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Applying video analysis to oscillatory motion: a tool for experimental physics

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Abstract

This study explores the use of video analysis as a tool for fostering meaningful learning and developing experimental skills in the study of oscillatory motion among engineering students. Conducted as a longitudinal study at the University of Costa Rica, the research examines how video analysis enables students to visualize and analyse motion using readily available technology. By eliminating the need for specialized sensors, this methodology provides an accessible alternative for experimental physics, particularly in low-resource institutions and distance learning environments. The results indicate that students found video analysis to be an engaging and effective complement to their learning process. Feedback highlights that this approach facilitates the connection between theoretical concepts and practical applications, reinforcing its role as a valuable tool in physics education.

Keywords: physics education, video analysis, semantic differential

1. Introduction

Video analysis has become an increasingly popular tool in physics education, offering a cost-effective and accessible means of studying motion. In particular, video-based approaches allow students to record and analyse motion without requiring specialized sensors, making them well-suited for low-resource institutions and distance learning environments. Oscillatory motion, a fundamental topic in mechanics, can be effectively studied using simple materials and readily available video analysis software, enabling students to visualize and quantify motion from real-world experiments conducted in classrooms or at home.

Laws and Pfister [1] demonstrated how digital video analysis facilitates the visualization of mechanical processes, bridging theoretical concepts with experimental practice. Their findings suggest that using video recordings for motion analysis improves students' ability to engage with physical phenomena and obtain precise

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measurements without relying on laboratory-grade equipment.

Similarly, Bryan [2] investigated the application of video analysis in energy conservation experiments, showing that these tools help students connect abstract physics concepts to practical observations. By enabling students to track motion frame by frame, video analysis enhances their ability to interpret energy transformations in dynamic systems.

Brown and Cox [3] expanded on this by integrating video analysis into traditional physics experiments, such as projectile motion and collisions. They emphasized the flexibility of this approach, allowing students to study fundamental mechanics concepts at their own pace and reinforcing their analytical skills.

Desbien [4] further explored video analysis by incorporating high-speed cameras to study rapid motion events, such as collisions and oscillations. This technique provided students with a clearer understanding of dynamic systems and allowed for more detailed motion analysis than would be possible with direct observation alone.

From an educational standpoint, Jaime and Escudero [5] emphasized the significance of experiential learning in the domain of physics education, positing that practical methodologies such as video analysis are crucial for the reinforcement of theoretical constructs. Their research underpins the notion that learners derive greater advantages from actively interacting with empirical data as opposed to solely depending on simulations or theoretical frameworks.

The motivational advantages associated with video analysis have also been investigated. Lampara and Maquiling [6] discovered that video-centric experiments foster active learning methodologies and enhance students' levels of engagement in physics courses. Likewise, Putra [7] demonstrated that video analysis facilitates students in connecting abstract principles to tangible real-world contexts, thereby rendering physics more comprehensible and nurturing problem-solving abilities.

In addition, Tarjanyi andd Tarjányiová [8] demonstrated that video analysis enhances both conceptual understanding and practical problem-solving abilities in mechanical systems. Their study suggests that video-based learning can complement traditional instruction by encouraging students to critically analyse motion using real experimental data.

Wee and Lee [9] emphasized the pedagogical benefits of video analysis tools like Tracker, showing that students who actively analyse real-world data demonstrate increased engagement with physics concepts. Their findings support the integration of video analysis into instructional methods to reinforce experimental learning.

Building upon the existing body of academic literature, this study outlines a sequence of carefully constructed video analysis experiments designed to investigate oscillatory motion utilizing essential materials and readily available software tools. This empirical methodology is congruent with investigations regarding the utilization of segmented visual representations to enhance conceptual comprehension, exemplified by the 'snapshot' technique introduced by Knight and colleagues [10]. Analogous to the manner in which sequential energy diagrams facilitate students' development of a progressive model of energy conservation [11], our implementation of video analysis empowers students to deconstruct motion into discrete, analysable frames, thereby promoting a systematic understanding of oscillatory motion.

2. Methodology

This research is based on a longitudinal experimental study designed to observe the effect of the educational approach over time [12, 13]. The study aimed to investigate the impact of video analysis on the understanding and motivation of students regarding oscillatory motion. Over the course of three semesters, students were divided into small groups and assigned one of four experimental setups. The experiments were conducted in a controlled laboratory environment, with students using video analysis tools to record and analyse the motion of various physical systems. Each group performed their assigned experiment during the semester, utilizing video analysis to record the motion of the physical systems with smartphones. They analysed the data using Pasco Capstone software [14], which generated real-time graphs for detailed analysis. After completing their experiments, students submitted reports detailing their methods, results, and reflections on the learning process. In addition, a survey was administered to collect feedback on your experiences using video analysis. The survey responses were notable, as many students reported an increased understanding of the concepts of oscillatory motion. They described how video analysis helped them visualize abstract concepts, making the learning experience more interactive and engaging. Furthermore, the technique was highly appreciated for maintaining student interest and participation, two key components of effective learning [15].

2.1. Participants and setting

The participants were undergraduate students enrolled in engineering programs at the University of Costa Rica. They were selected to represent a diverse group of individuals who could benefit from improved instructional methods in physics. The cohort consisted of second and third-year students, all of whom had previously completed their first physics course and were currently taking General Physics II during the study. Each group was required to submit a comprehensive report after the experiment. These reports included both quantitative data from their experimental work and qualitative reflections on how video analysis influenced their learning. The reports provided valuable insights into how well students grasped the concepts and their overall engagement with the experiments. A final survey was administered at the end of the semester to further assess the students' experiences. It focused on their perceived understanding of oscillatory motion, engagement during the experiment, and overall motivation.

3. Results and discussion

3.1. Experiment 1: spring-mass system

The spring-mass system experiment (see figure 1) was designed to help students understand the principles of harmonic motion by analysing the oscillatory behaviour of a mass-spring system. The students recorded the motion using their cellphones and performed video analysis with the Pasco Capstone software. The results obtained by the student groups are summarized in the table below, which includes the angular frequencies for two different spring cases, the calculated spring constants (k1), and the error percentages.

In the spring-mass system experiment (table 1), both groups recorded similar angular frequencies, with average values of 10.55 rad s^{-1} and 7.83 rad s^{-1} for the two cases, demonstrating consistent and reliable experimental outcomes. The fact that both groups achieved such close measurements highlights the precision of their experimental methods.

Utilizing these angular frequencies, the participants engaged in the computation of the spring constant (k_1) pertinent to each scenario. The experimental spring constants determined by Group 1 were 6.42 N m^{-1} initially and 3.37 N m^{-1} subsequently, and Group 2 discovered 6.06 N m^{-1} and 3.36 N m^{-1} for their respective experiments. The assessed mean spring constants among the groups were recorded as 6.12 N m^{-1} and 3.37 N m^{-1}, reflecting a considerable harmony between the groups and further validating the integrity of their methodological practices.

In order to evaluate the precision of these experimental spring constants in relation to the theoretical values, error percentages were computed. For the initial scenario, Group 1 documented an error percentage of 6.0%, while Group 2 indicated a marginally elevated error of 12.14%, culminating in an average error percentage of 8.98%. Conversely, for the subsequent scenario, the error percentages were significantly reduced, with Group 1 registering an error of merely 0.83% and Group 2 noting 1.09%, resulting in an average of 0.96%. These minimal error percentages, particularly for the second scenario, corroborate the exceptional accuracy of the experimental findings.

Overall, the findings from the spring-mass system experiment underscore the effectiveness of video analysis as a tool for accurately measuring and analysing oscillatory motion. The close alignment between the angular frequencies, spring constants, and the low error percentages demonstrate that students were able to capture and analyse the motion of the spring-mass system with a high degree of precision. These results suggest that integrating video analysis into physics education can greatly enhance students' understanding of harmonic motion and improve the accuracy of their experimental outcomes.

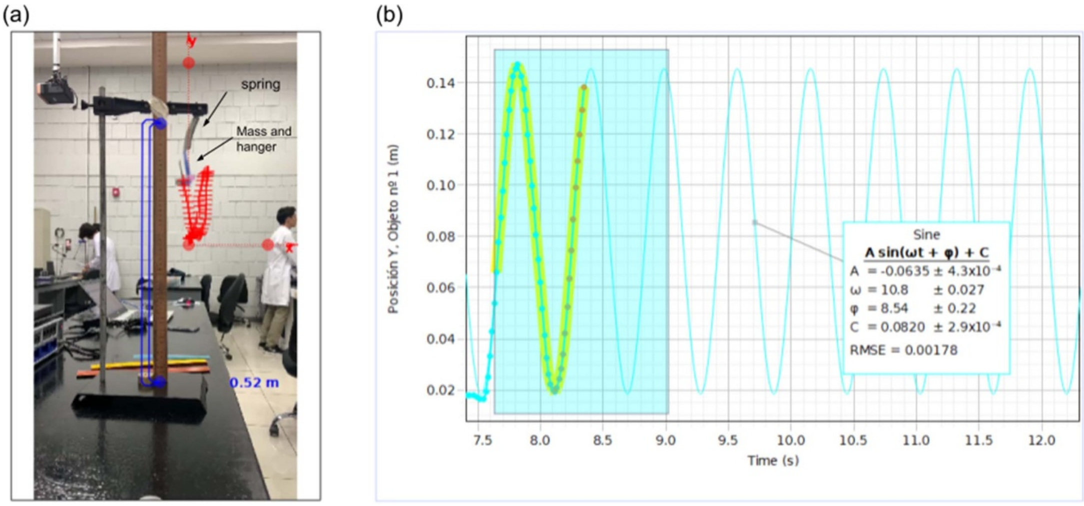

Figure 1. (a) Experimental setup of the spring-mass system, using the specified equipment to analyse harmonic motion. (b) A sample of the students' analysis, showing the position of the mass as a function of time, generated through video analysis.

Table 1. Experimental results of the spring-mass system experiment for two student groups.

Group	Angular Frequency Case 1 (rad s^{-1})	Experimental k1 Case 1 (N m^{-1})	% Error Case 1	Angular Frequency Case 2 (rad s^{-1})	Experimental k2 Case 2 (N m^{-1})	% Error Case 2
Group 1	10.8	6.42	6.00	7.83	3.37	0.83
Group 2	10.5	6.06	12.14	7.82	3.36	1.09
Average	10.55	6.12	8.98	7.83	3.37	0.96

3.2. Experiment 2: pendulum

The pendulum experiment (see figure 2) aimed to provide students with a hands-on experience to visualize oscillatory motion and relate it to theoretical concepts through video analysis. The results obtained (see table 2) by the student groups are summarized in the table below, which includes the experimental angular frequencies, the average angular frequency, the calculated gravitational acceleration, and the error percentage.

The angular frequencies recorded by both groups were consistent, with Group 1 obtaining values of 5.42 rad s^{-1} and 5.20 rad s^{-1}, and Group 2 obtaining 5.43 rad s^{-1} and 5.23 rad s^{-1}. These measurements were used to calculate the average angular frequency for each group. Group 1 had an average angular frequency of 5.31 rad s^{-1}, while Group 2's average was 5.33 rad s^{-1}. The close similarity in these values indicates good experimental consistency and precision among the students.

Utilizing the mean angular frequency, the students ascertained the gravitational acceleration. The anticipated value of gravitational acceleration is approximately 9.7758 m s^{-2}. Group 1 discovered a gravitational acceleration measured at 10.71 m s^{-2}, contrasting with Group 2's evaluation which found it at 10.80 m s^{-2}. Both of these measurements are marginally greater than the anticipated value, which may be attributable to experimental inaccuracies or approximations conducted during the analytical process.

The percentage error was computed to quantify the divergence of the experimental gravitational acceleration from the theoretical value. The findings indicated that Group 1's error percentage was 9.60%, but Group 2's error percentage reached 10.43%. These error percentages fall within an acceptable range for

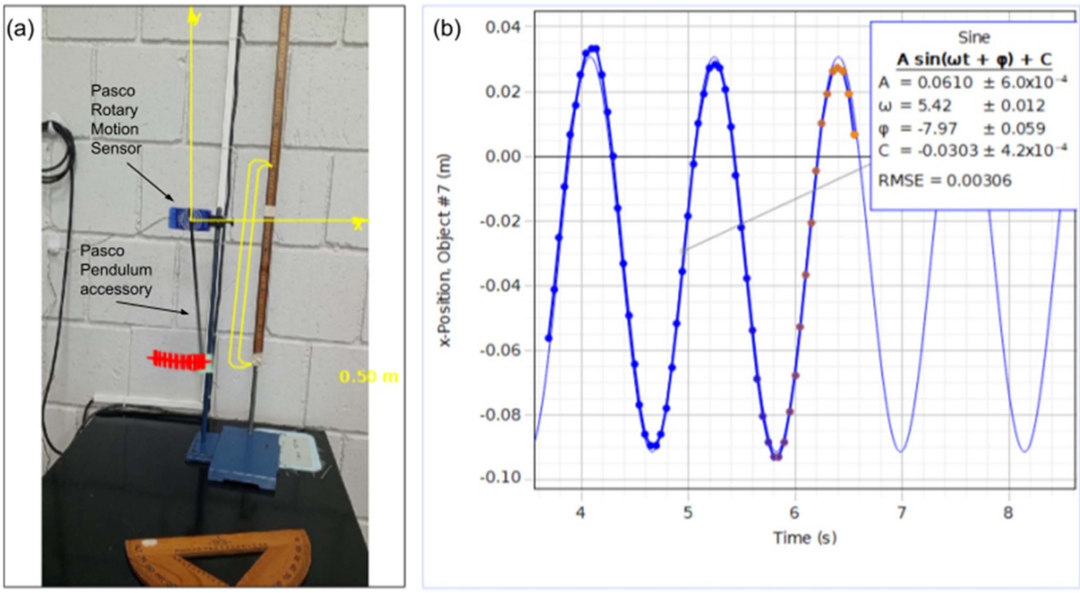

Figure 2. (a) Pendulum experiment setup with the Pasco Pendulum accessory and Rotary Motion Sensor. (b) Position vs. time plot from the video analysis, demonstrating the pendulum's oscillatory motion.

Table 2. Experimental results of the pendulum experiment for two student groups.

Group	Angular Frequency 1 (rad s^{-1})	Angular Frequency 2 (rad s^{-1})	Average AngularFrequency (rad s^{-1})	Gravity Acceleration (m/s^2)	Error Percentage (%)
Group 1	5.42	5.20	5.31	10.71	9.60
Group 2	5.43	5.23	5.33	10.80	10.43
Average	5.43	5.22	5.32	10.75	10.02

a student-conducted experiment, implying that the employed methodology and video analysis yielded results of reasonably high accuracy.

The results of the pendulum experiment demonstrate that the use of video analysis tools can yield reliable and educationally valuable data. The consistency in the angular frequencies and the relatively low error percentages indicate that the students were able to accurately capture and analyse the pendulum's motion. The slight overestimation of the gravitational acceleration suggests areas for improvement in the experimental setup, such as minimizing friction and ensuring precise measurements of the pendulum's length and oscillation period. Overall, the experiment successfully achieved its educational objectives, allowing students to directly relate their observations to theoretical physics concepts and validating the effectiveness of video analysis in enhancing their understanding of oscillatory motion. These findings support the continued integration of video analysis tools in physics education to foster active learning and improve conceptual comprehension.

3.3. Experiment 3: circular and oscillatory movement

The experimental investigation into circular motion and oscillatory motion (see figure 3) was meticulously designed to elucidate the relationship between these distinct forms of motion

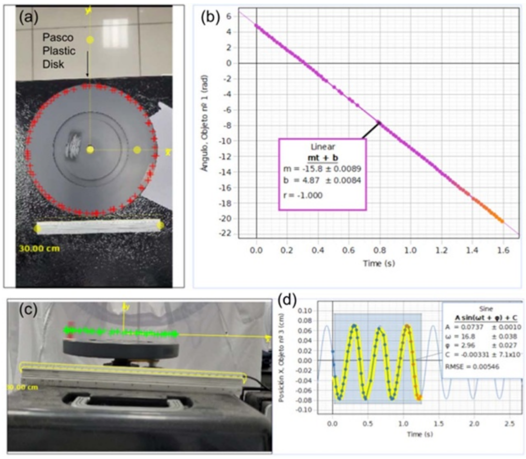

Figure 3. (a) Top view of the experimental setup for studying circular motion using the Electrical Cable Cap. (b) Position vs. time plot for the circular motion. (c) Side view of the same setup for studying oscillatory motion. (d) Position vs. time plot for the oscillatory motion.

and to substantiate the theoretical equivalence of their respective angular frequencies. The students meticulously documented recordings of an electrical cable cap affixed to a solid disk, effectively capturing the circular motion from a superior perspective and the corresponding oscillatory motion from a lateral perspective. The findings acquired by the student groups are systematically compiled in the table below, which encompasses the angular frequencies pertaining to both circular and oscillatory motion, in addition to the percentage disparity observed between them.

During the experimental analysis (see table 3), Group 1 documented an angular frequency of 15.8 rad s^{-1} for circular dynamics and 16.7 rad s^{-1} for oscillatory dynamics. Alternatively, Group 2 accomplished an angular frequency of 16.5 rad s^{-1} for the circular motion and 16.8 rad s^{-1} for the oscillatory motion. The proximity of the angular frequencies for both circular and oscillatory motions across both groups effectively illustrates the theoretical equivalence inherent to these two forms of motion.

The percentage difference between the angular frequencies was computed to evaluate the precision of the measurements. Group 1 exhibited a percentage difference of 5.54%, signifying an exceptionally high degree of accuracy in their experimental outcomes. In contrast, Group 2 demonstrated a marginally elevated percentage difference of 1.80%, which nonetheless indicates a commendable level of accuracy. These minimal percentage differences substantiate the anticipated theoretical correlation between circular and oscillatory motions.

The results of this experiment validate the theoretical prediction that the projection of a circular motion can be described as an oscillatory motion with equivalent angular frequencies. The consistency in the measured angular frequencies and the low percentage differences highlight the effectiveness of video analysis tools in capturing and analysing complex motions. These findings support the continued use of video analysis in physics education to help students visualize and understand the intricate relationships between different types of motion, thereby enhancing their overall comprehension of physical concepts.

3.4. *Experiment 4: coupled oscillations*

The coupled oscillations experiment (see figure 4) aimed to investigate the interaction between two oscillating systems using a Pasco Spring Set, an Aluminum Dynamics Track, and a Pasco PAScar. Students recorded the motion of the PAScar and analysed the data using video analysis techniques to understand the effects of coupling on the oscillatory behaviour. The results obtained (see table 4) by the student groups are summarized in the table below, which includes the angular frequencies for two different cases and the corresponding error percentages.

In the experiment concerning coupled oscillations, Group 1 documented an angular frequency of 7.13 rad s^{-1} for the initial case and 6.18 rad s^{-1} for the subsequent case. In a comparable manner, Group 2 registered results that were similar, logging angular frequencies of 7.12 rad s^{-1} for the initial case and 6.19 rad s^{-1} for the latter case. The close correspondence between the measurements obtained by the two groups signifies that the experimental methodology was uniformly implemented and that the data acquired was dependable.

The error margin for the first instance was calculated at 3.33% for Group 1 while Group 2 showed a margin of 3.47%. Shifting focus, in relation to the second situation, the frequency of errors

Table 3. Experimental results of the circular and oscillatory motion experiment for two student groups.

Group	Angular Frequency Circular Motion (rad s^{-1})	Angular Frequency Oscillatory Motion (rad s^{-1})	Percentage Difference (%)
Group 1	15.8	16.7	5.54
Group 2	16.5	16.8	1.80
Average	16.15	16.75	3.67

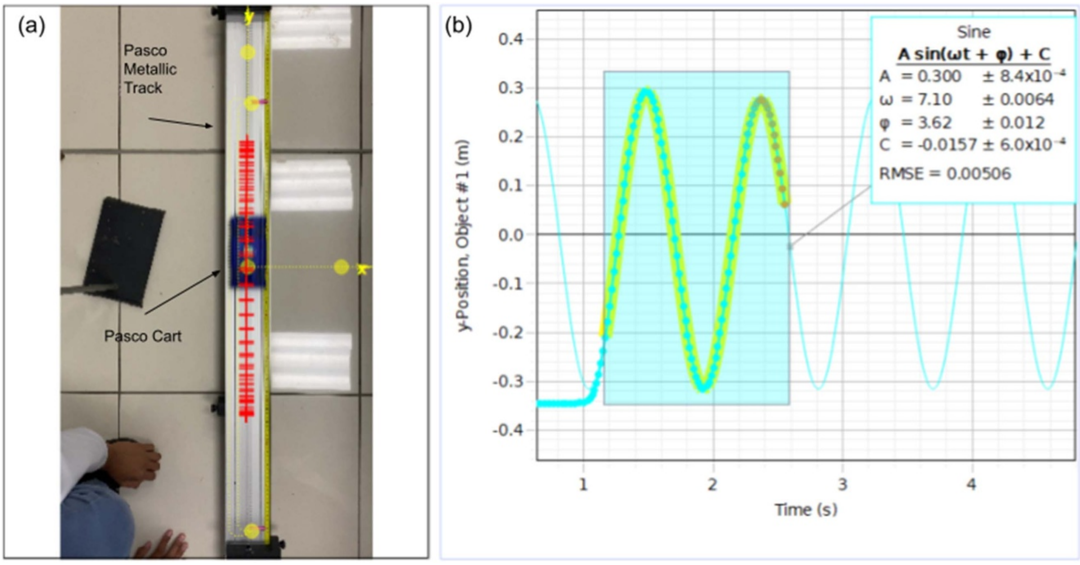

Figure 4. (a) Experimental setup for the coupled oscillations system, showing the PAScar and springs. (b) Position vs. time analysis of the system's oscillatory motion.

Table 4. Experimental results of the coupled oscillations experiment for two student groups.

Group	Angular Frequency Case 1 (rad s^{-1})	Error Percentage Case 1 (%)	Angular Frequency Case 2 (rad s^{-1})	Error Percentage Case 2 (%)
Group 1	7.13	3.33	6.18	0.60
Group 2	7.12	3.47	6.19	1.80
Average	7.13	3.40	6.19	1.2

saw a significant downward trend, as Group 1 logged an error of 0.60% while Group 2 logged an error of 1.80%. These relatively low error percentages imply that the experimental methodologies employed by the students, along with the video analysis, were executed with a high degree of accuracy.

The outcomes of the coupled oscillations experiment illustrate the efficacy of video analysis tools in capturing and scrutinizing the intricate interactions present in coupled oscillatory systems. The uniformity in the angular frequencies, along with the comparatively low error percentages, suggests that the students successfully measured the coupled oscillations and comprehended the impact of coupling on the behaviour of the system. These results underscore the importance of integrating video analysis into physics education to enhance students' comprehension of complex oscillatory phenomena and to augment the precision of their experimental endeavors.

4. Student feedback and analysis

To assess students' perceptions of video analysis as a tool for studying oscillatory motion, a semantic differential scale survey was conducted (refer to figure 5). The survey examined various aspects of students' experiences, including engagement, interest, ease of implementation, adequacy of time allocation, clarity of instructions, and overall usefulness of the method in conducting physics experiments.

A large proportion of students found the video analysis experiments engaging, with 70.37% rating their experience positively. Only 11.11% responded neutrally, and none rated the experience as negative. Furthermore, 59.26% of students reported that they enjoyed the process, while 25.93% considered it somewhat enjoyable. These results suggest that video analysis provides an interactive and accessible way to conduct oscillatory motion experiments without requiring specialized laboratory equipment.

In terms of interest, 51.85% of students described the experiments as captivating, and 33.33% found them moderately interesting. A smaller proportion (14.81%) remained neutral, and none found the experiments uninteresting. This indicates that the method effectively maintained student attention and curiosity while providing a hands-on approach to studying motion.

The perceived ease of conducting the experiments showed more variation. While 25.93% of participants found them straightforward, 11.11% described them as somewhat easy, and 33.33% were neutral. Meanwhile, 22.22% found them somewhat challenging, and 7.41% considered them difficult. This range of responses suggests that some students may benefit from additional guidance or refinements in the experiment design to ensure accessibility for all learners.

With respect to the time span assigned for the experimental undertakings, 48.15% of the participants asserted that the time allocated was adequate, while 11.11% deemed it moderately adequate, and 11.11% conveyed a neutral sentiment. Conversely, 25.93% expressed the opinion that the allotted time was somewhat inadequate, and 3.70% classified it as entirely insufficient. Although the majority of students successfully completed the tasks within the designated timeframe, the data indicates that modifications in scheduling or the provision of supplementary support materials could enhance the overall experience for all participants.

Students also provided feedback on the comprehensibility of the instructions, with 66.67% evaluating them as clear and 14.81% as somewhat clear. A minor fraction (7.41%) remained neutral, while 11.11% found the instructions to be somewhat unclear. Although a significant number of students did not encounter challenges, the refinement of instructional materials to enhance clarity could further assist those who experienced difficulties.

In conclusion, students were solicited to assess the efficacy of video analysis in the context of studying oscillatory motion. A substantial 51.85% regarded the experiments as highly beneficial for their comprehension, while 37.04% classified them as somewhat useful. The remaining 11.11% maintained a neutral perspective, and none indicated that the experiments were ineffective. These findings imply that video analysis constitutes a viable approach for conducting physics experiments in contexts where conventional laboratory resources may be constrained.

In summary, the feedback from students underscores video analysis as a pragmatic and engaging instrument for the exploration of oscillatory motion. Its accessibility enables students to engage in meaningful experimental activities without necessitating costly sensors, rendering it particularly advantageous for remote learning and educational environments with limited resources. Additionally, this methodology can be implemented using various software tools, including open-source and freely available options, further enhancing its accessibility and adaptability. The survey results support the continued integration

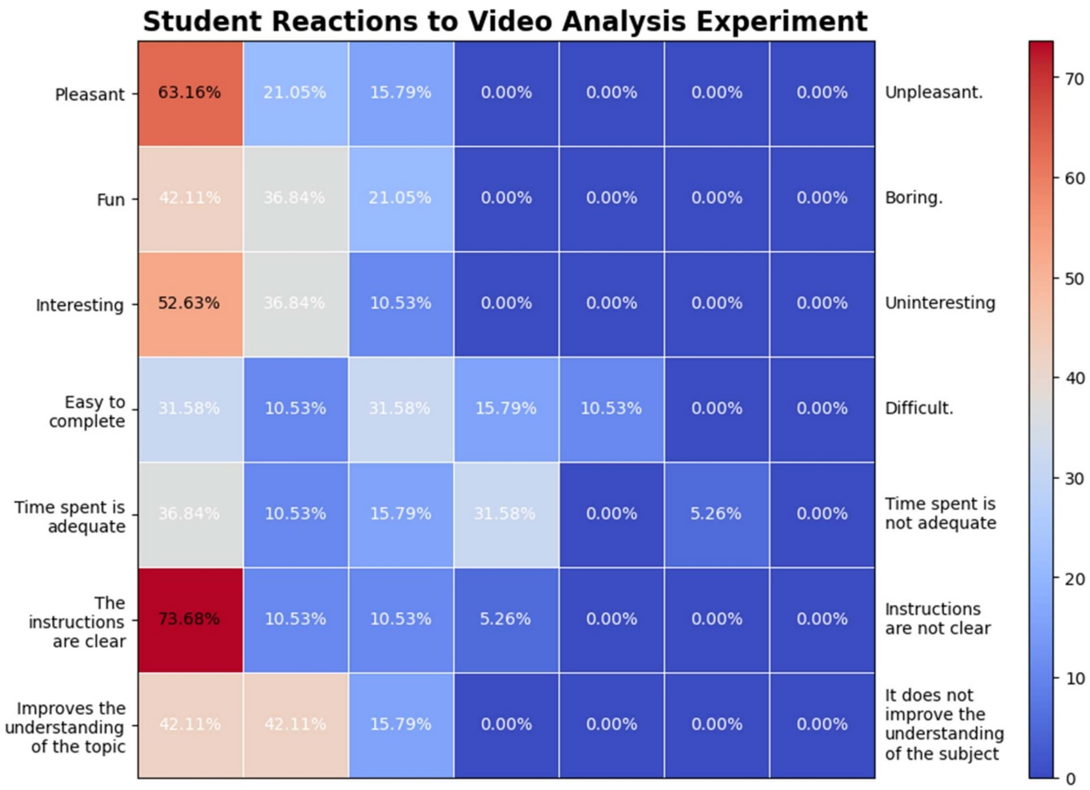

Figure 5. Results from the semantic differential scale poll, showing students' perceptions of the video analysis experiments, including engagement, enjoyment, and educational value.

of video analysis into physics education as a flexible alternative to traditional laboratory-based experiments.

Our findings suggest that video analysis provides students with an intuitive way to study oscillatory motion, particularly by allowing them to analyse movement frame by frame. This approach bears similarities to the 'snapshot' methodology discussed by Knight [10] and the model-building approach outlined by Hoellwarth and Moelter [11], where students develop conceptual understanding through progressive refinement of visual representations. By enabling students to engage with real experimental data in an incremental manner, video analysis serves as a complementary tool for physics instruction, particularly in low-resource settings where traditional laboratory experiments may be less accessible.

5. Conclusion

This study presents video analysis as a practical and accessible tool for studying oscillatory motion in physics education. The experimental results demonstrate that students were able to conduct meaningful motion analysis without requiring specialized sensors, highlighting the adaptability of this approach for various learning environments, including remote and resource-limited settings. The consistency in the measured angular frequencies and spring constants across multiple trials suggests that video analysis provides reliable experimental data using simple, readily available materials.

Student feedback further supports the feasibility of this method, with the majority of participants reporting that the experiments were engaging and enjoyable. The ability to record, visualize, and analyse motion using common devices such as smartphones and open-source software provided an intuitive and interactive approach to studying oscillatory motion. The findings suggest that video analysis is an effective alternative for students who may not have access to traditional laboratory equipment.

While the methodology proved significantly useful, some areas for improvement were identified. A subset of students found certain aspects of the experiments challenging, indicating that adjustments in instructional materials and additional guidance may enhance accessibility. Similarly, minor modifications in the experimental design could further optimize the clarity and usability of video analysis for students with varying levels of experience.

In conclusion, the present investigation underscores the promise of video analysis as an instrumental resource for the education of physics. Its inherent flexibility enables learners to execute experiments across varied environments, rendering it especially pertinent for remote instruction and educational establishments with constrained laboratory facilities. Through the incorporation of video analysis into physics educational frameworks, instructors can provide an alternative methodology that preserves experimental integrity while enhancing accessibility for a more extensive spectrum of learners.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Ethics statement

This study involved students conducting a physics experiment and completing a survey. Participation was entirely voluntary, and informed consent was obtained from all participants before data collection. As all students involved were adults (18 years or older), no parental or guardian consent was required. Participants were explicitly informed that their responses would be used for research purposes, including publication, and they agreed to the use of their anonymized data. The research was conducted in accordance with the ethical guidelines of the University of Costa Rica regarding classroom-based studies. As the study did not involve sensitive personal data, medical procedures, or interventions, and was not part of a funded or formally registered research project, approval from the institutional ethics committee was not required. The study adhered to the ethical principles outlined in the IOP Publishing Ethical Policy for research involving human subjects.

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References

[1] Laws P and Pfister H 1998 *Phys. Teach.* **36** 282–7
[2] Bryan J A 2010 *Phys. Educ.* **45** 50
[3] Brown D and Cox A J 2009 *Phys. Teach.* **47** 145–50
[4] Desbien D M 2011 *Phys. Teach.* **49** 332–3
[5] Jaime E A 2011 Enseñanza de las Ciencias *Rev. Invest. Exp. Didácticas* **29** 371–80
[6] Lampara E C L and Maquiling J 2021 The effect of video analysis on students *Motiv. Learn. Phys.* **11** 1
[7] Putra B E 2022 *J. sains pendidik.* **5** 10–15
[8] Tarjányi N and Tarjányiová G 2022 *Video Analysis of Physical Phenomena as a Training of Students for Solving Practical Technical Problems* (ELEKTRO) pp 1–4
[9] Wee L K and Lee T L 2012 arXiv: Physics Education (available at: www.semanticscholar.org/paper/b86be2b53e910bd44f41d7c08a48ff1ecfd5b64c)
[10] Knight R D 2007 *Physics for Scientists and Engineers: A Strategic Approach With Modern Physics and Masteringphysics* 2nd edn, ed D Randall (Benjamin Cummings)
[11] Hoellwarth C and Moelter M J 2011 *Phys. Teach.* **49** 180–3

[12] Martínez Ruiz H 2012 *Metodología de la Investigación : con Enfoque en Competencias : Sexto Semestre* 1st edn (Cengage Learning)

[13] Rizo F M 2020 EL nuevo oficio del investigador educativo (Libros en Acceso Abierto de la Universidad Autónoma de Aguascalientes) (available at: https://libros.uaa.mx/index.php/uaa/catalog/book/51)

[14] PASCO Capstone^{TM} Software (available at: www.pasco.com/products/software/capstone)

[15] Cervantes J 2019 Efecto fotoeléctrico y divisor de voltaje, su aprendizaje bajo la metodología ISLE *PhD Thesis* Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada Unidad Legaria