HCI Report: "A Comparative Study of 2D Simulations and Videos for Educational Outcomes"

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Abstract

This study compares 2D simulations and video-based instruction in learning and engagement across computational, biological, and physical sciences. Using test scores, the User Engagement Scale (UES), and NASA Task Load Index (NASA-TLX), results reveal simulations enhance comprehension, especially for abstract subjects, while videos excel in visualizing concepts. Effectiveness varies by topic, emphasizing 2D simulations as a practical, interactive educational tool.

1. Introduction

Videos are widely used for learning, offering accessible, visually engaging content but often promoting passive engagement. Interactive simulations, in contrast, enable experiential learning through direct interaction but are typically tied to resource-intensive VR/AR technologies, limiting accessibility.

This study explores whether simple, accessible 2D simulations can rival or surpass video-based instruction in learning outcomes and engagement. By examining topics like the K-means algorithm, biological processes, and physics principles, it aims to highlight the strengths and limitations of these approaches.

2. Related Work

AR and VR technologies enhance engagement and understanding in physics, as shown by Hyder et al. [1] with an AR particle simulator and Tsivitanidou et al. [6] with VR simulations. However, these methods often face usability and accessibility challenges. Similarly, Ihekoronye [2] highlighted the benefits of simulation-based flipped classrooms for abstract physics topics, though they require structured environments and preparation.

This research shifts focus to accessible 2D simulations in Unity and Python across algorithms, biology, and physics. Using the User Engagement Scale (UES) and NASA Task Load Index (NASA-TLX), it evaluates whether simpler tools can achieve comparable learning and engagement outcomes in everyday educational contexts.

3. Methodology

3.1. Interactive simulation

We developed an interactive 2D simulation in Unity to teach the K-means algorithm, prioritizing simplicity over the added complexity of 3D or VR environments. The simulation included text-based instructions and guided exercises to present key concepts in a structured, interactive format.

Two additional 2D simulations, built with Python visual libraries, covered biology and physics. The biology simulation demonstrated ATP-driven particle movement across membranes, illustrating diffusion, active transport, and ATP's role. The physics simulation involved calculating collision positions based on initial distance and velocities, offering visual, hands-on learning for complex topics.

3.2. Videos

Participants were provided with curated instructional videos from YouTube, chosen for their clarity, relevance, and effectiveness. Instead of creating new videos, we leveraged high-quality existing content to reflect realistic, independent learning practices. This approach ensures a practical comparison, as YouTube is a common resource for students. References to the selected videos are included to acknowledge their contribution. [4][5][3]

3.3. Participants and Experimental Setup

The study involved 10 university students, all with a computer science background but no prior knowledge of the K-means algorithm, biology, or physics topics. Participants were divided into two groups of five and alternated between video-based instruction and interactive simulation over two sessions.

The experiment combined online (video calls) and offline setups. Simulations were accessed via computer, while videos were viewed on smartphones or computers, reflecting common student practices. In session one, participants engaged with either the video or simulation for the K-means algorithm; in session two, they switched modalities for biology and physics topics.

After each session, participants completed questionnaires assessing comprehension, engagement (via the User Engagement Scale), and mental workload (via the NASA Task Load Index). Specific questions used are detailed in the results section.

4. Results

4.1. Objective Measure: Topic comprehension

Participants' understanding was assessed through tests after each session. Results in Table 1 show higher scores for simulation-based learning compared to videos.

For the K-means algorithm, the simulation group averaged 77

4.2. Engagement (UES)

To evaluate engagement, we selected specific questions from the User Engagement Scale (UES) that were most relevant to comparing simulations with videos. The full UES was

Scenario	Average	Standard Deviation (std)
K-means with Simulation	77%	8%
K-means with Video	57%	23%
Physics/Biology with Simulation	93%	13%
Physics/Biology with Video	83%	18%

Table 1: Performance results for different scenarios based on the objective measure (test scores).

not used, as many questions were not applicable in the context of this study, which focused on comparing the effectiveness of different teaching modalities. Instead, we selected one question from each UES category to capture key dimensions of engagement:

- Focused Attention: "I was absorbed in this experience."
- Perceived Usability: "This experience was demanding."
- Aesthetic Appeal: "This learning experience was attractive."
- Reward Factor: "The content of the learning incited my curiosity."
- Perceived Usability: "Using this learning method is a frustrating experience."

The results, presented in Table 2, are summarized below for the two learning topics.

For the K-means algorithm, participants rated the simulation higher than the video in terms of absorption (3.4 vs. 3.0), aesthetic appeal (4.0 vs. 2.8), and curiosity (4.2 vs. 3.0). The simulation was also perceived as less frustrating (1.4 vs. 3.2). However, both methods were rated similarly in terms of demandingness (3.4 vs. 3.2).

For the Physics/Biology topics, participants rated the video higher than the simulation in terms of absorption (3.0 vs. 2.6) and aesthetic appeal (3.0 vs. 2.4). Curiosity ratings were similar for both methods (3.0 vs. 2.8). The simulation was perceived as slightly less demanding (2.0 vs. 2.2) but more frustrating (3.4 vs. 2.8).

Scenario	Absorbed	Demanding	Attractive	Curiosity
K-means with Simulation	3.4 (0.80)	3.4 (0.80)	4.0 (0.00)	4.2 (0.40)
K-means with Video	3.0 (1.10)	3.2 (0.75)	2.8 (1.17)	3.0 (0.89)
Physics/Biology with Simulation	2.6 (0.80)	2.0 (0.89)	2.4 (0.80)	2.8 (1.47)
Physics/Biology with Video	3.0 (0.89)	2.2 (0.75)	3.0 (0.89)	3.0 (0.63)

Table 2: Engagement scores for different scenarios based on the User Engagement Scale (UES), where responses range from 1 (strongly disagree) to 5 (strongly agree). Values represent averages, with standard deviations in parentheses.

4.3. NASA-TLX Respones

To assess mental workload and perceived task success, two NASA-TLX questions were used: mental demand ("How mentally demanding was the task?") and performance ("How successful were you in accomplishing what you were asked to do?"), rated on a 1–20 scale.

For the K-means algorithm, mental demand was similar for both methods, with simulations slightly higher (12.2 ± 1.33 vs. 11.4 ± 4.18). Participants rated their success higher with simulations (14.0 ± 2.37) than videos (10.6 ± 6.05).

For Physics/Biology, simulations were rated as less mentally demanding (5.0 ± 2.76 vs. 7.2 ± 2.14). Success ratings were similar, with videos slightly higher (14.8 ± 3.49 vs. 13.6 ± 3.67).

Scenario	**Mental Demand (1-20)**	**Success (1-20)**
K-means with Simulation	12.2 (1.33)	14.0 (2.37)
K-means with Video	11.4 (4.18)	10.6 (6.05)
Physics/Biology with Simulation	5.0 (2.76)	13.6 (3.67)
Physics/Biology with Video	7.2 (2.14)	14.8 (3.49)

Table 3: Mental demand and success scores for the different scenarios based on NASA TLX responses, where responses range from 1 (very low/failure) to 20 (very high/success). Values represent averages, with standard deviations in parentheses.

5. Discussion

5.1. Interpretation of Learning Outcomes

The objective test scores provide a clear indication that, overall, simulations can be more effective than videos for promoting comprehension, particularly for more abstract or process-driven topics. In the case of K-means, participants scored substantially higher and showed more consistent performance (lower standard deviation) when learning through simulations, suggesting that interactive elements may facilitate a deeper or more uniform understanding of algorithmic concepts. This benefit of simulations could be attributed to the immediate feedback participants receive when they adjust parameters and observe clustering behavior in real time.

In contrast, while there was still a favorable trend toward simulations for the Physics/Biology topics, the difference in average scores was less pronounced, and in some cases the standard deviation for simulations was larger. One explanation might be that certain Physics/Biology concepts can be conveyed effectively through visual demonstrations provided by videos—especially if those videos offer high-quality animations or clear step-by-step explanations. In other words, there may be aspects of these topics that do not require the same level of interactivity to grasp the core principles. However, the overall advantage for simulations in these topics (93% vs. 83%) still supports the notion that hands-on, experiential learning can be powerful in reinforcing understanding.

5.2. Engagement and User experience

The engagement results (UES) reveal a nuanced picture. For K-means, participants found the simulation to be significantly more absorbing and aesthetically appealing, and it triggered higher curiosity. Moreover, the simulation was perceived as less frustrating, suggesting that hands-on manipulation of algorithm parameters and immediate visual feedback can mitigate confusion and maintain user interest.

However, for the Physics/Biology topics, the video method fared better in terms of immersion (absorption) and perceived aesthetics. One reason may lie in the nature of the content: visually compelling experiments or phenomena can be well-demonstrated in a video, leading to a higher level of aesthetic enjoyment and immersion. Meanwhile, the simulation in these areas, while interactive, might not have been as visually engaging or intuitive in illustrating real-world processes. Interestingly, simulation for Physics/Biology was rated as slightly less demanding, yet participants simultaneously reported higher frustration. This finding could point to shortcomings in the specific simulation design (e.g., unclear instructions or interfaces), leading to an experience that feels both easier (less cognitively taxing) but more aggravating (poorly guided interactions or usability issues).

5.3. Potential Explanations and Limitations

One reason for the mixed engagement and workload results may be the diversity of content domains. K-means, being abstract and algorithmic, benefits from interactive manipulation, while Physics/Biology topics often rely on intuitive visualizations that videos can effectively convey. The quality of the materials also played a role; well-crafted videos with clear visuals and narration might surpass less engaging or poorly designed simulations.

Limitations include the small sample size and the specific tasks chosen. Different subtopics or learning preferences (e.g., kinesthetic, auditory, visual) might yield varying results. Additionally, using only selected items from UES and NASA-TLX may have missed certain dimensions of engagement or workload.

5.4. Implications for Design and Future Work

From an instructional design perspective, these findings highlight that interactivity and immediate feedback can significantly enhance learning outcomes, especially for algorithmic or abstract content areas such as K-means. However, educators should also recognize that some topics—particularly those that benefit from realistic demonstrations—may be equally well served or even better served by high-quality videos. Designers of educational simulations should pay close attention to usability, clarity, and aesthetic appeal to avoid frustration and fully leverage the potential of interactive learning.

Future research might systematically explore which specific features (e.g., visual fidelity, interactivity level, instructional scaffolding) influence engagement, learning outcomes, and workload across different content domains. Expanding the study to larger and more diverse populations, as well as employing the full UES and NASA-TLX instruments, could yield deeper insights into how best to integrate simulations and videos in educational contexts.

6. Conclusion

This study highlights the potential of 2D simulations as an accessible and effective alternative to video-based instruction, with our findings showing better test results for animations, particularly for abstract and process-driven topics like the K-means algorithm. While videos demonstrated strengths in visually engaging content, especially for Physics and Biology, the effectiveness of each modality depended on the topic and the design of the simulation. Simulations provided a deeper level of interactivity and engagement, enabling learners to explore and manipulate concepts directly.

References

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