Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #48150

Integrating 3D Printing and Tracker Software for Enhanced Data Acquisition in Experimental Physics Education

Mr. CARLOS PINEIDA, Universidad Andres Bello, Chile.

Carlos Pineida has dedicated over 20 years to teaching physics. He earned a Master's degree in University Teaching, focusing on developing experimental skill in students and fostering their scientific thinking. Carlos has the privilege of inspiring numerous students in the fascinating world of science. He is currently a faculty member at the University Andres Bello in Chile, teaching physics within the faculty of Engineering. He specializes in courses for the first two years of the university program and also lectures in other faculties. Additionally, due to his training and experience, he is responsible for developing innovative educational programs integrating cutting-edge technology and active learning methodologies in STEM. Lastly, his interest in improving the teaching-learning process leads to engage in educational research projects in collaboration whit faculty from his university and other academic institutions.

Prof. Angeles Dominguez, Tecnologico de Monterrey, Monterrey, Mexico (ITESM); Universidad Andres Bello, Santiago, Chile (UNAB)

Angeles Dominguez is a researcher at the Institute for the Future of Education at Tecnologico de Monterrey, Mexico. She also collaborates with the School of Engineering at the Universidad Andres Bello in Santiago, Chile. Angeles holds a bachelor's degree in Physics Engineering from Tecnologico de Monterrey and a doctoral degree in Mathematics Education from Syracuse University, NY. For her research, she is Researchers' National System in Mexico (Level 2), Associate Editor of the Ibero-American Journal of Learning Technologies (IEEE-RITA), and a guest editor for the journals Education Sciences, Frontiers in Education, and Discover Sustainability. Her main research areas are: interdisciplinarity in science, gender studies in STEM, and faculty development. Due to her interest in women's participation in science, she has been a mentor in several programs, received the Mentor in Science distinction from the British Council Mexico, and coordinates mentoring program at the Tecnologico de Monterrey and at Universidad Andres Bello. Angeles leads projects on gender studies in STEM, mathematical and interdisciplinary modeling, and teacher training.

Prof. Genaro Zavala, Tecnologico de Monterrey, Monterrey, Mexico; Universidad Andres Bello, Santiago, Chile

Dr. Genaro Zavala is Associate Director of the Research Laboratory at the Institute for the Future of Education, Tecnológico de Monterrey. He collaborates with the School of Engineering of the Universidad Andrés Bello in Santiago, Chile. A National Researcher Level 2 (SNI-CONACYT), he has over 20 years of experience in educational research. His work spans conceptual understanding in physics, active learning, AI in education, and STEM interdisciplinarity. He leads initiatives on faculty development, competency assessment, and technology-enhanced learning. With 100+ publications, he integrates educational psychology, digital transformation, and sustainability. Dr. Zavala also pioneers projects using neuroscience tools and learning analytics to improve student engagement and foster innovative, student-centered learning environments.

Integrating 3D Printing and Tracker Software for Enhanced Data Acquisition in Experimental Physics Education

Abstract

In a Latin American university's engineering program, the experimental physics course is a key component of the undergraduate curriculum, with 29 sections and around 1,100 students. This study introduces an innovative approach to data acquisition in physics experiments by integrating *Tracker© software* with 3D printing technology to enhance data collection accuracy and student learning outcomes in kinematics experiments. The core of this study is a pilot experiment designed within the physics lab, where a custom 3D-printed model (referred to as the "flag") is incorporated into the traditional kinematics experiment setup. Data acquisition is then compared between two experimental conditions: with the 3D-printed flag and without it. *Tracker© software* captures the data in real-time, and Excel is used for analysis and modeling. This combination of tools offers immediate processing and visualization capabilities. Student feedback (n=811 participants) suggests that this technology integration may help reduce data acquisition challenges, potentially allowing students to focus more on analyzing physics concepts. The methodology involves deploying this experimental activity across multiple course sections during the second semester of 2024, followed by surveys administered to the participating students and their instructors. The student survey aims to assess the use of Tracker as a tool to collect data, the incorporation of a 3D-printed flag to improve the accuracy of the data, and their perspective on the impact of tools on their learning experience. In contrast, the instructor survey gathers insights into the practical aspects of implementing this innovation in a lab setting. Expected outcomes include enhanced data acquisition processes and a noticeable improvement in student comprehension of kinematic principles. The results support that low-cost, custom-designed equipment can significantly benefit experimental physics education by providing more reliable data and a deeper learning experience for students. Ultimately, this research contributes to physics education by illustrating the value of combining technology and hands-on learning tools to improve experimental practices. The study's findings guide future curriculum design, advocating for the inclusion of 3D printing and advanced data analysis software in physics labs to enrich educational outcomes.

Keywords: Physics Education Research, Educational Innovation, STEM Education, Kinematics, Experimental Physics, 3D Printing Technology, Tracker Software

INTRODUCTION

Physics education research has increasingly highlighted the need for improvements in laboratory instruction, particularly in fostering conceptual understanding and experimental design skills [1] and [2]. Holmes and Wieman argue that traditional introductory physics labs often fail to reinforce conceptual learning effectively [3]. Additionally, model-based reasoning has been identified as a crucial component in experimental physics learning [4]. This study contributes to this ongoing discussion by exploring the integration of the *Tracker© software* and 3D printing to enhance data collection and student engagement in experimental physics.

Learning experimental physics presents unique challenges that demand innovative tools to facilitate the visualization, analysis, and understanding of physical phenomena [5] and [6]. Among such tools, *Tracker© software*, developed as part of the Open Source Physics (OSP) project, has emerged as a pivotal resource in physics education [7]. Tracker enables detailed movement analysis from videos, providing students with an active and engaging experience in acquiring and processing experimental data. Its ability to track an object's position by recognizing specific pixels in videos recorded using accessible devices, such as smartphones, makes it a versatile, cost-effective, and highly suitable tool for educational environments with limited resources [8], [9], and [10].

In introductory physics courses, such as those offered at a private university in Latin America, Tracker has proven to be an effective means of integrating technology into educational experiments. By actively enabling students to engage in data collection and analysis, the software fosters deeper, more meaningful learning and promotes the development of essential hands-on scientific skills. These experiences are particularly valuable as they strengthen critical reasoning, problem-solving abilities, and understanding of abstract concepts through direct experimentation [11].

Despite its numerous benefits, the implementation of Tracker is not without challenges. The videos' quality and format significantly affect the accuracy of the analysis. Videos with poor lighting, unfavorable angles, or low resolution can compromise the reliability of results. Additionally, initial software configurations, such as setting scales, reference axes, and measurement parameters, can present difficulties for some students, slowing the data collection process and leading to frustration. Another common obstacle is defining the object to be tracked, especially when there is insufficient contrast between the object and its background. This issue can fail automatic tracking, necessitating a more time-consuming manual process.

Nevertheless, Tracker offers substantial advantages over traditional data acquisition methods. Chief among these is its ability to reduce dependence on expensive equipment, such as specialized sensors, advanced interfaces, and high-performance computers, while simultaneously promoting student autonomy and active learning. These attributes make it an inclusive and adaptable tool across diverse educational settings.

To overcome the barriers associated with using Tracker, it is necessary to innovate and optimize its application in educational laboratories. This study proposes integrating *Tracker© software* with 3D printing technology to address these challenges and enhance the accuracy of experimental data. By incorporating a 3D-printed model designed explicitly for kinematics experiments, this approach seeks to mitigate experimental noise and human error while enriching students' learning experiences with more efficient and accessible tools [12].

This study evaluates the implementation of 3D printing and video tracking in a physics lab course, assessing its feasibility, student engagement, and perceived impact on data collection processes. This work aims to provide practical solutions for developing more effective laboratory practices. Leveraging technology highlights the transformative potential of combining innovative tools to enhance experiential learning (by improving data collection) in physics education.

METHODOLOGY

The present study employed an experimental design and a survey to evaluate the impact of integrating the personalized flag into the experimental physics course activities. The methodology was structured in two main phases: implementation of experimental activities and data collection through a survey.

Context

The students who participated in the study belonged to engineering careers (Civil Mining Engineering, Geology, Informatics and Computer Engineering, Civil Industrial Engineering, Civil Computer Engineering, Industrial Engineering, Merchant Marine Engineering, Bachelor of Science, Computer Engineering), the experimental physics course is located as a second semester of the curriculum and is taught nationwide, in five different centrally coordinated sites.

Students must pass the general physics course, which corresponds to an introductory one. In this course, they analyze concepts such as kinematics, force, and thermodynamics, among others. In parallel, students are taking a calculus course (derivative and integral calculus).

The experimental physics course takes place in the physics laboratories. It uses some *Pasco* brand materials and equipment [13]. These laboratories have interfaces, such as the 850 Universal Interface (UI-5000), and various sensors, including photogates and dynamic systems, such as the Photogates and Fences Dynamics System (ME-9471). These devices have been widely used in experimental practices, offering accuracy in data acquisition, but also present significant challenges in their implementation and use.

One of the main challenges in using this equipment is training students in its proper handling. This includes the initial configuration of the interfaces and sensors, and interpreting the data obtained. In addition, it is crucial to ensure that the equipment works correctly during laboratory sessions and that students can identify and solve possible errors associated with its use, especially for data collection for further analysis. These technical difficulties can distract students from the main objective of the students' learning: understanding the physical concepts underlying the experiments performed.

To address these limitations and facilitate learning, Pasco equipment was decided to be complemented by *Tracker© software*, an accessible and versatile tool for video-based motion analysis. Tracker not only simplifies the data acquisition process, eliminating the need for complex interfaces and sensors, but it also encourages more active and autonomous learning by allowing students to focus on physical phenomena and their analysis.

Among the difficulties previously identified, a recurring problem is the lack of adequate contrast between moving objects and the video background, which negatively affects the accuracy of automatic tracing in Tracker. To solve this problem, a specific object was designed that eliminates the contrast problem. This design was carried out using *Autodesk Inventor Professional* 2025 software (Figure 1) and materialized by 3D printing technology using a filament printer (Ender 3 V3 Ke). From now on, this object is referred to as the flag.

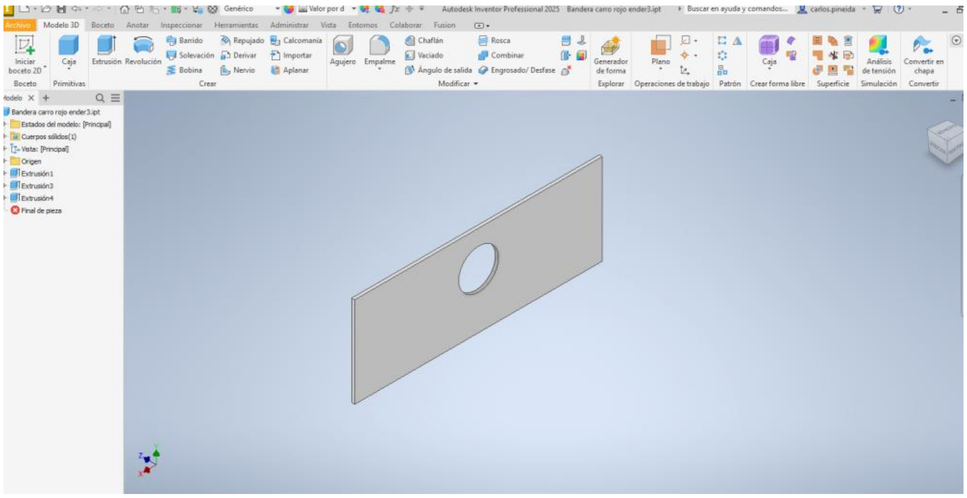


Figure 1. Autodesk Inventor Professional 2025 software for designing the flag to improve the contrast between the moving object and the background.

The flag was designed with high-contrast colors and distinct geometric edges to improve visibility in video recordings. Additionally, its fixed position on the cart ensures stable tracking in *Tracker© software*, reducing the likelihood of pixelation errors (Figure 2). Considering that a 3D printer may not be accessible to everybody, with some creativity, it is possible to recreate the flag using school supplies or even recycling materials.

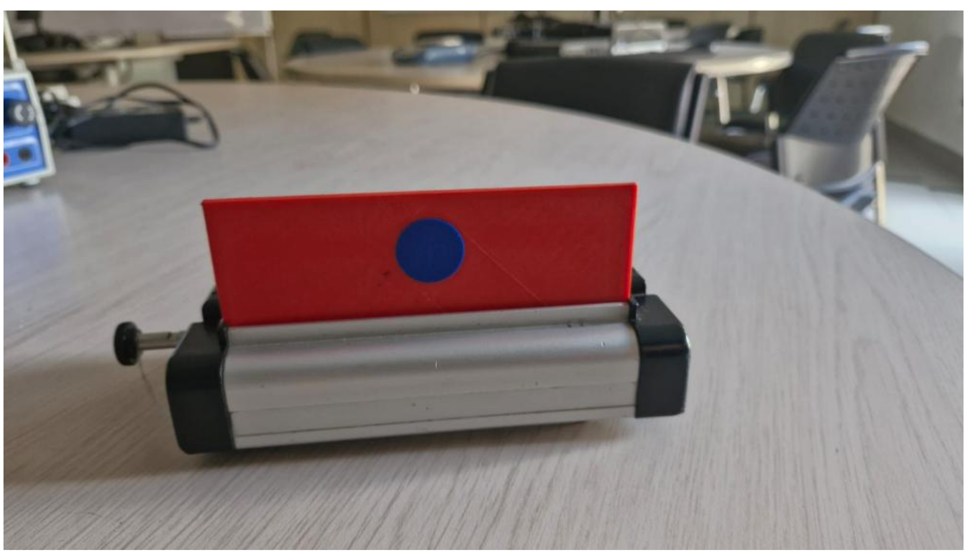


Figure 2. A designed and printed flag is mounted on the cart.

This approach combines advanced and accessible technologies, such as 3D printing and *Tracker© software*, to overcome the limitations of traditional methods. Incorporating the flag into existing equipment optimizes experimental data quality, reduces reliance on complex interfaces, and encourages the integration of technological tools into the educational context.

Experimental Activities

In the experimental physics course, students perform eight experiments. Three of the experiments use the *Tracker© software*. The first activity takes five sessions for students to install the software, familiarize themselves with its functions, and import data to Excel to analyze, graph, and determine the equation that models the movement. Two experimental activities were carried out using the flag explicitly designed for this study. In one of these activities, students were asked to track a moving object using the *Tracker© software*, both with and without the flag (Figure 3). This strategy allowed students to compare the ease of data acquisition between the two conditions. It is worth noting that this is the first semester in which we have introduced a high-contrast flag on top of the cart, so we asked students to run the experiment without and with the flag and record any changes in the data collected.

Figure 3. Experiment without the flag (upper image) and using the flag (lower image).

The students recorded videos of the experiments in both configurations and subsequently used Tracker to perform data extraction and analysis. The software tracked the movement of the object and generated position and time plots to evaluate the accuracy and quality of the data obtained in each case.

Survey

The survey consisted of both Likert-scale and open-ended questions. The open-ended responses were analyzed qualitatively using thematic analysis. Likert-scale responses were summarized descriptively to capture trends in student perceptions, but no inferential statistical analysis was conducted. The survey was administered after students completed both experimental conditions—tracking data without and with the flag—to compare their perceptions of each approach. The survey was administered online using Google Forms, and students were asked to respond within a week. There were 1,100 students enrolled in 29 sections of the course; we received 859 responses, out of which 48 responses were eliminated since students responded to all items with “1” or “5”.

The survey comprised 13 items on a 5-point Likert scale (1=completely disagree and 5=completely agree) and one open-ended question. The Likert-type questions were designed to assess aspects such as Tracker's ease of use, students' perception of the usefulness of the flag in improving data accuracy, and its impact on their understanding of the physical concepts involved. The open-ended question allowed students to share additional comments on their experience. The Likert-type questions were mandatory, and the open question was optional.

Given that 22 instructors taught the course, they were also asked to respond to a survey to gather their perceptions about the use of the *Tracker© software* as a tool to promote learning and students’ collaboration, their interest in using this tool in other courses, and suggestions to improve the course. The survey consisted of five items on a 5-point Likert scale (1=completely disagree and 5=completely agree) and six open-ended questions.

Data Analysis

The data collected through the survey were analyzed to identify trends and significant differences in student perceptions between using Tracker with and without the flag. The analysis included comparing responses on Likert scales and a qualitative categorization and analysis of open-ended responses. This allowed us to establish the impact of the flag on the learning experience, the ease of use of the software, and the quality of data acquisition. In the next section, the results of the data analysis include only those students who responded to all the questions, except for the open question, since it was not mandatory.

RESULTS

This section presents the most significant findings for both surveys (students and instructors). For the nature of the questions, we categorize students' responses into four themes and teachers' responses into two themes (Figure 4).

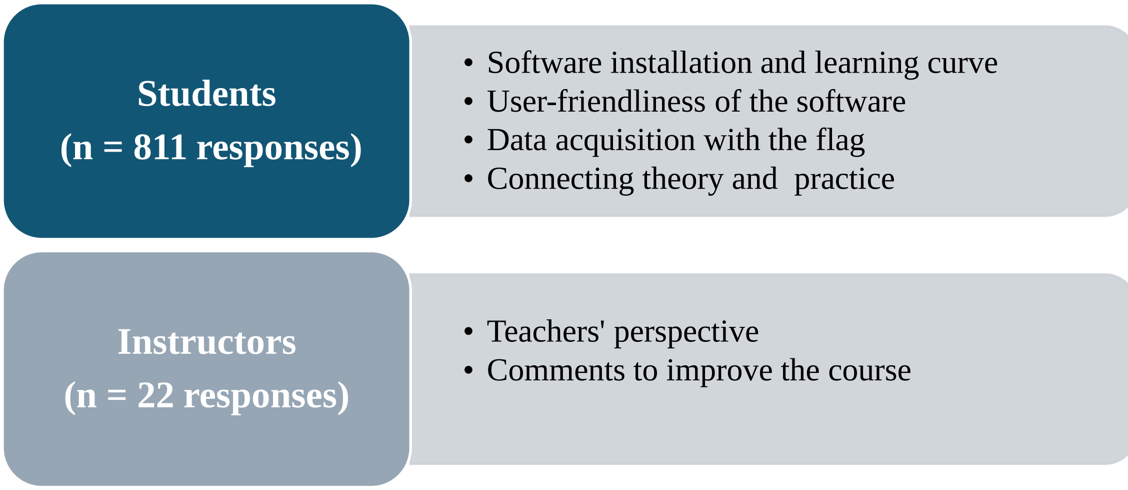


Figure 4. Categories of analyses of data collected from students and instructors via online surveys.

Software Installation and Learning Curve

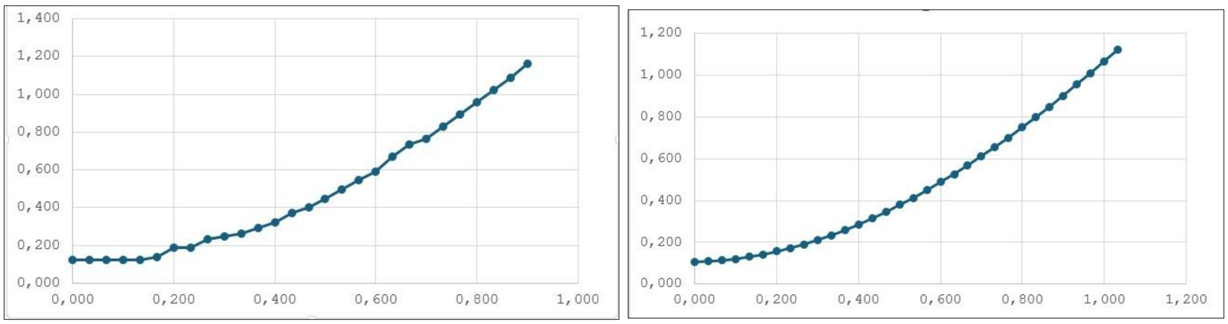
The survey revealed varying perceptions of the Tracker software's usability. Most students (79%) reported that installing the *Tracker© software* was straightforward. This reflects their digital proficiency and familiarity with technology, an advantage of engaging a generation of digital natives. However, the learning curve presented a notable challenge, as nearly half (48%) of the students found mastering the software time-consuming. This suggests that while the software is accessible and easy to install, a lack of structured onboarding materials may impede efficient adoption. To address this, future implementations could incorporate pre-laboratory training modules, interactive tutorials, or video guides to streamline the learning process and improve student confidence with the tool.

User-Friendliness of the Tracker© software

Students' perceptions of the system's user-friendliness were mixed but leaned positively. Approximately 74% of participants recognized Tracker as a useful and practical data collection and analysis tool. Students valued its potential to simplify complex experimental procedures. However, 45% indicated that the time investment required to become comfortable with the system was significant; while challenging to learn (as indicated in the previous point), once learned is perceived as a good tool. This highlights the dual importance of clear, well-organized instructional materials and sufficient in-class support. Future research could explore the effectiveness of real-time support sessions or peer-to-peer mentoring systems in improving the perceived usability of the software.

Data Acquisition with the Flag

The introduction of the 3D-printed flag aimed to enhance data acquisition by addressing contrast-related tracking issues. Most students (60%) perceived that the flag facilitated more accurate and efficient data collection. Although not all students perceived that the flag facilitated more accurate data collection, observations during laboratory sessions corroborated it, demonstrating that the flag significantly improved contrast and reduced tracking errors. In Figure 5, we present experimental results without using the flag (Figure 5a) and with the flag (Figure 5b). Using the flag, the data obtained clearly visualized accelerated movement behavior when selecting the object to follow as the blue circle. Without using a flag in previous semesters, the graphs presented errors, such as jumps in the graphs and deviations due to the software not correctly locating the object.



(a) (b)

Figure 5. Students' data acquisition without using the flag (a) and using the flag (b).

The relatively modest approval rate suggests that students may require further practice and clearer demonstrations of the flag's benefits. To increase student engagement and satisfaction, additional iterations of the experiment could focus on refining the flag's design or providing targeted instructions on its application.

Connecting Theory and Experimental Practice

Most students (73%) indicated that recalling theoretical concepts was essential for successfully performing experimental tasks. Similarly, 71% agreed that the software helped them bridge prior knowledge with practical experiments. This demonstrates the potential of technology-enhanced learning tools to facilitate meaningful connections between classroom theory and experimental practice. Future curriculum enhancements could include explicit scaffolding strategies, such as pre-lab concept reviews or reflective discussions to reinforce these connections.

Teacher's Perspective

Instructors strongly supported using Tracker and the 3D-printed flag, with 100% of responses affirming its role in fostering collaborative learning. Additionally, 63% expressed a willingness to integrate Tracker into other courses, citing its potential to enhance student engagement and understanding. Nevertheless, some instructors identified areas for improvement, particularly the need for more comprehensive training resources and step-by-step guides for students. Addressing these concerns by creating detailed implementation frameworks could ensure a smoother transition and broader adoption of these tools across various courses.

Comments to Improve the Course

Instructors commented on the need to incorporate more real experiments to collect and analyze data, foster intradisciplinary (physics) and interdisciplinary (physics and math) connections, improve guidelines on using Tracker, provide tips to enhance video shooting, and incorporate feedback on the written reports. On the other hand, students also mentioned the need to improve the guidelines, offer grading points for the written report, and provide a video tutorial for shooting a video for later use on the Tracker.

DISCUSSION

The results reflect strengths and areas for improvement in implementing Tracker and the flag in experimental physics laboratory activities. On the one hand, integrating the software with a custom fixture such as the flag facilitates data acquisition by eliminating contrast issues and reducing experimental noise (Figure 5). This improves data accuracy and allows students to spend more time analyzing and interpreting graphical representations, key aspects of learning physics.

On the other hand, the results also highlight important challenges. The learning curve associated with using Tracker and the need for more guidance during the activities suggest that additional support materials, such as tutorials, step-by-step guides, and training sessions, should be developed to maximize the impact of these tools.

Incorporating 3D printing in laboratories has proven to be an innovative and cost-effective solution, and it also opens up new possibilities for the design and customization of laboratory equipment [14] and [15]. This approach can be extended to other areas of physics, such as electromagnetics and modern physics, offering opportunities to design implementations tailored to the specific needs of each course. The accessibility of free repositories with printable models reinforces the feasibility of this strategy to enrich experimental teaching in a sustainable and versatile way.

Our findings align with existing concerns about the effectiveness of physics laboratories in promoting conceptual understanding [1], [2] and [3]. While our results suggest that students perceive improvements in data acquisition, further research is needed to assess the impact of model-based reasoning, as explored by others [4].

Finally, although the survey revealed some initial difficulty in working with and analyzing the data, implementing these technologies facilitated more collaborative and practical learning, laying the groundwork for exploring and developing new tools to promote innovative teaching in physics laboratories. The instructors' responses support this, as all agree that the activity fostered collaborative learning and are willing to incorporate the technology into other courses.

It is important to note that while students reported improvements in data accuracy, this study did not conduct an independent validation of data precision or error reduction. We presented and compared students' graphs when using and without the flag; however, future research should incorporate direct comparisons of measured accuracy with and without the 3D-printed flag.

While students' responses suggest that *Tracker© software* may aid in connecting theoretical concepts to experiments, we recognize that self-reported perceptions do not necessarily translate to measurable learning gains. Future studies should employ controlled experimental designs with pre/post-conceptual assessments to quantify learning outcomes.

CONCLUSIONS

This study highlights the potential of integrating 3D printing technology with *Tracker© software* to improve data acquisition and enhance learning in experimental physics education. Using a custom-designed 3D-printed flag in kinematics experiments successfully addressed common issues with video-based motion analysis, such as contrast problems, while promoting deeper student engagement and understanding of theoretical concepts.

The findings suggest that *Tracker© software*, complemented by innovative tools like the 3D-printed flag, is perceived by students as enhancing data acquisition and facilitating engagement with experimental activities. Surveys indicated that students valued the software's capabilities, although challenges related to the learning curve and the need for more precise instructional materials were identified. These insights underscore the importance of providing comprehensive onboarding resources to maximize the effectiveness of these tools in educational settings. However, as this study is based on self-reported perceptions, further research is needed to assess improvements in data accuracy and student learning outcomes through controlled studies.

Additionally, the instructors' overwhelmingly positive feedback reflects the practicality and scalability of this approach in broader educational contexts. Incorporating 3D printing also presents a cost-effective and sustainable solution for customizing laboratory equipment, offering opportunities for broader applications across other areas of physics education, such as electromagnetics and modern physics.

Ultimately, this research highlights the potential of leveraging accessible technological tools to address challenges in experimental teaching [16]. Future investigations incorporating control groups and objective learning measures could further validate these tools' impact on students' conceptual understanding and data collection precision. By integrating accessible, low-cost tools into laboratory practices, institutions can enrich experimental physics education and better prepare students for the demands of scientific inquiry.

Conflict of interest

The authors declare that there are no conflicts of interest to disclose.

Acknowledgments

The authors gratefully acknowledge the leadership and financial support of the School of Engineering at the Universidad Andres Bello, Chile. We also thank the Educational Research and Academic Development Unit (UNIDA) for its mentorship and guidance in developing research skills for higher education faculty.

References

[1] A. Suarez, S. Kahan, G. Zavala, & A. C. Marti, "Students' Conceptual Difficulties in Hydrodynamics," *Physical Review Physics Education Research*, vol. 13, no. 2, pp. 020132, 2017, https://doi.org/10.1103/PhysRevPhysEducRes.13.020132.

[2] E. Campos, G. Zavala, Kristina Zuza & J. Guisasola, "Electric field lines: The implications of students' interpretation on their understanding of the concept of electric field and of the superposition principle," *American Journal of Physics*, vol. 87, no. 8, pp. 660–667, 1 August 2019, https://doi.org/10.1119/1.5100588

[3] N. G. Holmes & C. E. Wieman, "Introductory physics labs: We can do better," *Physics Today*, vol. 71, no. 1, pp. 38–45, 2018, https://doi.org/10.1063/PT.3.3816

[4] B. M. Zwickl, D. Hu, N. Finkelstein & H. J. Lewandowski, "Model-based reasoning in the physics laboratory: Framework and initial results," *Physical Review Special Topics—Physics Education Research,* vol. 11, no. 2, pp. 020113, 2015, https://doi.org/10.1103/PhysRevSTPER.11.020113

[5] R. J. Beichner, "Impact of video motion analysis on kinematics graph interpretation skills," *American Journal of Physics*, vol. 64, no. 10, pp. 1272-1277, 1996, https://doi.org/10.1119/1.18390.

[6] H. Brasell, "The effect of real-time laboratory graphing on learning graphic representations of distance and velocity," *Journal of Research in Science Teaching*, vol. 24, no. 4, pp. 385-395, 1987, https://doi.org/10.1002/tea.3660240409

[7] D. Brown, R. Hanson & W. Christian, "Tracker Video Analysis and Modeling Tool" (Version 6.2.0) [Computer software], retrieved January 21, 2025, from https://physlets.org/tracker/

[8] W. Christian & M. Belloni, "Physlet Physics: Interactive Illustrations, Explorations and Problems for Introductory Physics," Addison-Wesley, 2003.

[9] W. Christian & F. Esquembre, "Modeling Physics with Easy Java Simulations," *The Physics Teacher*, vol. 45, no. 8, pp. 475-480, 2007, https://doi.org/10.1119/1.2798358

[10] L. Mesquita, G. Brockington, P. A. De Almeida, M. E. Truyol, L. A. Testoni, and P. F. F. Sousa, "Using a fidget spinner to teach physics," Physics Education, vol. 53, no. 4, p. 045024, Jul. 2018, https://doi.org/10.1088/1361-6552/aac69f

[11] J. Kuhn, P. Vogt & A. Müller, "Analyzing elevator oscillation with the smartphone acceleration sensors," *The Physics Teacher*, vol. 52, no. 1, pp. 55-56, 2014, https://doi.org/10.1119/1.4849161

[12] H. Lipson & M. Kurman, M., "Fabricated: The New World of 3D Printing," Wiley, 2013.

[13] Pasco Products, https://www.pasco.com/

[14] S. Greenhalgh, "The effects of 3D printing in design thinking and design education", *Journal of Engineering, Design and Technology*, vol. 14, no. 4, pp. 752-769, 2016, https://doi.org/10.1108/JEDT-02-2014-0005

[15] N. Gershenfeld, A. Gershenfeld & J. Cutcher-Gershenfeld, 2019). "Designing Reality: How to Survive and Thrive in the Third Digital Revolution," Basic Books, 2019.

[16] C. Pineida & A. Dominguez, "An Innovative Laboratory Physics Course Using Specialized Software and Digital Media: Students' and Instructors' Perspectives," in 2023 ASEE Annual Conference & Exposition Proceedings, Baltimore, Maryland: ASEE Conferences, Jun. 2023, p. 42625, https://doi.org/10.18260/1-2--42625.