



## Extended Abstract—Log Data as a Window into Learning: Embodied Interactions in a Virtual Reality Simulation

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**Abstract.** While there has been a steadily growing corpus of literature to support the critical role the body plays in the learning process, recent advances in immersive technologies have allowed learning scientists to take command of the embodied dimensions of learning in ways not previously possible. In addition, the ways that embodied interaction and embodied learning are measured and analyzed have also changed significantly with the rise of extended reality technologies such as virtual and augmented reality. This study investigates how movement log data collected from a biology virtual reality (VR) simulation, *ChromosoME*, can provide insights into students' learning processes. The simulation, designed to teach high school students the stages of cell division, tracks students' interactions with virtual objects and analyzes their movement patterns. A key research focus is the relationship between students' physical engagement, measured through controller movement and interactions with specific objects, and their learning outcomes. Our results show that increased movement efficiency correlates with improved understanding of cell division concepts, while an overemphasis on correct object interactions may detract from deeper learning. These findings highlight the importance of balanced interaction design in VR learning environments and offer a novel approach to using log data for educational research.

**Keywords:** Virtual Reality Simulation, Interaction Log Data Analysis, Science Learning, Embodied Learning.

### 1 Introduction

While the critical role of the body in the processes of learning and cognition a growing foundation of literature ranging from the biological [1-4] to classroom application [5-7], the act of designing to explicitly leverage embodied theories of learning is still a developing area of the learning sciences, with new theoretical frameworks, design guidance, and implementation studies [8-10].

The advent of immersive technologies has opened new avenues for the study of embodied learning, allowing for the design of environments that facilitate embodied input and representations. These technologies enable educators to curate sensory experiences in ways that were previously unattainable, thereby allowing for a detailed examination of embodied interactions during learning processes [11,12]. For instance, research has shown that engaging with immersive virtual reality (VR) can enhance learning outcomes by providing students with opportunities to physically interact with educational content, which aligns with the principles of embodied cognition [13]. This capability to engage learners in embodied ways has been shown to foster deeper understanding and retention of complex concepts, particularly in STEM education [14-15].

Recent frameworks, such as the learning in embodied activity framework (LEAF), have sought to structure the design and analysis of embodied learning experiences, particularly in technology-facilitated environments. These frameworks not only focus on learners directly interacting with technology but also consider the roles of observers and the broader communication of experiences among learners [16-17]. For example, studies have demonstrated that embodied simulations can significantly improve learning transfer and conceptual understanding in science education, highlighting the effectiveness of high-embodied versus low-embodied instructional strategies [10,18].

Moreover, the integration of multimodal teaching strategies in VR environments has been identified as a promising approach to enhance engagement and learning outcomes [11,12].

With these highly immersive and engaging environments come complex forms of learner interaction. As a consequence of this, analysis of learning and embodied interaction in immersive environments must take on a multi-modal, data-rich role [19-21]. Customized digital platforms allow for the collection of highly curated environment and learner log data, enabling new avenues for analysis that increase the fidelity with which embodied learning can be examined. As one example of this, the following manuscript explores the design and implementation of an embodied biology learning simulation: *ChromosoME*. *ChromosoME* integrates a custom-built learning environment, embodied inputs, detailed user interaction log tracking, and standards-aligned learning content to explore the following research question: *How can log data of learner interactions with VR simulations provide meaningful insights into students' learning processes?*

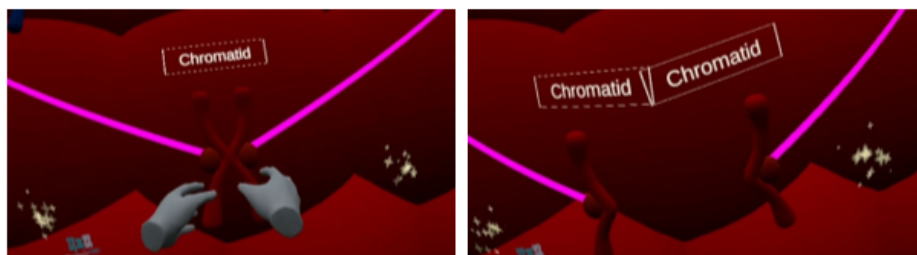
## 2 Methods

### 2.1 VR Simulation Development

*ChromosoME*, developed using the Oculus Quest 1 device, is designed to help students learn about the cell division process at a first-year high school level through interactions with virtual objects. In collaboration with local high school teachers, we crafted the learning objectives students are expected to achieve, the design of the 3D objects they will interact with, the modes of interaction, and the feedback provided within the system. During the development process, we visited classrooms twice to gather feedback from students on the prototype. Through this design and development process, we structured the simulation so that students could interact with the content as outlined in Table 1.

**Table 1.** List of Activities in the Developed VR Simulation.

Phase	Mission & Interaction
Interphase	Supply nutrients such as Vitamin C, magnesium, and protein to the mitochondria to generate the energy required for cell division.
Prophase	Once the energy has been gathered, condense the DNA into chromosome form.
Metaphase	Align the condensed chromosomes in a straight line with other chromosomes at the center of the cell.
Anaphase	Position the separated chromatids at opposite poles of the cell. (See Fig 1)
Telophase	Divide the mother cell into two identical daughter cells.



**Fig. 1.** (Left) Grab and detach the chromatids with both hands. (Right) Spread the arms and place chromatids at each node.

We also ensured that these interaction processes could be extracted as log data, and this study focuses on how students' movements and interactions can provide insights into their learning outcomes. To support this, we developed the system to generate log data, as shown in Table 2.

**Table 2.** List of Collected Log Data Types.

Type	Format	Sample Values
Left controller position	(Float coordinates) x, y, z	(12.34, 5.24, 0.22)
Right controller position	(Float coordinates) x, y, z	(19.22, 9.72, 7.19)
Left-hand touch	(String) Object names	Protein_LeftTouch
Right-hand touch	(String) Object names	Mitochondrion_RightTouch

Left-hand grab button pressed	(Bool) True or false	0, 1
Right-hand grab button pressed	(Bool) True or false	0, 1

We intentionally designed the simulation so that students would repeat the cell division process three times. This design allowed us to track changes in students' gestures and interactions as they engaged with the same learning content over multiple iterations. Moreover, since not all students are familiar with VR devices, this repetition gave them time to become more comfortable with interacting within the VR environment. Furthermore, since cell division is a continuous process in our bodies, this repetition was also intended to emphasize to students that cell division is not a one-time event.

## 2.2 Research Design

A total of 20 first-year high school students from a local Midwestern high school participated in this study, with 11 female and 9 male students. These students were recruited just before learning about cell division in school, meaning they participated without prior knowledge of the topic, which we intended for them to learn through the simulation. However, introducing both new technology and new learning content simultaneously could result in cognitive overload. To mitigate this, we provided a minimal learning opportunity on cell division to ease the potential cognitive burden. Therefore, before engaging with the VR simulation, they were given a brief self-study period using paper materials to familiarize themselves with the content they would encounter in the simulation. This self-study allowed students to become familiar with the basic concepts of cell division before interacting with the VR simulation.

In addition, in collaboration with a local high school teacher, we developed a coding scheme to assess students' post-simulation learning outcomes by evaluating how well they could explain the cell division process. This coding scheme, shown in Table 3, was designed based on the missions and interactions required of students during the simulation. Using the coding scheme, we asked the students to explain the cell division process after completing the VR simulation, transcribed their explanations, and scored them accordingly.

**Table 3.** Coding Scheme for the Five Key Elements.

Phase	Element #	Description	Example
Interphase	1	Mitochondria utilize nutrients to produce energy for cell division.	"It seems like the mitochondria are responsible for energy production at this stage."
Prophase	2	DNA forms a condensed structure in the shape of chromosomes.	"Next, the DNA starts to condense into the chromosome shape."
Metaphase	3	Chromosomes align at the metaphase plate in the center of the cell.	"The chromosomes all line up in the middle."
Anaphase	4	Chromatids are pulled toward opposite poles of the cell.	"The chromosomes are being pulled apart to opposite sides."
Telophase	5	The cell splits into two identical daughter cells.	"After that, the cell divides into two identical daughter cells."

## 3 Results

### 3.1 Association Between Increased Controller Movement Rate and Learning Outcomes in the VR Simulations

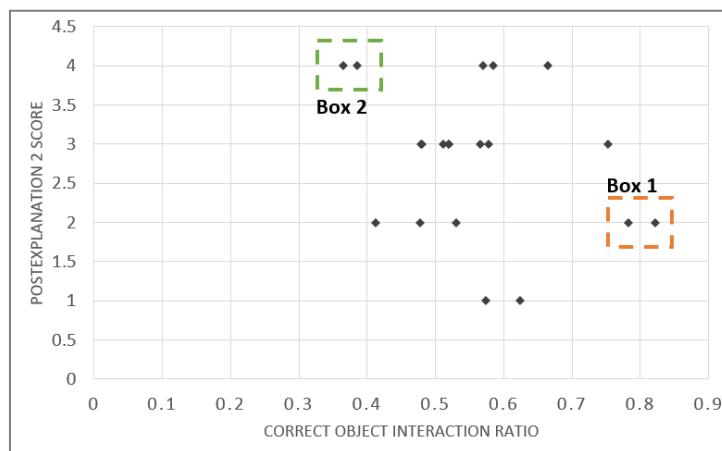
In this analysis, we investigated the association between students' controller movements and their learning outcomes by comparing the rate of controller movement per second during the first and third iterations of the cell division simulation. Analyzing the movement rate per second, rather than the total amount of movement, allowed for a more consistent comparison between students. This method ensured that the analysis accounted for the efficiency of movements within a given time frame, rather than simply the quantity of movement. By focusing on how much a student moved per second, we avoided mistakenly categorizing students who completed necessary gestures quickly and efficiently as less active. This approach normalized the data by considering the time factor, ensuring that all students' actions were evaluated on an equal basis.

For instance, during a student's initial playthrough of the cell division simulation, the total change in the x, y, and z-axis movements of both controllers was 88.17, and the total playtime was 149.72 seconds. Consequently, we calculated his movement rate during the first round of simulation play at 1.69 per second. In contrast, during the third round, he moved the controllers a total of 28.29, with an overall playtime of 56.43 seconds, resulting in a movement rate of 1.99 per second. Therefore, we determined the difference in movement rate per second between the third and first rounds to be 0.29.

Additionally, because there were no objects for students to interact with during the final stage of cell division, telophase, we excluded data related to telophase. Consequently, in the students' post-explanation, we removed elements related to telophase, making the highest possible score four points. After calculating the movement rate per second difference for all students, we observed a positive correlation of 0.35 with the scores from post-explanation. This indicates that students who increased their movement rate per second during the third round of simulation play, compared to the first round, were more likely to achieve higher learning outcomes.

### 3.2 Correlation Between Time Spent Interacting with Correct Objects and Learning Outcomes in VR Simulations

Our subsequent analysis focused on the duration and frequency of students' interactions with various objects in the VR simulation. Specifically, we examined the extent to which students interacted with the correct objects during each phase of cell division and the percentage of total interaction time this represented. Total playtime was broken down into periods spent interacting with correct objects, incorrect objects, and no objects at all. We calculated the proportion of time spent interacting with the correct objects for each student, analyzing only the data from the third iteration of the cell division process to ensure that the results reflected adequate learning. We excluded telophase data due to the absence of interactive objects during this phase. Accordingly, elements related to telophase were also omitted from the students' post-explanation, setting the maximum possible score at four points. Our analysis of the proportion of time all students spent interacting with the correct objects against their scores in post-explanation revealed a negative correlation of -0.27. This suggests that spending a higher proportion of time interacting with the correct objects might correspond to lower learning achievements.

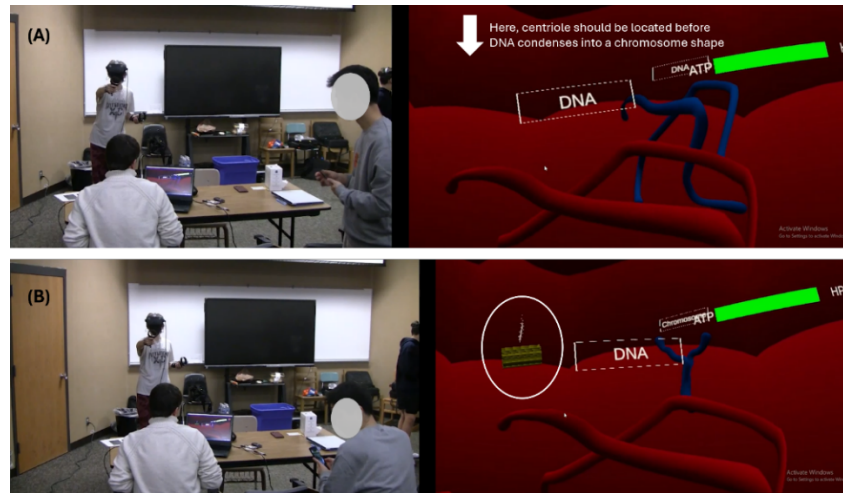


**Fig. 2.** Proportion of Time Spent Interacting With Correct Objects vs. Post-explanation Scores.

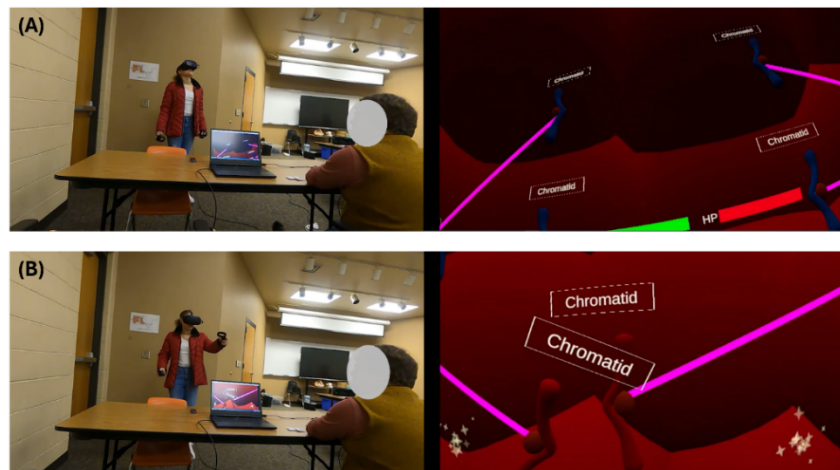
This outcome prompted further investigation into individual student data to discern why there was an observed negative correlation between the rate of interaction with correct objects and learning outcomes. Fig. 2 presents the time spent by the 20 students interacting with the correct objects during the third round of simulation play, juxtaposed with their scores in post-explanation. The data indicate that most students (15 out of 20) interacted with the correct objects for 40% to 70% of their total playtime. However, the two students outlined in dotted box 1 (orange colored), who interacted with the correct objects for nearly 80% of their time, scored only 2 out of 4 points. In contrast, the two students in dotted box 2 (green colored), who spent less than 40% of their playtime interacting with the correct objects, achieved full marks in post-explanation. Given the small sample size of 20 students, the data from these four students could have significantly impacted the negative correlation. We conducted a more detailed investigation through video analysis to better understand these patterns.

The video analysis revealed that the two students highlighted in the orange dotted box aimed to complete the simulation as rapidly as possible. They appeared to fully understand which objects were required for each phase and focused on swiftly progressing to the next phase after each interaction. For instance, one student knew to

duplicate the centriole and condense the DNA but tried to condense the DNA before the centriole had finished moving to the cell's ends. Consequently, this student missed the animation of the centriole moving and remained fixated on the DNA (see Fig. 3). Both students in the orange dotted box maintained this approach throughout the third round, completing it in 48.54 and 65.86 seconds, respectively. One student experienced a slight delay in metaphase due to incorrect chromosome placement but failed to observe the movements of other objects.



**Fig. 3.** One of the Box 2 Students (A) Attempting to Interact With the Next Object (B) Without Waiting for Other Objects to Be Ready After Interacting With the Correct Object.



**Fig. 4.** One of the Box 1 Students (A) Observing Overall Events at Each Stage Before (B) Attempting to Interact With the Correct Object and Moving to the Next Phase.

Conversely, the two students highlighted in the green dotted box (Fig. 2) interacted with the simulation objects differently. Like their counterparts, these students demonstrated confidence in selecting the correct objects during the third round, indicating a solid understanding of the required interactions. However, unlike the others, these students paused to observe the movements of other objects after each interaction phase (e.g., aligning chromosomes during metaphase) instead of rushing to the next phase. As illustrated in Fig. 4, one student watched the blue chromatids (automatically moving objects in the simulation) transition from metaphase to anaphase before moving their own chromatids (red chromatids) to the ends of the cell. They occasionally paused to survey the entire cell, assessing the positions of each object. These students proceeded with the next interaction only after other objects in the simulation had stopped moving. This pattern was observed in both students, who spent 75.54 and 72.37 seconds, respectively, on the third round—a bit longer than the students in the orange dotted box. Therefore, with a clear understanding of the objects they needed to interact with, these students also monitored the movements of other objects and undertook a thorough observation of the scientific phenomena unfolding in the simulation.

## 4 Discussion

In this study, we analyzed how log data extracted from VR simulations can offer significant insights into students' learning processes and outcomes. Notably, only one paper [22] presented at the Learning Analytics & Knowledge Conference over the past five years (2019-2023) focused on experimental research in learning analytics within VR environments, concentrating exclusively on eye-tracking. This underscores the substantial need for research into how various interaction log data collected in VR simulations can elucidate aspects of student learning.

Initially, we calculated the average movement speed of students for each iteration of play. The increase in students' average movement speed suggests that they were either more actively engaged or had a clearer understanding of the required actions, thereby enabling them to interact with objects without hesitation. Knowledge of which objects to interact with and how to engage with them typically enhances a student's active participation in the task [23]. Despite this, there remains a research gap concerning how such increased physical activity affects learning outcomes. Therefore, we investigated whether students who moved faster in the third iteration than in the first demonstrated improved learning outcomes. The findings revealed a positive correlation, indicating that students who moved faster on average in their final simulation play compared to their initial attempt generally achieved higher learning outcomes. This suggests that students gained confidence and became more assertive in navigating the simulation as they became more familiar with which objects to interact with and what gestures to perform in each stage. However, caution is needed because faster movement does not necessarily mean students have successfully learned all the required learning objectives. Some students appeared to focus more on completing the simulation as quickly as possible after learning the game mechanics, rather than concentrating on the content itself. For example, after learning that in the interphase, various nutrients must be delivered to the mitochondria, some students in their second simulation play immediately picked up objects resembling nutrients and quickly delivered them to the mitochondria as soon as they saw them. Although these students' average movement speed may have increased with each simulation play, it is uncertain whether they genuinely learned the targeted science concepts.

To better understand whether students learned the science concepts, we introduced an additional layer of log analysis: the correct object interaction ratio. This analysis focused on when and with which objects students interacted. Given the relatively limited number of objects and scenarios available for interaction at each stage, we opted to calculate the percentage of time students spent interacting with the correct objects during the respective phase, rather than employing sequencing data mining techniques. For instance, during the interphase, we measured the ratio of time spent interacting with nutrients, mitochondria, and centrioles relative to the total time spent in the interphase. However, this analysis was based solely on data from the third play to understand patterns after students became accustomed to the simulation. After calculating the time ratio of interaction with the correct objects in the third round of play and correlating this with the scores from post-explanation, a negative correlation emerged, which was unexpected because we anticipated that a higher ratio of interaction with the correct objects would indicate better learning outcomes. Yet, upon analyzing videos of students who interacted with the correct objects at an extremely high rate (around 80%), we found that, although these students knew which objects they needed to interact with at each stage, they paid little attention to what was happening around them, focusing only on performing the correct interactions to proceed to the next stage. Conversely, students who interacted with the correct objects for a relatively lower proportion of the total playtime tended to observe what was happening at each stage of the simulation before interacting with the correct object to proceed to the next stage. Therefore, combining this with the analysis of average movement speed, if students' average movement speed increased, but they also had a very high interaction time ratio with the correct objects, it is likely they were focused more on clearing the game by learning the VR simulation mechanics rather than truly understanding the science concepts.

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