ISSN 2529-9824

Research article

Audiovisual support for a flipped classroom in Engineering Mathematics labs

Apoyo audiovisual en un modelo de aula invertida en las prácticas de Matemáticas en Grados de Ingeniería

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Receipt Date: 15/04/2025

Acceptance Date: 16/05/2025

Publication Date: 20/05/2025

How to cite the article

Egorova, V., Bedia Jiménez, J., Frías Domínguez, M. D., García Manzanas, R., Pérez Carabaza, S., Sordo García, C., & Casanueva Vicente, A. (2025). Audiovisual support for a flipped classroom model in Engineering Mathematics labs [Apoyo audiovisual en un modelo de aula invertida en las prácticas de Matemáticas en Grados de Ingeniería]. *European Public & Social Innovation Review*, 10, 01-22. https://doi.org/10.31637/epsir-2025-2121

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Abstract
Introduction: The study focuses on the incorporation of audiovisual resources and the flipped classroom strategy in computer laboratories. These techniques are effective in enriching the teaching-learning process, providing students with a more interactive approach. **Methodology**: The methodology implemented during the 2023-24 academic year by the "InMaths" teaching innovation group at the University of Cantabria is presented. The methodology included the production of videos, their integration into computer practical classes, and the analysis of their impact on learning the use of software in mathematics. **Results:** Results from 300 surveys across all subjects included in the study indicate that the implementation of the flipped classroom strategy with audiovisual support improves student motivation and participation in their learning. Students value the videos positively and believe that this strategy better prepares them for practical activities. **Discussion:** The results are consistent with previous research indicating that the flipped classroom strategy can enhance student preparation and participation, although the evaluation experience with control and experimental groups only showed grade improvements in some subjects and student groups. **Conclusions**: The methodology can help students develop a deeper understanding of mathematical concepts and improve their skills in solving problems with specific software.

Keywords: audiovisual resources; computer lab practices; educational videos; engineering students; flipped classroom; self-directed learning; mathematical software; mathematics teaching.

Resumen
Introducción: El estudio se enfoca en la incorporación de recursos audiovisuales y la estrategia del aula invertida en prácticas de ordenador. Estas técnicas son efectivas para enriquecer el proceso de enseñanza-aprendizaje, proporcionando a los estudiantes un enfoque más interactivo **Metodología:** Se presenta la metodología implementada durante el curso 2023-24 por el grupo de innovación docente "InMaths" en la Universidad de Cantabria. La metodología incluyó la producción de videos, su integración en clases prácticas de ordenador y el análisis del impacto de los mismos en el aprendizaje del uso de software en matemáticas. **Resultados:** Los resultados de 300 encuestas realizadas en todas las materias del estudio indican que la implementación del aula invertida con soporte audiovisual mejora la motivación y la participación del alumnado en su aprendizaje. Los alumnos valoran positivamente los videos y creen que esta estrategia les prepara mejor para las actividades de prácticas. **Discusión:** Los resultados son coherentes con investigaciones anteriores que indican que la estrategia del aula invertida puede mejorar la preparación y participación del alumnado aunque en la experiencia de evaluación realizada con grupos de control y experimental solo se ha observado una mejora en la calificación en algunas asignaturas y grupos de estudiantes. **Conclusiones:** La metodología utilizada está muy bien percibida por el alumnado y puede mejorar sus habilidades para resolver problemas académicos a través del uso de herramientas de software.

Palabras clave: recursos audiovisuales; prácticas de ordenador; vídeos educativos; estudiantes de ingeniería; aula invertida; autoaprendizaje; software matemático; enseñanza de matemáticas.

1. Introduction

Effective mathematics education requires a balance between theoretical understanding and practical application. Traditional methods like lectures and textbooks are crucial for building a strong foundation in mathematical concepts. However, computer labs offer a valuable platform for experiential learning in higher education, solidifying the connection between theory and practice (Onyeaka et al., 2023). This is especially crucial for Engineering Degree students, who rely heavily on applying mathematical principles to solve real-world problems. To achieve this balance, effective design of computer lab practices is essential.

In recent years, the flipped classroom approach has emerged as a transformative force in educational technology, gaining significant popularity in higher education (Baig & Yadegaridehkordi, 2023; Bergmann & Sams, 2012; Bye, 2017). This approach flips the traditional script: students actively engage with supplementary materials outside of class, allowing for a more interactive classroom environment focused on discussions, problem-solving activities, and hands-on experiences. These preliminary supplementary materials, such as videos, podcasts, lecture notes, etc., provide flexible learning options, allowing students to learn at their own pace and revisit complex concepts as needed (Zaneldin et al., 2019).

The integration of these innovative methods, particularly the flipped classroom with pre-lab videos, has garnered significant attention in engineering education (Bedia Jiménez et al., 2023; Casanueva Vicente et al., 2022; Rengel et al., 2017). Studies like Ishak et al. (2020) demonstrate that pre-class videos significantly improve student motivation, engagement, and overall satisfaction, particularly within a flipped classroom setting. However, Amalric et al. (2023) has recently shown that brief educational videos alone are insufficient for significant long-term learning in mathematics, highlighting the need for more robust educational methods for lasting impact.

The use of online pre-lab quizzes is another effective strategy within the flipped classroom methodology, as demonstrated by Cann (2016). By requiring them to complete quizzes before attending lab sessions, instructors can ensure that students arrive better prepared and more engaged. This approach not only enhances student preparedness but also promotes active participation and confidence in practical classes (O'Flaherty & Phillips, 2015).

Therefore, the combination of well-designed pre-laboratory online resources, such as quizzes, exercises, and audiovisual materials, is a promising tool to enhance the overall educational experience and efficacy of engineering students in computer laboratory classes. This study aims to analyze the impact of the flipped classroom approach with audiovisual support in Mathematics labs learning. The tested pre-lab videos include interaction points with questions related to the content (Kaltura Quiz) and links to interactive pedagogical tools (e.g. MATLAB Grader and GeoGebra) so that students can demonstrate their acquired knowledge by writing and executing a programming code (Pérez Carabaza et al., 2023). In addition, the option of including open-ended questions with Kaltura Quiz allow students to raise questions about the teaching material presented in the videos, which can be answered later in the class. In face-to-face classes, the practice will be reviewed through an online questionnaire (Kahoot, Quizizz, etc.), the results of which will give the teacher the opportunity to emphasize the concepts that have not been clear and to adapt the lecture pace.

2. Methodology

2.1. Participants

A total of 607 first- and second-year undergraduate engineering students enrolled in 10 different mathematical courses at the Universidad de Cantabria, Spain, during the 2023-2024 academic year have participated in this study. Table 1 presents a detailed breakdown, including the subjects they are enrolled in, their respective degree programs, the semester in which the course was taken, the proportion of laboratory credits to total course credits, and the number of students enrolled in each subject. Most students are in their first course (1st and 2nd semesters) while 118 are enrolled in subjects of the second course (3rd and 4th semesters), namely *Extension of Mathematics*, *Statistics* (Chemical Engineering Degree) and *Mathematical Methods for Engineering*. Also, in most subjects (six out of ten) lab sessions represent about one-fourth of the total number of credits, thus consequently they entail an important part of the grade.

Table 1.

Participants of the study

Subject	Degree	Semester	Lab Credits / Total Credits	Number of students
Algebra	Chemical Engineering (Chem. Eng.)	2	1,5/6	72
Algebra and Geometry	Industrial Technologies Engineering (Ind. Eng.)	2	1,5/6	69
Linear Algebra and Geometry	Energy Resources Engineering & Mining Resources Engineering (Min. Eng.)	1	0,8 /6	42
Calculus	Civil Engineering (Civ. Eng.)	1	0,6/6	63
Calculus I	Electrical Engineering & Industrial Electronic Engineering and Automatic Control Systems (Elec. Eng.)	1	1,5/6	84
Calculus II	Telecommunication Technologies Engineering (Telec. Eng.)	2	1,5/6	95
Extension of Mathematics	Energy Resources Engineering & Mining Resources Engineering (Min. Eng.)	4	0,8/6	21
Statistics	Chemical Engineering (Chem. Eng.)	3	1,4/6	43
Statistics	Civil Engineering (Civ. Eng.)	2	1,2/6	64
Mathematical Methods for Engineering	Electrical Engineering & Industrial Electronic Engineering and Automatic Control Systems (Elec. Eng.)	3	1,5/6	54
Total			**12,3/60**	**607**

Source: Own design (2024).

2.2. Research design

2.2.1. Pre-Laboratory Videos

In this study, we developed short instructional videos showcasing the application of specialized mathematical software, like GeoGebra, and programming languages including R and MATLAB (Table 2). These videos were designed to support the flipped classroom methodology applied at the ten courses listed in Table 1. The videos are complementary learning resources apart from the laboratory guides (typically static documents).

To create these videos efficiently and promote open access, we prioritized the use of free and open-source software tools such as OBS Studio, Shotcut and OpenShot. These tools empowered instructors to produce high-quality educational content without budgetary constraints. Once created, the videos were uploaded to Moodle using the Kaltura media integration platform[2], which is fully integrated in the University of Cantabria Moodle. This tool allows video editing and includes options for navigation and adding subtitles and transcripts, improving accessibility for international students or those with hearing impairments. Subtitles could be automatically generated in the video's original language and easily refined using an integrated editing tool.

Another important feature of Kaltura is the insertion of interaction points (e.g. links to other resources) and the integration of questions within the videos (Kaltura Quiz). These questions can serve as self-assessment tools for students, providing instant feedback on their understanding of the material. The quiz results are recorded within Moodle, allowing instructors to monitor the students' progress and identify areas needing further clarification. More details about Kaltura quizzes can be found in Bedia Jiménez et al. (2023).

Table 2.

Number of videos created per subject, indicating also the number of subtitled videos (in Spanish -SP- and/or in English -EN) and the kind of interactive element implemented in the videos. Here, the subjects in Table 1 have been grouped in Algebra, Calculus, Statistics and Numerical Methods. "Common" refers to introductory software videos which can be used regardless of the subject

Subject	Number of videos	Subtitled videos	Interactive elements
Algebra	4	4 (SP)	MATLAB Grader (2)
Calculus	25	23 (SP), 8 (EN)	Quiz (4), MATLAB Grader (8), GeoGebra (4)
Statistics	5	5 (SP), 5 (EN)	Quiz (3)
Numerical Methods	15	13 (SP), 1 (EN)	Quiz (11), MATLAB Grader (4)
Common	8	7 (SP), 6 (EN)	Quiz (5)
Total	**57**	**52 (SP), 20 (EN)**	**Quiz (23), MATLAB Grader (14), GeoGebra (4)**

Source: Own design (2024).

[2] https://corp.kaltura.com/

2.2.2. Interactive exercises

Beyond the inclusion of questions (Kaltura Quiz), the videos also incorporated interaction points with links to other resources, such as MATLAB Grader and GeoGebra (Table 2). The objective of using these tools was to require students to actively engage with specific software to answer questions, rather than passively watching the videos.

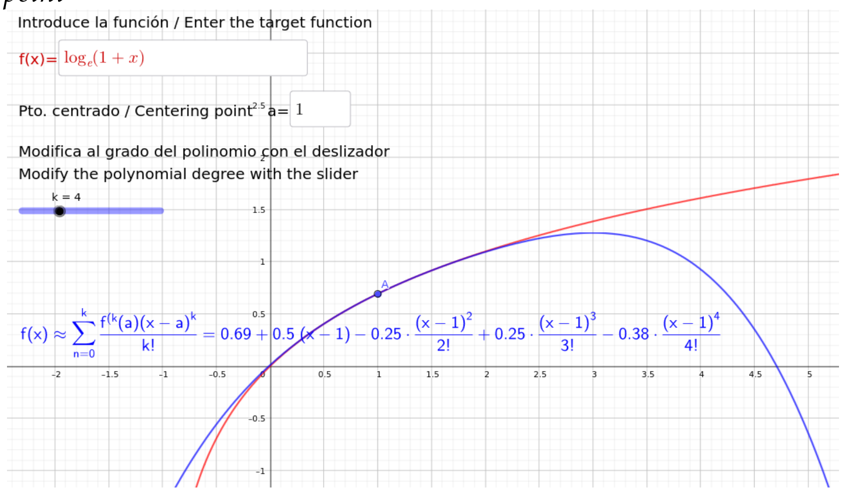
GeoGebra[3], an interactive educational tool for exploring and experimenting with mathematical concepts, was seamlessly integrated into the videos, see Tamam & Dasari, (2021) for more details. These introductory segments explained key concepts, provided step-by-step demonstrations, and offered guided practice exercises. Students, for example, might manipulate applets to answer questions about plotting functions or constructing geometric figures as shown in Figure 1.

MATLAB Grader, a browser-based platform for creating and automatically evaluating MATLAB programming problems, also enhanced student engagement. Instructors provide resolution templates with intermediate steps leading to the final solution (Figure 2). Since its full integration with Moodle, MATLAB Grader has allowed educators to create, manage, share, and evaluate these resources seamlessly. The teaching team's experience suggests that the immediate, step-by-step feedback provided by MATLAB Grader, combined with its user-friendly interface, has been effective in helping students master MATLAB.

By integrating these pre-lab videos into the flipped classroom model, the study aimed to enhance student engagement and learning outcomes in computer laboratory classes. The instant feedback from quizzes and the ability to track student progress allowed instructors to tailor in-class sessions to address specific learning needs, ultimately optimizing the educational experience.

Figure 1.

Example of GeoGebra usage: Interactive visualization of Taylor Polynomial's n-th order approximation at an arbitrary point



Source: https://www.geogebra.org/m/bfcammpd (2024).

[3] www.geogebra.org

Figure 2.

Example of MATLAB Grader usage

Source: Own design (2024).

2.2.3. Laboratory sessions

The laboratory sessions in this study followed entirely the flipped classroom approach, providing students with hands-on experience in applying mathematical concepts using specific software tools. These sessions were designed to reinforce pre-lab preparations and maximize student engagement and understanding. To support this, the content of the practice was reviewed at the beginning of the lab using a questionnaire (either a Moodle questionnaire or Kahoot, Quizizz, etc.), aiming to increase active participation and boost confidence in practical classes. The questionnaire results gave the instructors the opportunity to emphasize the concepts that have not been clear in the pre-lab materials and to adapt the lecture pace.

The laboratory sessions focused on practical exercises that required students to apply the knowledge gained through the pre-lab learning materials. During the lab sessions, instructors offered real-time support, answering questions and providing guidance as needed. This ensured that students could address any misunderstandings immediately and benefit from personalized instruction.

Flipped classroom methodology encourages student autonomy, promotes a more dynamic learning experience, and maximizes the use of class time for practical activities. Emphasis is placed on active student participation and individualized support to address the challenges of programming and computer-based problem-solving. Additionally, collaborative work is encouraged, allowing the exchange of knowledge and strategies that enrich the educational experience and foster the development of social and soft skills, such as teamwork and analytical thinking (Ovejero Bernal, 2013).

2.3. *Data collection*

The first step in the data analysis involved examining the participation statistics provided by Kaltura for the multimedia resources available to students through the Moodle platform of each course. This analysis aimed to track and evaluate student engagement with the pre-lab videos, including metrics such as number of plays, reactions, average watch time, and completion rates.

Secondly, a common survey was created in the Moodle platform of each course to gather student feedback on the inclusion of videos in laboratory practices and the overall flipped classroom strategies. This survey aimed to collect students' opinions on the effectiveness, usability, and impact of the pre-lab videos and their interactive components.

Finally, the evaluation of the academic performance in computer lab practices involved designing a controlled experiment to quantify potential grade improvements resulting from the implementation of the flipped classroom methodology with pre-lab audiovisual support. This was achieved by comparing the academic performance in computer lab practices of two groups: control and experimental, in the courses where two separate groups of students were ensured.

The control group followed the flipped classroom methodology, relying only on the laboratory guide (static document) for pre-lab preparation. The experimental group also followed the flipped classroom methodology, but with the added benefit of pre-lab videos and interactive tools. In each course, the controlled experiment was carried out in two lab sessions, in which the experimental group watched the videos in the classroom to ensure the actual effect of watching them. Students were organized in the two groups in a way that they belonged to one and another in each lab session. Thus, they participated in either group once and only results of students in the two groups were considered (i.e. the grades of those who did not attend the full experiment were disregarded).

Academic performance is measured through the grades obtained in laboratory activities, more precisely those of the questionnaire after watching (or not) the video and/or the grade of the practical exercises solved during the lab session. The latter was considered in courses whose evaluation consists in the work during the lab sessions, rather than a final exam. By comparing the performance of both groups, we can gain insights into the effectiveness of the pre-lab videos as a support mechanism within the flipped classroom approach.

3. Results and Discussions

This section analyzes the results from Kaltura statistics, students' surveys, and academic performance evaluations.

3.1. Students' engagement: Kaltura statistics

The study involved preparing 57 videos (detailed information in Table 2) and uploading them to Moodle through Kaltura, a video hosting platform, which allows us to track student interaction with the videos. Students could watch the videos at their own pace and as many times as they want to, as preparation for the lab sessions. On average, 86% of the plays were accessed through the computer. Table 3 summarizes this interaction by subject. It analyzes three key metrics: number of plays (total views), number of unique users per video (students who viewed any videos) and mean total completion rate (average percentage watched). This completion rate is further broken down by overall average and by gender (female and male users). This analysis allows us to compare how much of the video, on average, students of each gender typically watched. Females exhibit a slightly higher overall completion rate (74,2%) compared to males (69,6%). However, this trend appears to differ for *Algebra*, where males have a higher completion rate. Note that the number of men and women is not even in the analyzed Engineering Degrees. In fact, overall, there are approximately half as many women as men and *Statistics* is the only subject with a similar number of men and women.

Table 3.

Interaction with the videos by subject, in terms of number of plays, unique users and total completion rate (mean over subjects included in Table 1, in %). The last row shows the sum of plays and unique users and the mean of the total competition rates

Subject	Number of plays	Number of unique users	Mean total completion rate (all | females | males)
Algebra	393	248	77,6 | 71,4 | 82,6
Calculus	1.390	815	70,7 | 71,2 | 70,4
Statistics	435	311	80,5 | 85,7 | 78,7
Numerical Methods	311	269	62 | 79 | 59
Common	646	465	58,9 | 63,6 |57,4
Total	**3.175**	**2.108**	**70,0 | 74,2 | 69,6**

Source: Own design (2024).

3.2. Students' survey

The pre-lab videos are designed to prepare students for the computer practice session. Therefore, student feedback is crucial to this study. At the end of each course, typically during the last class, students complete an anonymous survey with 12 questions about the videos. We collected a total of 300 surveys across all subjects included in the study.

Table 4 provides an overview of video viewership across different subjects. According to the survey, 85 students watched all the assigned videos, while only 9 students reported not watching any videos at all. Most students (67%) watched either all or most of the videos, reflecting a generally high level of engagement with the video content. Additionally, the fact that only a small minority (3%) did not watch any videos suggests that the vast majority of students are at least somewhat engaged with the video materials.

Table 4.

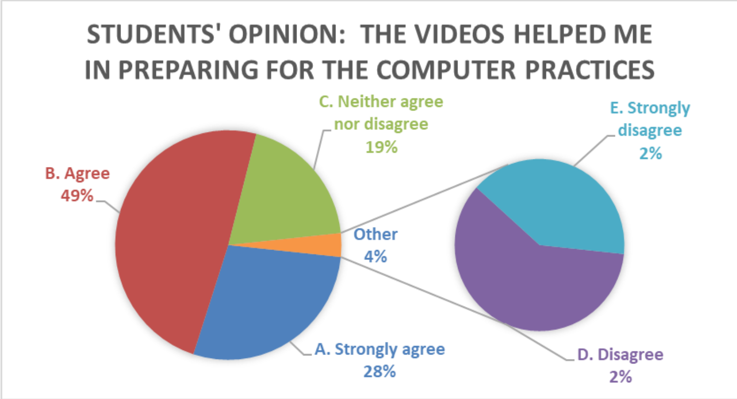
Students' opinion: how many videos have you watched?

Answer	Algebra	Calculus	Statistics	Total
All	26	34	25	85
Most	47	39	31	117
Few	43	21	25	89
None	6	2	1	9
Total	**122**	**96**	**82**	**300**

Source: Own design (2024).

Figure 3.

Student opinions on the effectiveness of videos for preparing for computer practices



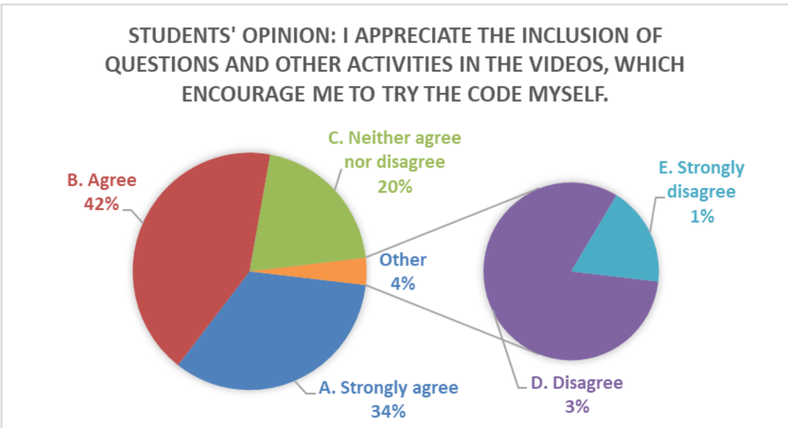
Source: Own design (2024).

Next, we asked students to rate the extent to which the videos helped them in preparing for computer practices. The responses are categorized into five levels of agreement: Strongly agree, Agree, neither agree nor disagree, Disagree, and Strongly disagree (Figure 3). The survey results indicate a strong positive impact of the videos on students' preparation. A significant majority of students (77%) either strongly agreed (28%) or agreed (49%) that the videos helped in preparing for computer practices. This suggests that students found the video content to be a valuable tool in preparing for computer practices.

Including interactive elements like questions (Kaltura Quiz), MATLAB Grader exercises, or GeoGebra assignments might enhance the effectiveness of the pre-lab videos. To investigate this, the survey included a question about the students' opinion on these interaction points. Figure 4 presents the results. A substantial majority of students (76%) either strongly agreed (34%) or agreed (42%) that the interaction points were helpful. This suggests that students generally viewed these interactive elements as beneficial for their learning. Also, 20,3% of students neither agreed nor disagreed, suggesting that while they did not find the interactive elements particularly attractive, they also did not find them unproductive. This group might require more information about these interactive features to form a more definite opinion.

Figure 4.

Students' opinions on the effectiveness of interactions in the videos.



Source: Own design (2024).

3.3. Academic Performance Evaluation

To further investigate the impact of pre-lab videos, we compared the performance of two groups within the flipped classroom setting (see Sec. 2.3.3). The control group relied primarily on the laboratory guide (a static document) for pre-lab preparation, as typically done in flipped classrooms. The experimental group received the same flipped classroom instruction but with the added benefit of pre-lab videos and interactive tools to enhance understanding before the lab session.

During the computer practice session, students completed one or two assessments depending on the subject: a brief questionnaire (5-10 questions) focused on the current lab session material right after watching (or not) the videos in the class; and/or practical assessment to evaluate their hands-on skills during the lab session. To control for potential order effects, we repeated the experiment in another lab session, but with the groups reversed. In the second session, the original control group received the pre-lab videos and tools (becoming the experimental group), and the original experimental group relied solely on the laboratory guide (becoming the control group). Therefore, for each student, we have two sets of data: one reflecting their performance when they had access to audiovisual support (pre-lab videos and interactive tools), and the other reflecting their performance without this support.

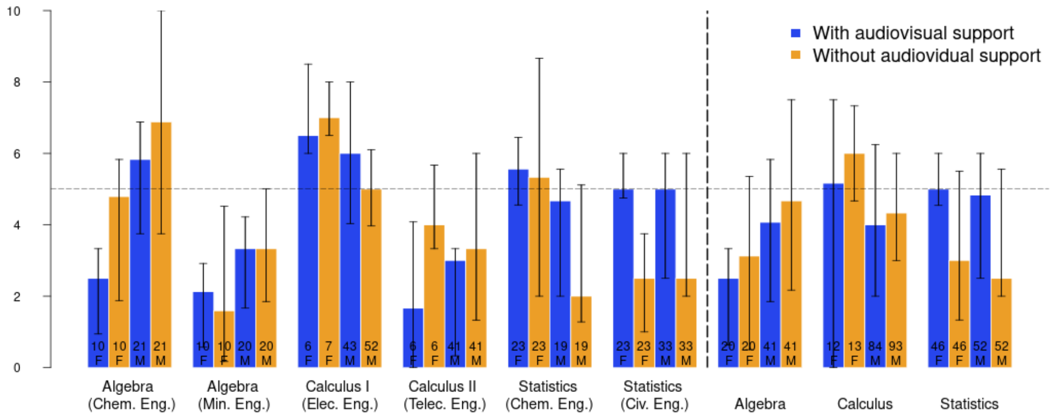
In addition to descriptive statistics, we fitted a linear mixed-effect model to disentangle the variability associated with the results. Our dependent variable was the students' grades, and our independent variable was whether or not the students watched a video before the evaluation. We considered both the student and the subject as random effects, thus allowing each student and each subject to have their own intercept. This implies that each student may have a different baseline performance (some may naturally perform better than others), and each subject may have a different baseline difficulty level (some may naturally be more difficult than others). This is particularly useful when we expect there to be variability among our subjects (students) or repeated measures (subjects) that is not explained by our fixed variables (in this case, whether or not they watched the video and the student's sex). By allowing the intercepts to vary, we are modeling this variability and preventing it from being confounded with the effect of our fixed variables. We employed a mixed linear effects model using the *lmer* function from the *lme4* package (Bates et al., 2015) in R (R Core Team 2024). The p-values provided for the fixed effects are the results of the estimation of degrees of freedom by the Satterthwaite method, especially useful when the data have a complex variance structure, as is the case with mixed-effects models where both fixed and random effects are present. We use the implementation in the R package *lmerTest* (Kuznetsova et al., 2017).

3.3.1. Questionnaire results

We collected test scores from a total of 265 students across the subjects included in the study. Figure 5 presents the average test grades for each subject, broken down by gender and audiovisual support.

Figure 5.

Test grades per subject and degree (see Table 1) and gender. Bars indicate mean grades and whiskers the interquartile range. The number in each bar depicts the number of women (F = Female) and men (M = male). The last three groups of bars show the aggregated results for Algebra, Calculus and Statistics



Source: Own design (2024).

It is worth mentioning that mean scores are generally low, below 6 points (over 10) in almost all cases and below 5 points (passing grade, dashed line in Figure 5) in many of them. Overall, the average grade with audiovisual support (4,31) is slightly higher than the average grade without support (4,21). However, this trend is not consistent across all subjects. In *Statistics*, students performed better with audiovisual support, while in *Algebra* and *Calculus*, the trend is reversed, with slightly higher average grades without support. In the specific case of *Statistics*, applying a two-sample hypothesis test leads to the conclusion that we can accept, with 99% confidence, that the average test score is higher if the video is watched than if it is not. Bear in mind that one of the considered *Statistics* courses (Chemical Engineering Degree with 43 students) takes place during the third semester, thus we expect these students to be more settled and to have a better background. Female students showed a slight improvement in their average grades. In general, females with audiovisual support scored an average of 4,3, while those without support scored an average of 4,0. Male students, on the other hand, maintained a consistent average grade of 4,3 across both groups (with and without audiovisual support).

We also analyzed the impact of audiovisual support by comparing the rate of improvement in each student's grades. Since we have paired data for each student (grades with and without support), we calculated the percentage of students who improved their grade when given audiovisual support (Table 5). *Statistics* has the highest overall improvement rate. A significant portion of both genders improved (62% of females and 55% of males), suggesting that the audiovisual support was particularly helpful in this subject. While *Calculus* shows the lowest overall improvement rate. Here, males outperform females, with 45% improvement compared to 27% of females. It is also worth noting the differences between subjects within the same category, e.g. the percentage of males improving their grades is 32% for *Calculus II* (Telecommunication Technologies Engineering) and 60% for *Calculus I* (Electrical Engineering & Industrial Electronic Engineering and Automatic Control Systems).

Table 5.

Percentage of students who improved test grades with audiovisual support, per subject and degree (see Table 1) and aggregated for Algebra, Calculus and Statistics

Subject	Female	Male	Total
Algebra	**42,11%**	**39,02%**	**40,00%**
Chem. Engineering	33,33%	47,62%	43,33%
Min. Engineering	50,00%	30,00%	36,67%
Calculus	**27,27%**	**44,59%**	**42,35%**
Elec. Engineering	40,00%	60,61%	57,89%
Telec. Engineering	16,67%	31,71%	29,79%
Statistics	**62,22%**	**54,55%**	**58,00%**
Civ. Engineering	73,91%	55,88%	63,16%
Chem. Engineering	50,00%	52,38%	51,16%

Source: Own design (2024).

These preliminary analyses revealed significant variability in the results depending on the subject considered. This subject-specific variation underscores the complexity of our dataset and the unique characteristics inherent to each subject. To better reflect this diversity and provide a more nuanced understanding of our data, we constructed the mixed linear effect models separated by subjects. This approach allows us to inspect more deeply the subject-specific patterns that might be obscured in an aggregated analysis. For brevity, we have chosen to present detailed statistical analysis results from two contrasting subjects in this paper. On the one hand, in *Algebra* (Table 6) we did not find a relevant positive effect of the videos on the test performance, in line with *Calculus* (not shown). On the other hand, the results from the subject *Statistics* (Table 7) depict a positive effect of watching the video prior to the test on the final grades attained; the latter aligns more closely with our initial assumptions that encouraged us to introduce this innovation in our subjects.

Table 6 shows the results of the linear model considering fixed effects for *Algebra*. The term '(Intercept)' represents the expected mean test grade for a female student who has not watched the video. Its estimate is 3,4854. 'watched_video (Yes)' represents the expected change in the test grade for students who have watched the video compared to those who have not watched the video. Its estimate is -0,7128, suggesting that, on average, students who watched the video scored lower on the test, and did not reach, on average, the passing grade of 5, although this effect is not statistically significant, and therefore it cannot be concluded that watching the videos has a negative effect on the test grades. Similarly, we cannot assert that it helped to improve the grades in Algebra. On the other hand, 'sex (Male)' represents the expected difference in the test score between male and female students, assuming they did not watch the video. Its estimate is 1,3428, showing that, on average, male students scored this amount higher on the test than female students. This effect is statistically significant at the 5% level.

The random effect 'student (Intercept)' with a variance of 1,606 suggests that there is substantial variability in test grades between different students that is not explained by whether they watched the video or their sex.

This could be due to individual differences in study habits, prior knowledge or math skills, motivation, etc. Similarly, the random effect ‘subject (Intercept)’ with a variance of 2.046 indicates that there is also significant variability in test grades between different degrees, that is not accounted for by the fixed effects in the model. This could be attributed to differences in the difficulty of the degrees, the teaching style, etc. Overall, these results support the introduction of random effects to account for the variability in the groups and highlight the heterogeneity of student performance in our classrooms, that can be -at least partially- attributed to different cut-off marks for the access to the different degrees involved and that the majority of subjects are first-year ones, a factor that can introduce greater heterogeneity in the students’ profiles. There is still a significant amount of unexplained variability (*Residual* = 7,770), more than two thirds of the total variance), suggesting that other important factors and/or a higher sample size might be needed to obtain more robust results.

Table 6.

Summary of the linear mixed-effects model examining the impact of video watching (watched_video) and gender (sex) on test grades (test_grade), with random effects for individual students (student) and subjects (subject_id). ‘subject_id’ corresponds to the ‘degree’ column in Table 1 (namely Chemical Engineering and Energy Resources Engineering & Mining Resources Engineering). The table presents the variance and standard deviation for the random effects, the estimates, standard errors, degrees of freedom, t-values, and p-values for the fixed effects, and the correlation between the fixed effects. The model was fitted on a subset of 153 observations from two subjects, with 92 unique students. Significant effects at the 95% confidence level are highlighted in boldface

Random effects - Algebra	
	Variance
student (Intercept)	1,606
subject (Intercept)	2,046
Residual	7,770

Number of obs: 153, groups: student, 92; subject_id, 2;

Fixed effects - Algebra					
	Estimate	Std. error	df	t value	Pr(>|t|)
(Intercept)	3,4854	1,1218	1,3200	3,107	0,1474
watched_video (Yes)	-0,7128	0,4591	75,2306	-1,553	0,1247
Sex (Male)	1,3428	0,5470	80,1543	2,455	**0,0163**

Source: Own design (2024).

Unlike *Algebra*, the model of the *Statistics* subject (Table 7) unveils a strong significant effect of watching the video on the test results, with non-significant effect of sex on these results. The ‘watched_video (Yes)’ term represents the estimated change in the mean test grade after having watched the video, holding all other variables constant. Here, it’s 0.9661 with a standard error of 0.3086, meaning that on average, watching the video adds almost +1 point on the test grade. The p-value is 0.00227 and it is therefore significant at the 0.01 level. The results of *Statistics* therefore support the positive effects of the video methodology to improve the overall test grades (Figure 5).

Table 7.

Same as Table 6, but for the subject Statistics. In this case, the model was fitted on a subset of 205 observations from two subject_id's (Chemical and Civil Engineerings), with 107 unique students

Random effects - Statistics	
	Variance
student (Intercept)	2,0391
subject (Intercept)	0,1973
Residual	4,8150

Number of obs: 205, groups: student, 107; subject_id, 2;

Fixed effects - Statistics					
	Estimate	Std. error	df	t value	Pr(>|t|)
(Intercept)	3,9078	0,4623	2,1971	8,454	**0,01025**
watched_video (Yes)	0,9661	0,3086	102,1942	3,131	**0,00227**
Sex (Male)	-0,3417	0,4162	107,6934	-0,821	0,41344

Source: Own design (2024).

3.3.2. Practical assessment results

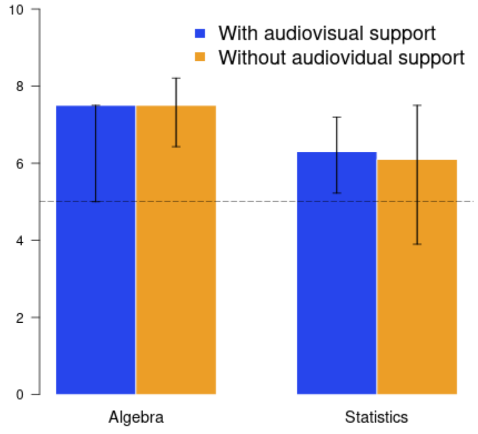
Similar analysis is performed for the grades of practical assessments. The results are available only for *Algebra* (Industrial Technologies Engineering and Mining Resources Engineering) and *Statistics* (Chemical Engineering) and presented in Figure 6.

The overall average grades are very similar, with a slight increase when audiovisual support is used. In particular, in *Algebra*, students achieved similar results with or without audiovisual support (7,5), whereas students in *Statistics* performed better with audiovisual support (6,3) compared to without support (6,1).

Our study reveals significant differences in the outcomes of the flipped classroom methodology across various subjects. Several factors may contribute to this observation. As (Yousafzai and Jamil, 2019) demonstrated, admission criteria significantly influence student academic performance. Consequently, the diverse academic backgrounds of students entering different programs may explain the substantial performance variations observed within specific subjects. For instance, some degrees have more stringent admission cutoff grades than others (e.g. Industrial Technologies Engineering 9.121 *vs.* Mining Resources Engineering, 5), which could influence the range of student performance.

Figure 6.

Average practical assessment grades across subjects



Source: Own design (2024).

Secondly, the diversity of subjects included in the study (such as statistics, algebra, and calculus) introduces a broad spectrum of new topics for first-year students. This diversity could explain why certain aspects are more effectively addressed by audio-visual aids during homework preparation than others.

Lastly, lab practices are conducted in different programming languages, including R and MATLAB. These languages require varying degrees of familiarity with syntax and other environment aspects. Consequently, students' performance may be influenced by their previous experience with these programming environments, which is very limited for first-semester students.

The design of the instructional materials and activities in the flipped classroom can also impact their effectiveness. For example, the clarity of the videos, the relevance of the in-class activities to the pre-class videos, and the difficulty level of the assignments can all influence students' performance. These aspects have been considered since the beginning in the planning stage, but we hypothesize that more concise videos ("video pills") enriched with interaction points and/or quizzes and very focused activities may prove key aspects to improve the effectiveness of flipped classroom dynamics.

4. Conclusions

This study aimed to evaluate the impact of integrating pre-lab videos within a flipped classroom approach on the engagement and academic performance of undergraduate engineering students in mathematics laboratory sessions.

The student survey yielded valuable insights into the effectiveness of pre-lab videos and their associated interaction points. The results revealed a high level of engagement with the videos, with a significant portion of students watching all the videos and most students watching either all or most of them. Additionally, the survey indicated that students find the videos helpful in preparing for computer practices.

Furthermore, many students agreed that the interaction points enhance the learning experience and encourage them to actively engage with the coding exercises.

The findings underscore the potential benefits of using multimedia resources to enhance the learning experience, though the results also highlight areas needing further exploration and improvement.

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AUTHORS' CONTRIBUTIONS, FINANCING ANDACKNOWLEDGMENTS

Contributions of authors: All authors contributed equally to this work.

Funding: The present work is supported by the University of Cantabria through the project “Recursos Audiovisuales para la Implementación de Estrategias de Aula Invertida en Laboratorios de INGeniería (RAISING)” of the II Convocatoria de Generación de Recursos Docentes Audiovisuales and by the Department of Applied Mathematics and Computational Science.

Acknowledgements: This work was made possible by the project “Recursos Audiovisuales para la Implementación de Estrategias de Aula Invertida en Laboratorios de INGeniería (RAISING)” of the II Convocatoria de Generación de Recursos Docentes Audiovisuales at the University of Cantabria, Spain. Authors express sincere gratitude to the Department of Applied Mathematics and Computational Science of the University of Cantabria for their support.

Conflict of interest: There are no conflicts of interest.

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