Enhancing Kinematics Understanding Through a Real-Time Graph-Based Motion Video Game

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Abstract. Kinematics is a core topic in early physics courses, yet students often struggle to interpret motion and its graphical representations. To tackle these difficulties, we developed MissionMotion, a physical–computational videogame where students reproduce target motion graphs using real-time data from their own movements or from sensors connected through micro:bit or Arduino. The system displays both the target and the user-generated graph, providing immediate visual feedback and a score based on similarity. We piloted the environment with ninth-grade students in different school contexts and evaluated their experience using the MEEGA+ instrument. The results show strong engagement, positive perceptions of usability, and evidence that the game promotes reflection on motion graphs in ways that rarely emerge in traditional lessons. MissionMotion runs on any web-enabled device and all materials are openly available, offering teachers an accessible tool to integrate experimentation, computational thinking, and playful learning into physics classrooms.

1 A Broader View on Motion Learning in the Classroom

The study of motion and its causes is fundamental to understanding how we interact with the world—from the operation of vehicles and the flight of a ball to human movement and the dynamics of the solar system. This central role is reflected in physics curricula across educational levels. Yet research consistently shows that many students struggle to grasp the fundamental concepts of kinematics even after years of instruction [1, 2, 3, 4]. In an educational landscape that increasingly values interdisciplinarity and meaningful engagement, teachers face the challenge of adopting approaches that promote deeper conceptual understanding while connecting physics to students' everyday experiences.

In this project, we designed and implemented a physical–computational videogame environment supported by a set of activities and open resources. The approach is inspired by large-scale educational technology initiatives such as Uruguay's Plan Ceibal, a nationwide program that provided every primary and secondary student with a laptop and free internet access, coupled with extensive teacher training and a robust national monitoring framework (for additional information see `http://ceibal.edu.uy`). Our system integrates programmable boards, sensors, and robotics kits to teach kinematics while fostering both scientific inquiry and computational thinking skills. Concretely, the main outcome is *MissionMotion*, a cross-platform web application that challenges students to reproduce motion graphs in real time: they control a paper-ball avatar moving along a ruler-like axis while its position or velocity is dynamically plotted next to a target graph. Unlike traditional simulations, the environment incorporates real-world sensor data and invites students to interact using their own body movements, mirroring actions suggested by the program under teacher guidance; depending on available resources, motion can be controlled via mouse, touchscreen, or external devices such as ultrasonic sensors connected through micro:bit or Arduino boards. Accessible through any web browser and compatible with mobile devices, tablets, and computers, the platform allows students to record their progress and share it with instructors.

The project is ongoing, and the first rounds of systematic evaluation indicate very positive outcomes in terms of engagement, usability, and students' reflection on motion graphs. Evidence regarding conceptual learning gains in scientific and computational reasoning is currently being collected through standardized pre- and post-assessments and will be reported in future work. All resources are freely available as open educational materials in the website `http://missionmotion.uy`. In this paper, we expand upon the results presented at the GIREP 2025 Conference (GIREP–EPEC) held in Leiden, The Netherlands. Within this broader project, the present article focuses on the design of *MissionMotion* and on the results of an initial exploratory classroom implementation. The aim of this study is not to evaluate learning gains, but to examine how students and teachers interact with the environment and how they perceive its usability and player experience in authentic educational contexts. By reporting findings from this exploratory phase, we seek to establish a foundation for subsequent stages of systematic evaluation and further refinement of the platform.

2 Theoretical Framework

Motion provides a unifying framework for describing and explaining physical phenomena across a wide range of scales, from everyday human activities to complex technological and natural systems. Concepts such as position, velocity, and acceleration are essential for modeling how objects evolve in time and for establishing the foundations of classical mechanics. For this reason, kinematics plays a structuring role in physics education, particularly in secondary school curricula, where it is introduced as a central component of general physics courses, and later in university-level introductory physics, where it supports the development of more advanced ideas in mechanics and engineering.

Despite its importance and repeated inclusion in curricula, numerous studies have shown that students experience persistent difficulties in grasping basic kinematic concepts. These include confusions between position, displacement, distance, velocity, and acceleration [3, 4, 2]. When interpreting graphs of position, velocity, or acceleration as functions of time, students often misinterpret graphs as literal pictures of motion, or mistake the slope at a point for the value on the vertical axis [5, 1, 6]. Such conceptual challenges highlight the limitations of traditional instruction and underscore the need for new teaching strategies that promote active engagement and deeper conceptual understanding.

Active learning methodologies have consistently demonstrated substantial improvements in students' conceptual understanding of physics and reasoning skills. In particular, real-time graphical visualization of motion has proven effective in helping students connect mathematical representations with physical experiences [7, 8, 9]. Another promising approach is *gamification*, the use of game design elements in non-game contexts, which can enhance motivation and engagement in science education [10]. By integrating these approaches, educators can help students not only learn abstract concepts but also experience and manipulate them through interactive, embodied activities that invite iterative experimentation with graphical representations of motion. In line with this perspective, we adopt here a definition of gamification as the deliberate incorporation of selected game design elements into educational contexts to foster engagement and sustained interaction. Within *MissionMotion*, these elements are operationalized through real-time feedback, a scoring system based on graph similarity, progressive levels of challenge, and structured competitive dynamics. Rather than aiming to test gamification theory itself, our interest lies in examining how such design choices shape students' interaction with graphical representations of motion in classroom settings.

In the Uruguayan educational context, *Plan Ceibal* has played a transformative role in introducing digital tools and programmable hardware—such as micro:bit boards, tablets, 3D printers, and robotics kits—into schools. These technologies provide fertile ground for designing interactive and experimental activities in science education [11]. Furthermore, several studies have demonstrated that computational tools can support students' understanding of physical phenomena by enabling data visualization and problem-solving in new ways [12]. As physics becomes increasingly computational in nature, introductory courses represent an ideal context for developing *computational thinking* (CT) skills [13]. Physics education standards worldwide are encouraging instructors to integrate CT as a fundamental component of scientific practice.

Computational thinking—defined as the ability to model real-world problems and design algorithmic solutions that can be computationally implemented—has emerged as a core 21st-century competency [14]. Ceibal's national initiatives have embraced this perspective, promoting CT as a transversal competence across subjects. Through programming and robotics, students engage with logical reasoning, creativity, collaboration, and problem-solving, applying these skills in diverse domains such as mathematics, language, and the sciences [15]. This integration encourages interdisciplinary approaches where CT becomes a driving force for developing conceptual understanding and procedural fluency in multiple areas of the curriculum.

Physics, as an experimental and model-based science, provides an ideal context for connecting CT with scientific inquiry. Previous research has shown that integrating CT into physics instruction allows students to construct and test models, analyze data, and reflect on the relationships between physical quantities and computational representations [16, 17, 18, 19]. These studies suggest that CT-oriented learning environments can foster both conceptual understanding and critical reasoning. However, questions remain regarding the most effective ways to embed these practices in school settings, particularly in lower and upper secondary levels where abstract reasoning skills are still developing [20].Within this broader perspective, *MissionMotion* has been conceived as a platform capable of supporting computational engagement through programmable devices and sensor-based interaction. By enabling students to interface motion sensors, adjust parameters, and potentially program hardware components, the environment creates opportunities for integrating computational thinking into physics activities.

Against this backdrop, our project draws on gamification as a design strategy to support the integration of computational thinking and graphical reasoning in physics education. Specifically, we developed a physical–computational videogame environment aimed at helping students overcome conceptual difficulties in kinematics and graphical interpretation while promoting engagement and motivation. The environment links real-world motion—captured through sensors—to a digital game interface, enabling students to visualize their own movements as graphs of position, velocity, or acceleration in real time. By comparing their motion-generated graphs with target graphs provided by the game, students receive immediate feedback and a performance score based on accuracy.

This dual physical–digital interaction bridges abstract representations with embodied experience, creating conditions that may support conceptual understanding through active participation. The environment also supports multiple modes of use: a simple mode in which students control a virtual character using a mouse or keyboard, and more advanced modes that employ motion sensors to track real physical movement. Teachers may further extend the activity by having students program the sensors or robots that interface with the game, thereby opening opportunities for computational engagement and for the development of problem-solving, debugging, and iterative design practices.

At the project level, the evaluation plan integrates multiple sources of evidence. Learning outcomes are assessed through rubrics aligned with national science and computer science curricula, focusing on students' ability to interpret graphical data, relate physical quantities, apply logical and creative thinking, and program devices that interact with their environment. In addition, pre- and post-assessment instruments commonly used in physics education research are employed to measure conceptual gains in kinematics. This comprehensive evaluation framework extends beyond the scope of the present article, which focuses on the initial implementation and user experience.

In summary, the theoretical framework situates the project at the intersection of physics education research, gamification, and computational thinking. It addresses well-documented learning difficulties in kinematics through active learning, real-time visualization, and interactive digital technologies. Within this research program, the article reports an initial validation study focused on design implementation and user experience, establishing the basis for subsequent empirical analysis.

3 Description and activities

The main project's outcome is *MissionMotion*, a cross-platform web application designed to improve conceptual understanding of kinematics by allowing students to reproduce motion graphs in real time. It operates as a physical–computational learning environment that bridges virtual interaction with real-world motion: students control a paper-ball avatar moving along a ruler-like axis while its position or velocity is dynamically plotted alongside a target graph they must imitate. Motion can be controlled via mouse, trackpad, touchscreen, or external ultrasonic sensors connected through micro:bit or Arduino, enabling seamless integration with existing Plan Ceibal kits in Uruguay. A scoring algorithm evaluates the similarity between the user-generated and reference graphs, providing immediate feedback. Beyond gameplay, the platform functions as an open-source resource hub offering sequenced activities, opportunities to program sensors or robots to foster computational thinking, publishable materials, and classroom implementation to systematically measure its educational impact. Its browser-based implementation ensures smooth operation across a wide range of devices without requiring any platform-specific installation or configuration. An example of the hardware connection setup is shown in Fig. 1, while a classroom implementation using a micro:bit board and an ultrasonic sensor is presented in Fig. 2.

To illustrate the versatility of the platform, we offer students a set of representative learning activities implemented within *MissionMotion*. These tasks invite students to reproduce position–time graphs using their own movement, receiving immediate visual feedback and performance scores based on accuracy. Interaction modes range from simple keyboard, mouse, or touchscreen control to more advanced configurations using ultrasonic sensors or programmed

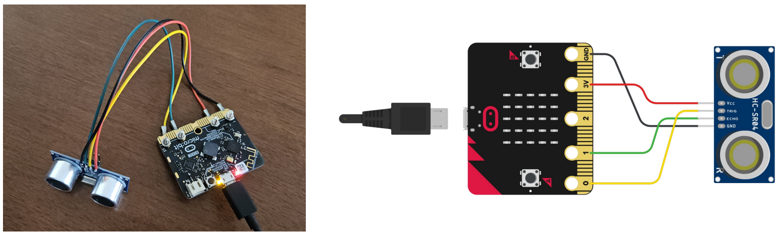

Figure 1: Connection setup used in *MissionMotion*, showing the micro:bit board connected to an ultrasonic distance sensor and interfaced with a laptop for real-time motion acquisition. When using micro:bit, the HC-SR04P ultrasonic sensor must be employed instead of the HC-SR04, as it is compatible with the 3.3 V operating voltage of the micro:bit.

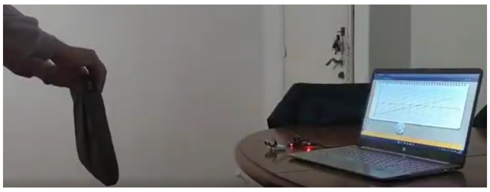

Figure 2: Micro:bit board linked to an ultrasonic sensor and interfaced with a laptop for real-time motion acquisition in *MissionMotion*. The photo also shows the player holding a folder used as a paddle to improve the ultrasonic sensor's tracking accuracy.

robotic systems, allowing teachers to tailor the experience to available resources and instructional goals. As shown in Fig. 3, the main interface displays the available activity modes, whereas Fig. 4 illustrates an example game scenario in which students attempt to match a target motion graph; once the task is completed, the system provides a score based on the similarity between the proposed and player-generated graphs.

The design of *MissionMotion* is inspired by specific, well-documented difficulties in students' interpretation of kinematics graphs. In particular, the requirement to continuously adjust motion to match a target position–time graph makes control of the slope an explicit and unavoidable aspect of the task. Students must anticipate changes in motion to improve their score, implicitly engaging with velocity as a rate of change rather than as a static quantity. The real-time comparison between the target and the user-generated graph makes mismatches immediately visible, supporting iterative refinement across repeated attempts. Rather than treating graphs as static representations, students interact with them as dynamic objects that respond directly to their actions. From an instructional perspective, this allows teachers to structure activities that emphasize individual exploration or collective discussion, depending on classroom goals and available time. The following section presents results from a classroom implementation, focusing on students' experience with the environment and on dimensions such as usability, engagement, and perceived educational value, as assessed using the MEEGA+ instrument.

4 Exploratory Study: Research Focus and Method

This exploratory study of *MissionMotion* conducted in regular classroom settings was focused on students' experience using the environment and to provide outputs for subsequent research phases. This section presents the research focus, methodological design, and results of this exploratory study. Accordingly, the study addresses the following research question:

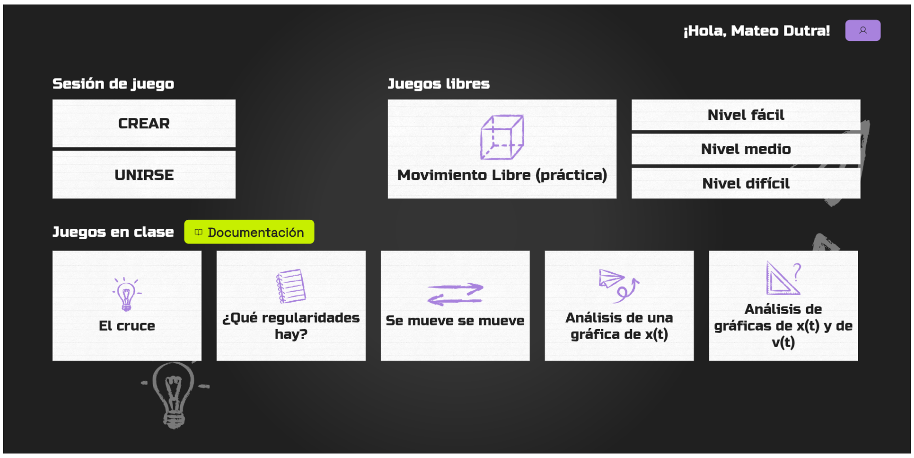

Figure 3: Main screen of *MissionMotion* displaying the activity menu, where students can choose among multiple motion-replication challenges and different input modes. The platform supports both individual gameplay and a classroom-oriented collective mode: teachers have access to a dedicated login that allows them to create virtual classrooms, invite students via code, and view all student results. The teacher menu also provides suggested activities and instructional sequences to support classroom implementation.

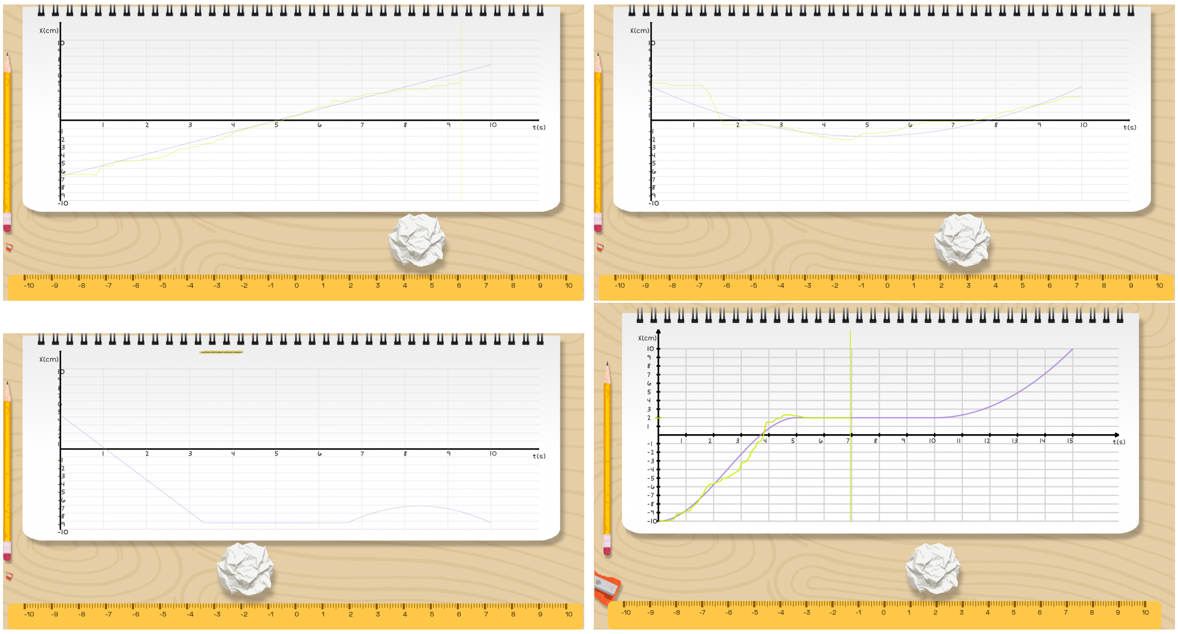

Figure 4: Four screenshots of gameplay scenes with different difficulty levels. The player must reproduce the purple position–time graph by moving the mouse or trackpad, represented visually by the paper-ball avatar at the bottom of the screen. As the player moves the mouse, the avatar's motion is displayed in real time and a yellow graph of the user-generated trajectory is drawn. At the end of the attempt, the system provides a score based on the similarity between the target and the player's graph.

> **RQ.** How do students evaluate the usability and player experience of *MissionMotion* during a exploratory classroom implementation?

The research was conducted in 2025 with five ninth-grade groups from three different educational contexts: a public high school in Montevideo, a public high school outside the capital, and a private high school in Montevideo. A total of 103 students participated in the activity. Students had previously received formal instruction on basic kinematics concepts as part of their regular curriculum. The intervention took place during regular class time under the supervision of their physics teachers.

The intervention consisted of a two-hour session integrated into regular physics instruction. During this phase, students interacted with *MissionMotion* using a mouse-based control mode only. Although the platform supports additional embodied interaction modes (e.g., external sensors and programmable devices), these were not implemented in this initial test. The session was structured in two stages. In the first stage, students explored the environment individually, playing at their own pace and familiarizing themselves with the interface and scoring system. In the second stage, collective challenges were introduced, allowing students to compare scores and engage in competitive dynamics.

To address the research question, we administered the MEEGA+ questionnaire (Model for the Evaluation of Educational Games), an internationally validated instrument designed to assess user experience in game-based learning environments [21]. MEEGA+ evaluates multiple dimensions of player experience, including usability, fun, challenge, immersion, social interaction, and perceived learning. Responses were analyzed descriptively to identify general trends and design implications for future iterations of the environment. Classroom observations and teachers' qualitative feedback were used to complement the questionnaire results.

5 Results: Usability and Player Experience

Student responses indicate a positive evaluation of the environment. The usability dimension (Fig. 5) shows high ratings in clarity of interface, ease of use, and perceived control. Most students reported that they were able to understand how to interact with the game without difficulty and that the feedback provided by the system supported their attempts to improve performance. No major usability barriers were identified during the session.

Regarding player experience (Fig. 6), students reported high levels of enjoyment and engagement. The competitive component introduced in the second phase of the activity was frequently mentioned as motivating, particularly when scores were compared among peers. The real-time graphical feedback was highlighted in open-ended responses as a distinctive and appealing feature of the environment.

Classroom observations were consistent with questionnaire results. During gameplay, students repeatedly adjusted their movements to better match the target graph and engaged in spontaneous discussions about strategies to improve their scores. In several groups, students who were typically less participative in traditional lessons showed active involvement during the activity. Teachers' qualitative feedback also aligned with these findings. In particular, instructors emphasized the motivational potential of the tool and its capacity to generate classroom discussions centered on motion graphs. One teacher who implemented *MissionMotion* in his classroom remarked:

> *MissionMotion* is an excellent tool for classroom work. Not only were my students highly motivated, but reflections about graphs appeared that would rarely surface in a traditional lesson. By trying to reproduce motions, they realized how

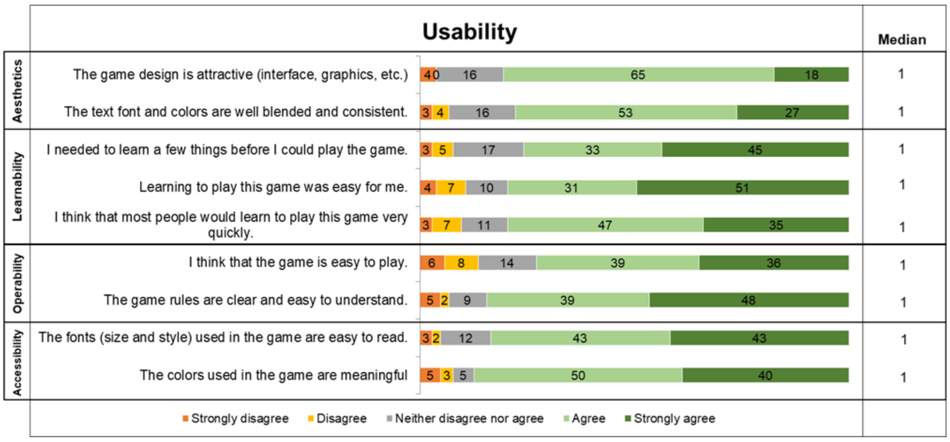

Figure 5: Usability evaluation results obtained with the MEEGA+ instrument. The figure summarizes student ratings across dimensions such as ease of use, clarity of interface, perceived control, and feedback effectiveness.

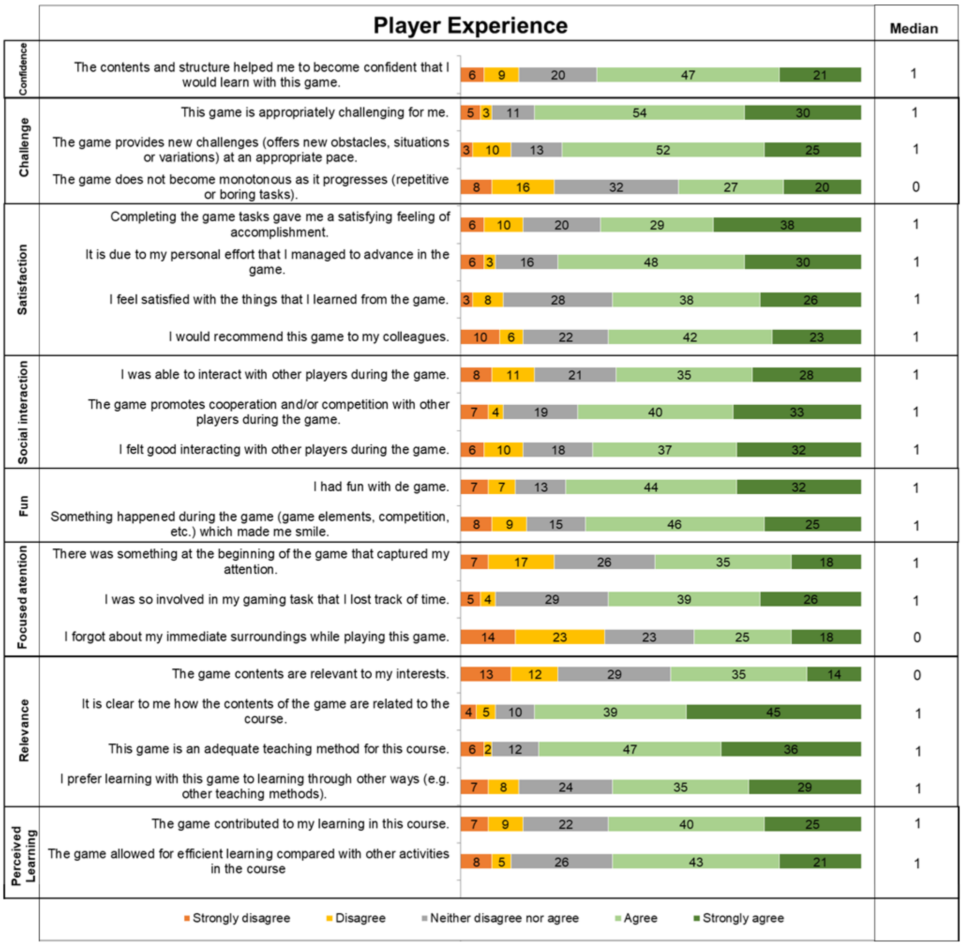

Figure 6: Player experience results from the MEEGA+ assessment. Scores reflect students' perceptions of enjoyment, challenge, engagement, social interaction, and immersion while interacting with the game environment.

> velocity should change—something that is difficult to notice when only interpreting a graph. The fact that they engaged their own movement promoted deeper reflection about motion characteristics.

This testimony illustrates an example of the positive feedbacks and highlights its perceived potential to promote reflective engagement with motion graphs within classroom dynamics.

6 Discussion and Limitations

The findings of this exploratory study indicate that *MissionMotion* was positively received across diverse classroom contexts. Students consistently reported high usability and strong engagement, and teachers highlighted the environment's capacity to stimulate discussion and active participation. Within the scope of this exploratory implementation, these results support the feasibility of integrating the platform into regular physics instruction and suggest that the design effectively promotes meaningful interaction with graphical representations of motion.

As an initial phase, the study was intentionally focused on usability and player experience rather than on measuring conceptual learning gains. This choice allowed us to examine how students and teachers respond to the environment in authentic classroom conditions before undertaking more comprehensive evaluative stages. The positive perceptions documented here provide a valuable foundation for such subsequent investigations. Nevertheless, certain limitations delimit the scope of the present conclusions. The intervention consisted of a single two-hour session, which does not allow for examining longer-term integration or sustained use. Furthermore, only the mouse-based interaction mode was implemented in this stage, while the platform supports additional embodied and sensor-based configurations that may influence classroom dynamics in different ways. The analysis presented is primarily descriptive and does not aim to establish causal claims regarding learning outcomes.

Rather than representing shortcomings, these aspects reflect the exploratory nature of this phase within a broader research and development process. Building on the encouraging reception documented here, future studies will incorporate pre- and post-assessments of conceptual understanding, explore extended instructional sequences, and examine how different interaction modalities shape students' engagement with motion concepts. In this sense, the present study establishes a solid empirical starting point for continued systematic evaluation of *MissionMotion*.

7 Closing remarks

The study presented in this article documents the first classroom-based evaluation of *MissionMotion* as a real-time, graph-centered learning environment. By focusing on usability and player experience, this phase offers empirical insight into how students and teachers engage with the platform under regular instructional conditions.

The results suggest that the design principles underlying the environment—particularly real-time feedback, graphical comparison, and interactive challenge—are well received and can be meaningfully integrated into classroom practice. These findings provide a grounded basis for advancing toward more comprehensive investigations of instructional impact. In this sense, the present work establishes an initial research-informed step in the iterative development of *MissionMotion*, bridging design, classroom implementation, and future systematic study.

8 Acknowledgments

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