithms modules are one of the main reasons why students drop-out from Computer Sciences courses (Watson and Li, 2014; Beaubouef and John, 2005). The cause of this is often attributed to the tediousness of the tasks involved in the learning of algorithms (Park and Ahmed, 2017) and the complexity of the subject (Stigall and Sharma, 2018). Jbara (2017) attributes the difficulties in learning scheduling algorithms to the way these algorithms are taught, the short time lecturers have to teach the subject, and the material that is available to the student.

Visualisation of scheduling algorithms has been shown to help students grasp the underlying concepts (Jbara 2017; Suranauwarat, 2015). However, Vrachnos and Jimoyiannis (2014) observed that visualisations are effective only when they are interactive, noting that passive visualisations of algorithms have little impact on student learning.

Immersive serious games (iSG) are naturally highly interactive and a highly effective tool in visualising abstract concepts. iSGs have been shown to have potential in improving theoretical understanding of abstract concepts and their practical applications within Physics (Villada Castillo, Bohorquez Santiago, and Martínez García, 2025; Zhang, Zhang, and Lee, 2025). The application of iSG to the teaching and learning of scheduling algorithms and data structures is still limited. Soussa et al. (2025) found that immersive virtual environments are effective in supporting students’ conceptual understanding, particularly in relation to stack and queues. However, Soussa et al. (2025) also observed that the IPQ presence score for their environment was low, we argue that this was due

to the lack of storification (Aura, Hassan, Hamari, 2021) within the virtual environment, which was presented as a learning tool rather than as an immersive experience.

In this paper we present “Sortica” a prototype iSG aimed at introducing students unfamiliar with scheduling algorithms to foundational algorithms within the subject, such as last-in-first-out (LIFO) and first-in-first-out (FIFO). Within “Sortica” students took on the role of a robot worker tasked to rebuild town street buildings using the LIFO and FIFO algorithms.

“Sortica” contributes to the field of iSG pedagogy by showing that the translation of abstract concepts into mundane tasks together with the development of storification of the experience can make virtual environments an engaging tool for introduction and consolidation of basic scheduling algorithms knowledge and understanding.

2. Related Work

Virtual reality (VR) shifts computer science education from passive observation to active, spatial participation (Khaleghian et al., 2026). Embodied cognition paradigms suggest that cognitive processes are fundamentally grounded in sensorimotor activities, as such, complex conceptual knowledge is strongly reinforced through physical interaction with an environment (Lehrman, 2025). The degree of this embodiment directly influences students' learning achievement and cognitive load (Suo et al., 2025). While students often struggle with the abstract nature of scheduling algorithms in traditional pedagogies, immersive environments enable learners to “sensemake” by externalizing mental models and anchoring computational relationships in concrete spatial structures (Brown, Mulder, and Mulder, 2026). Consequently, there is a distinct gap in the literature regarding how translating abstract data structures into tangible, embodied spatial interactions can specifically enhance the retention of algorithmic logic.

A persistent challenge in immersive serious games (iSGs) is ensuring that educational content does not feel disjointed from gameplay. Recent research emphasizes the necessity of “intrinsic integration,” an approach where the core game mechanics and the primary learning objectives are functionally inseparable (van der Linden et al., 2024). Furthermore, embedding these mechanics within cohesive narrative or “fantasy” contexts significantly enhances students' behavioral engagement and sustained interest (Li et al., 2024). Rather than treating learning as an extrinsic hurdle—such as pausing a VR experience to answer a traditional quiz—intrinsically integrated environments map rules directly onto the physical constraints of the virtual world. This indicates a need for iSGs that embed algorithmic logic entirely into the primary gameplay loop, ensuring learners must successfully execute the underlying educational protocols to progress.

Successfully executing embodied learning and intrinsic integration requires a rigorous overarching design framework to prevent user overwhelm. Systematic reviews warn that improperly managed extended reality (XR) environments significantly degrade cognitive task performance (Ahmed et al., 2025) and lower immersive VR self-efficacy. Addressing these risks requires structured theoretical approaches, such as the iSG design guidelines established by Beveridge and Gilardi (2025), which provide a holistic framework for balancing accessibility, storification, and cognitive load. Central to executing such guidelines is the minimization of “interaction cost” through diegetic interfaces—embedding necessary information seamlessly into the narrative environment rather than relying on abstract menus or traditional heads-up displays (Bellino & Vilches, 2025). Therefore, addressing the complexities of teaching scheduling algorithms in VR requires applying these specific design frameworks to create immediate, diegetic feedback systems that preserve presence while safeguarding the learner's cognitive capacity.

To better contextualize the effect immersion has on cognitive load, recent frameworks like the Cognitive Affective Model of Immersive Learning (CAMIL) (Makransky et al., 2021) highlight how presence and agency amplify both positive affect and cognitive load. However, isolating these effects remains a methodological challenge in immersive settings. While the NASA Task Load Index (NASA-TLX) remains a benchmark for assessing mental workload, its retrospective application introduces potential recall bias, as participants must evaluate their cognitive expenditure after the immersive experience has concluded.

3. Methodology

“Sortica” was developed following a human-centered iterative design process. Immersive serious games design guidelines by Beveridge and Gilardi (2025) and a yet to be published extension of such design guidelines were followed. Throughout the design process, multiple functional artifacts were developed and tested, which allowed to incorporate user feedback from the early design stages through to the final stages of development.

The objective of the research was to determine if “Sortica” is an effective tool for introducing and consolidating basic scheduling algorithms knowledge. In order to do this, data collection and analysis focused on understanding whether: there was an improvement in the understanding of the concepts; background, previous knowledge, and engagement affected the learning experience; participants were aware of their learning; the experience was cognitively demanding; and whether differences in play style and embodiment had an impact on the learning results.

Iterative testing during design and development stages of the game was implemented, five testers were involved, providing qualitative feedback at different stages of the design and development. The final evaluation data collection involved 26 undergraduate participants throughout four sessions. These participants were enrolled in undergraduate studies from levels 7, 8 and 10 on the Scottish Credit and Qualifications Framework (SCQF) where scheduling algorithms are not taught. Participants self-selected by volunteering for the evaluation. Out of the original 26 participants, two were excluded from the sample because they failed to complete at least one part of the study, and another one decided to opt out, leaving 23 valid participants.

The participants completed several measures: a background questionnaire on their previous experience with video-games, immersive technologies, and scheduling algorithms; pre-test and post-test questionnaires to gauge knowledge acquisition; and an engagement/perceived learning questionnaire. Furthermore, they rated various aspects of the experience using the NASA-TLX survey which utilized the Likert scale to measure six dimensions of cognitive load: mental, physical and temporal demand, as well performance, effort, and frustration. Data analytics from the game were also collected during the play sessions.

Quantitative data analysis was performed applying two complementary approaches: an exploratory data analysis on the gathered metrics, and a descriptive analysis of both gameplay logs and survey responses, as well as a comparative analysis between pre-test and post-test results. A final correlation analysis was performed using the Pearson Correlation Coefficient to examine the relationships between metrics.

The quantitative data was complemented by qualitative participants observations and interviews. Gameplay Observations were made during the data collection sessions, and the interviews were conducted at the end of the session, with the aim to determine if there were any recurrent issues players have run into, as well as to collect feedback on the experience and its effect on their understanding regarding scheduling algorithms.

4. Design and Development of Sortica

A Game Design Document (GDD) was created as an initial design step providing a full documentation of the design choices made during the initial design stage. In conjunction with the Beveridge and Gilardi (2025) guidelines, the GDD also served as a framework to guide the initial creative process and tie down storytelling, character design, mechanics, and difficulty progression, with needs related to accessibility, presence, immersion, and reduced cognitive load.

In the iSG, the player is a robotic worker that has to rebuild “Sorting Street”, to achieve this, in each level the player has to reorder items from an incoming queue into an outgoing queue, simulating scheduling algorithms: FIFO and LIFO.

Design artifacts were developed iteratively, including 360 wireframes (Figure 1) detailing the scenarios, and sketches of characters and primary elements that drive the gameplay mechanics. The initial design had three scenes: the headquarters, where the user could replay previous levels or go to the next scene: “Sorting Street”, where each building is a level, showing the state of completion (if the level has not been completed yet, the building remains demolished), each level was an additional scene. However, these scenes were revised based on user feedback during the testing stages, consolidating them into a single scene.



Figure 1: 360 wireframe drawings of the initial design of the game showing menus and interaction areas

An NPC character was designed, consisting of the player “supervisor”, which had the role to guide the player throughout the experience, fulfilling the main functions of storytelling and onboarding. In early iterations the gameplay mechanics in each level was based on incoming and outgoing queues, an auxiliary desk that allowed the player to place and reorder items before putting them into the outgoing queue, and the “Sorting Panel”, which allowed the player to visualize and alter the order of the items already fed into the outgoing queue.

A ShapesXR low-fidelity functional prototype (Figure 2 left) was built and tested with users to ensure diegetic UI elements were appropriately positioned, reachable and accessible. These testing sessions produced actionable feedback about design, mechanics and playability. The feedback ensured that game mechanics that felt complex and redundant were removed. For instance, in initial designs if a player fed the wrong item to the outgoing queue, the only feedback they would get was the item turning red in the “Sorting Panel”, which prevented players from recognizing mistakes. Additionally, items disappeared after being fed into the outgoing queue, leaving players confused about how to fix mistakes, as they could not go back and try again. Breaks in flow and presence were also discovered at this stage, to play the whole game, players would be transported to 4 different locations, and onboarding felt insufficient and superficial.

The game was entirely redesigned (Figure 2 right) by applying tester feedback and Beveridge and Gilardi’s (2025, 2025a) guidelines, creating a continuous experience within a single scenario. The queueing and “Sorting Panel” mechanics were replaced by a simpler system featuring “Matter Generator”, where items spawned, and a “Contention Unit”, where items were fed into. Unlike the original mechanic, this system only accepted correct items, while providing negative feedback otherwise. This approach provided instant feedback and permitted unpenalized repetition. The phases of the reconstruction process were progressively visualized after each correct item, via a smaller model of the building that’s hovering on top of the “Contention Unit”. Once a building was completed, the player was encouraged to grab it, allowing them to take a closer look at it, before the model was resized and placed in “Sorting Street”.



Figure 2: (left) ShapesXR low fidelity prototype showing prototype of the supervisor. (Right) Final Game

The iSG was implemented using Unity, including animations, the supervisor’s dialogues, a desert background for the scene, where “Sorting Street” is located, a progress indicator, and a lightbulb feedback system (green for success, red for mistakes). This implementation was tested, enabling to identify some issues regarding accessibility, the resulting improvements included changing the workbench to a half sector and tilting it slightly to allow objects to be within the players reach and for players to play statically, which is important if the players were playing seated or in a lying down position.

5. Initial Evaluation

Of the 23 valid participants 30% were female and 70% male, all were of an age between 18 and 25 years old. All participants had self-reported intermediate (39%) to expert (61%) experience with video games. Regarding VR experience 66% of participants reported having used VR a few times, 17% regularly, and 17% never used VR before. In relation to existing knowledge about scheduling algorithms 91% reported no pre-existing knowledge, while 9% reported having knowledge of them.

Post-experience, students were asked to what extent the iSG helped their understanding of the subject and how engaging the iSG experience was for them. Overall, the students thought the VR game helped them understand LIFO and FIFO concepts (Mean= 5.83, Median = 6). In terms of engagement students were positively engaged, (Mean= 5.48, Median = 5).

5.1 Pre-test Post-test Results

Pre-tests and post-tests tested whether students had previous understanding of scheduling algorithms and whether the intervention made any difference using the following four multiple choice questions.

1. Which of the following real-world scenarios is the best example of a Queue (FIFO)? a) A stack of plates in a cafeteria; b) A line of people waiting for a bus; c) The "Undo" function in a text editor; d) A deck of playing cards
2. Which of the following real-world scenarios is the best example of a Stack (LIFO)? a) A stack of plates in a cafeteria; b) A line of people waiting for a bus; c) A printer queue; d) A playlist set to shuffle
3. A Queue has the following items added in this order: A, B, C, using the FIFO algorithm. If two items are then removed, what item is now kept in the Queue? a) A b) B c) C d) The Queue is empty
4. A Stack has the following items added in this order: X, Y, Z. If two items are then removed, what is the only item left in the Stack? a) X b) Y c) Z d) The Stack is empty

The pre-test established a high baseline with success rates ranging from 56.52% to 78.26%, suggesting the instrument relied on general intuition. Despite this methodological limitation, the post-test results indicated a significant (Wilcoxon signed rank test with continuity correction: $W=42.5$, $p=0.019$, rank biserial = 0.89, 95% CI:[0.73, 0.96]) average score improvement of 14.13%, with only a single participant scoring lower than their initial baseline. (Figure 3).

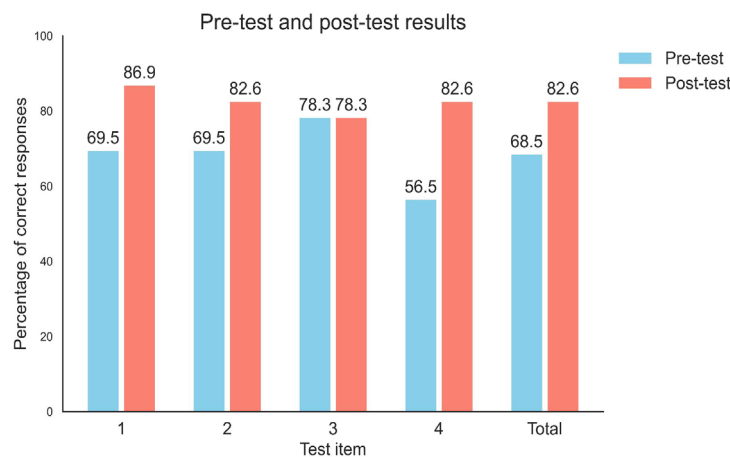


Figure 3: Bar plots showing number of correct answers on both the pre-test and the post-test

Previous experience with video games and VR technologies, as well as base knowledge of scheduling algorithms shows a weak correlation value to the difference in test scores. The students' rating on engagement and perceived learning correlated positively to an improvement in test scores (Figure 4).

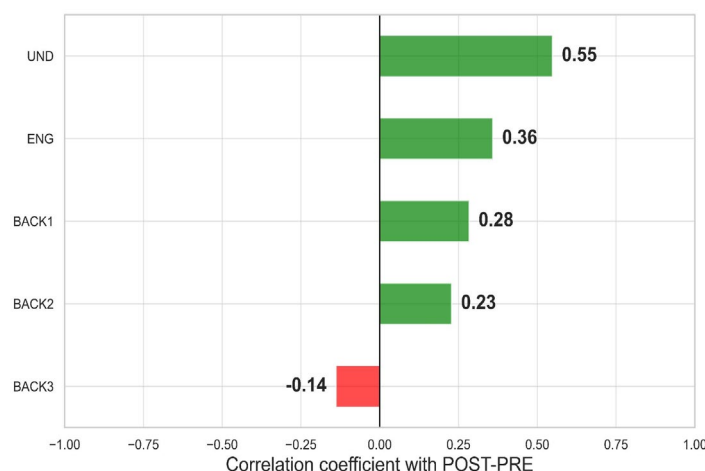


Figure 4: Correlation between video games experience (BACK1) VR experience (BACK2), base knowledge of scheduling algorithms (BACK4), engagement (ENG), and perceived learning (UND) with pre- post-test improvement in test scores

However, the p-values show that only the perceived learning results have a significant correlation to improvements in test scores (Table 1).

Table 1: p-values for correlations between video games experience (BACK1) VR experience (BACK2), base knowledge of scheduling algorithms (BACK4), engagement (ENG), and perceived learning (UND) survey items and improvement in test scores

	UND	ENG	BACK1	BACK2	BACK3
p-value	0.0068	0.0931	0.1899	0.2955	0.5291
Pearson r	0.55	0.36	0.28	0.23	0.14

5.2 Cognitive Load Results

As figure 5 shows, perceived accomplishment scored highest (Median = 5), indicating participants felt they performed the task successfully. In contrast, temporal demand was rated lowest (Median = 1), suggesting minimal time pressure. Temporal demand and frustration responses showed low variability, as the interquartile range is quite compressed near the lower end of the scale. On the contrary, perceived accomplishment and mental demand show wider box-plots, indicating a greater variance in how different participants perceived the difficulty and their own performance.

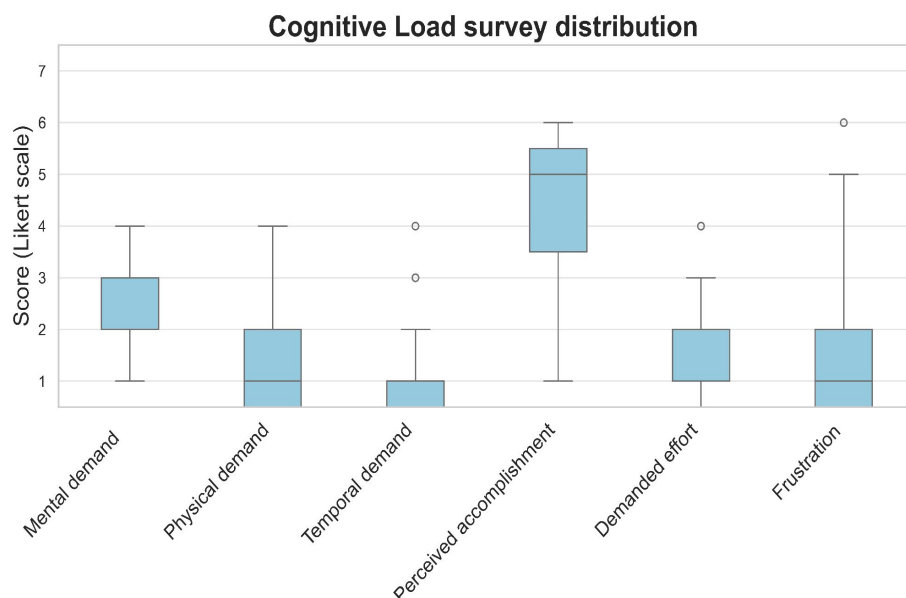


Figure 5: Box-plots of responses in the cognitive load survey

5.3 Data Analytics Results

Although there is no significant correlation between game metrics (see Table 2 and Figure 6) and improvement in test scores, the data analytics results provided insight on how players played the game. While the NPC was interacted with on average 12 times across the two levels of the iSG, the majority of players interacted with it between 15 and 22 times. Students committed an average of 2 mistakes; this could imply that students were hesitant on using the reset lever after getting at least one Matter Ball into the Contention Unit. On the other hand the minimum number of pick ups needed to complete the game was on average 17, but the distribution was skewed towards higher values, this showed that students actually engaged with the core mechanic, reordered the Matter Balls. Only two students used the reset lever after already successfully introducing some Matter Balls into the Contention Unit, suggesting that the reset lever has served as a useful tool for preventing students from just trying random combinations until they complete the level.

Table 2: p-values for correlations between game metrics and improvement in test scores

	n_npc	n_mistakes	n_pickUp	n_reset	play_time	n_correct
p-value	0.2978	0.9065	0.3874	0.2702	0.2409	0.0822
Pearson r	0.22	-0.03	-0.19	-0.24	-0.25	-0.37

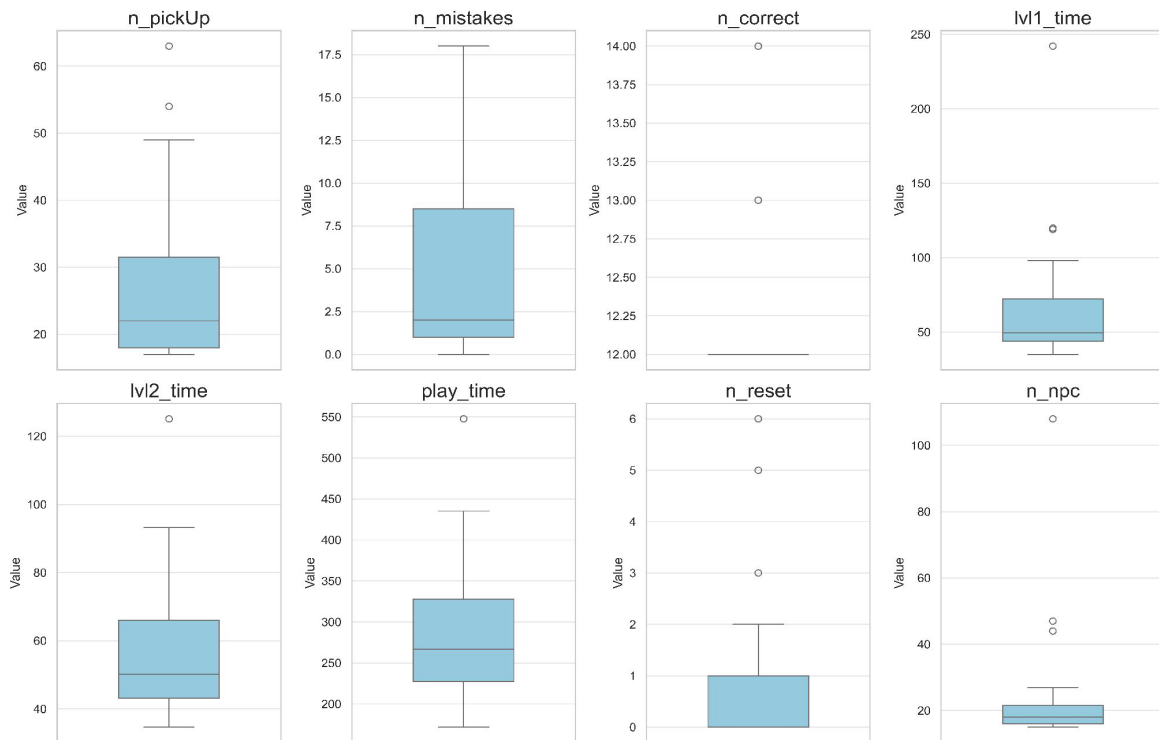


Figure 6: Data analytics box-plots

5.4 Qualitative Results

Observation data from sixteen participants highlighted several usability strengths and friction points. Participants effectively utilised instructional scaffolding, frequently re-triggering the supervisor character for task clarity. The task reset lever was effective, enabling participants to consolidate learning by restarting tasks upon realising errors.

However, friction occurred due to unintended affordances; while visual indicators like the progress gauge and colour-coded lights successfully signalled task status, their appearance led some participants to attempt non-existent interactions. Additionally, initial onboarding was unintuitive, as participants struggled to identify the interaction trigger to start the iSG. Finally, delayed offboarding animations following the interaction to enter the game's end-state created brief periods of uncertainty regarding the game session's conclusion.

Verbal feedback from final interviews indicated that all participants found the experience beneficial, reporting a basic understanding of the core concepts. While participants generally enjoyed the experience, they noted that the game's aesthetic was unpolished, which occasionally distracted them from primary objectives. Furthermore, technical friction during onboarding hindered students' ability to internalize instructions. While the lever mechanism was highly valued, as one participant noted, *"Having the lever allowed me not to worry about making any mistakes and actually focus on the game"*, many participants failed to realize that the supervisor could be utilized for assistance.

6. Discussion and Conclusion

The design and development of "Sortica" highlights the role of human-centered design when teaching fundamentally abstract concepts. Traditional pedagogies often make scheduling algorithms challenging for students to grasp (Jbara, 2017). "Sortica" addresses this by enabling "sensemaking" through mental model externalization (Brown, Mulder, & Mulder, 2026) and embodiment (Lehrman, 2025; Suo et al., 2026). By physically grasping, stacking, and reordering sequences in 3D space, learners cognitively map abstract algorithmic logic directly onto their physical movements.

While preliminary quantitative data showed a mean score improvement of 14.13%, from 68.5% to 82.6%, across the cohort, the pre-test ceiling effect limits the inferential power of this finding. This metric suggests that spatial embodiment supports learning scheduling algorithms in introductory computer science modules.

"Sortica" maps scheduling rules onto the virtual world's physical constraints, making learning an integrated experience. Utilizing a fantasy context (Bai and Hew, 2025), the "Contention Unit" blocks progression unless players execute the correct scheduling protocols, seamlessly embedding learning into gameplay. This integrated architecture yielded mean scores of 5.48 out of 7 for engagement and 5.83 for perceived learning. Observations confirmed players proactively used environmental scaffolds to retrace errors. Because educational parameters are baked into the physics of the environment (van der Linden, Meulenbroeks, and van Joolingen, 2024), immediate physical reactions establish formative boundaries that translate a high perceived sense of success (Mean = 5.35) into verified algorithmic competence.

"Sortica" supports this integration with a diegetic approach, replacing abstract menus with in-world feedback (e.g., color-shifting lightbulbs). This minimized "interaction costs" (Bellino and Vilches, 2025), which was reflected by low self-reported physical demand (Mean = 2.22) and temporal pressure (Mean = 2.00). However, a tension exists regarding users' internal states: mental demand (Mean = 3.39) and overall effort (Mean = 2.78) remained moderately high, accompanied by notable emotional frustration (Variance = 2.76). This friction explains why a 4.35% subset of users experienced a post-test performance decline.

Finally, "Sortica" serves as an empirical case study for the Immersive Serious Games (ISG) design guidelines proposed by Beveridge and Gilardi (2025, 2025a). Mapping scheduling mechanics directly to a street-rebuilding narrative established clear goals that fostered flow and engagement. The game successfully applied Beveridge and Gilardi (2025a) guidelines to "Allow users to undo and correct mistakes within the experience" via an unpenalized reset lever and ensured "Feedback should be accurate, fast, and clear" through the immediate visual transformation of correct items. However, while Beveridge and Gilardi (2025a) guidelines "Design a minimalistic UI" and "The UI should be clear" were achieved through a diegetic interface, this minimalism inadvertently created false interaction cues. Observations revealed that unintended physical affordances—such as users trying to interact with passive visual gauges—caused brief cognitive disorientation. This demonstrates that visual ambiguity in high-presence environments can escalate mental demand and degrade performance (Ahmed et al., 2025), which indicates that diegetic minimalism without strict interaction boundaries may confuse users, suggesting future guideline iterations must define more stringently the visual grammar of diegetic elements to prevent unintended affordances from escalating cognitive load.

This work is, however, limited by the small sample size and by the participants pool being from a single University, as well the lack of a control group, these factors limit the capabilities of our statistical analysis, and make it hard to determine the generalisability of the learning methodology. Future work should be undertaken in integrating the iSG within a module that teaches scheduling algorithms, conducting a longitudinal study on whether the use of the iSG improves retention of the concepts learned.

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AI Declaration: AI was used to proofread the paper.

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