



Enhancing practical laboratory skills through video-based flipped learning

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Abstract

Higher education must cultivate essential transversal abilities such as collaboration, communication, autonomy and critical analysis, which are vital in today's dynamic environments. These skills, central to 21st-century education, are often lacking in STEM graduates due to traditional, lecture-based instruction. Active student-centered methods, like the flipped classroom, address this shortfall by prioritizing engagement and applied learning. Integrating this model into lab settings enhances both conceptual understanding and hands-on skills, fostering adaptable graduates equipped for complex, real-world challenges in both professional and personal domains. This study evaluates the use of instructor-created videos in a flipped classroom for first-year Chemistry students in an Engineering program at the School of Experimental Sciences and Technology at Rey Juan Carlos University. Aimed at addressing knowledge gaps in lab techniques, the approach fostered active learning and transferable skill development. The activity is part of a study evaluating lab performance and student perceptions via pre- and post-practice surveys. It measures expectations, prior knowledge by an initial survey, as well as satisfaction by a final one. Participation in surveys is voluntary, with informed consent and ethical approval from the university's committee. Students' initial survey scores (3–3.5/on a 5-point Likert scale) showed strong engagement and interest in analyzing subject content. Final scores (3.5–4/5) highlighted improved understanding, especially through collaboration. Learners appreciated innovative group tasks and valued clarity in evaluation, reinforcing the activity's positive impact on learning. Student performance was analysed in relation to a prior cohort that did not engage with the video-based instructional strategy. Results revealed a notable shift, with participants attaining moderate to high marks. Success rates rose by 11%, and the proportion of top grades grew by 25%. These outcomes suggest that methodological enhancements positively influenced learning effectiveness, reflecting both increased academic achievement and strong student engagement with the innovative pedagogical approach.

Keywords: Flipped classroom; hands-on abilities; STEM education; technological skills; videos

1. Introduction

Universities have a critical responsibility to prepare students not only through the transmission of disciplinary knowledge but also by fostering a broad set of skills, attitudes, and ethical orientations essential for success in both professional and personal spheres (Bremner et al., 2022). These attributes—often referred to as transferable skills, employability traits, socio-emotional abilities, or, more broadly, competencies aligned with 21st-century learning models—are increasingly emphasized in educational discourse (McGunagle & Zizka, 2020). Despite this recognition, there is growing concern among employers regarding the inadequate development of such competencies among graduates in Science, Technology, Engineering, and Mathematics (STEM) fields. Unlike technical knowledge, these cross-cutting capabilities are rarely cultivated through traditional instructional methods, instead requiring iterative, experiential, and reflective learning processes. Their effective integration into curricula demands intentional and sustained pedagogical practices, which are frequently absent in conventional STEM education (Swafford, 2018). This misalignment has exacerbated the gap between the competencies valued within academic programs and those deemed vital in today's dynamic and interdisciplinary work environments.

Contemporary skill sets include effective communication, collaborative competence, proactive behavior, critical thinking, creativity, and organizational skills (van Laar et al., 2019). Addressing deficits in these areas necessitates a pedagogical shift from traditional, teacher-centered instruction to dynamic, student-centered approaches. The adoption of such learner-oriented methodologies is supported by economic, cognitive, and ethical rationales: economically, they better equip students for an increasingly fluid and unpredictable labor market; cognitively, they deepen understanding and enhance long-term retention; and from a social justice perspective, they promote equitable learning by fostering student agency, self-regulation, and inclusivity in educational processes. Central to these approaches is the cultivation of autonomous learning, a critical driver for metacognitive development. These competencies enable students to navigate complex problems, recognize their own knowledge gaps, apply diverse problem-solving strategies, and critically reflect on their learning trajectories (Ríos et al., 2020). As a result, learners not only achieve greater academic efficacy but also build the capacity to confront novel challenges independently. Active learning strategies, therefore, underscore the pivotal role of student autonomy and engagement in constructing meaningful knowledge and preparing individuals to meet the evolving expectations of both societal and professional realms (Dzaiy & Abdullah, 2024; Yang et al., 2024).

Among the diverse array of active learning methodologies, the flipped classroom has emerged as a particularly influential approach in contemporary higher education pedagogy. Its rise in prominence is attributed to its alignment with two prevailing educational innovations: the emphasis on active student engagement and the integration of Information and Communication Technologies (ICT) (Bindu, 2016). In recent years, this model has gained substantial traction, especially within STEM disciplines (Castillo-Cruz et al., 2025; El-Thalji, 2025; Gámiz-Sánchez, 2017). Unlike traditional lecture-centric formats, the flipped classroom inverts the standard instructional sequence by requiring students to interact with core content—often via digital media—prior to attending class (Cho et al., 2021). This shift allows in-person sessions to be repurposed for collaborative problem-solving, applied exercises, and in-depth discussions that reinforce and contextualize learning. The model is associated with enhanced student motivation and improved academic outcomes, offering the key advantage of accommodating individualized learning paces (Lo & Hew, 2019). By reallocating class time to active tasks, educators are better positioned to recognize and respond to the diverse learning needs of their students, thereby facilitating more tailored instruction (Prevalla & Uzunboyulu, 2019; Yough et

al., 2017). In STEM education, laboratory work is pivotal for cultivating essential competencies such as empirical reasoning, teamwork, technical skill, and critical analysis. To optimize these outcomes, adequate preparation before laboratory sessions is vital (Del Río-Gamero et al., 2022; Mshayisa & Basitere, 2021). Traditionally a central component of science instruction, the laboratory environment provides experiential learning opportunities that link abstract theory to tangible application. Incorporating the flipped classroom model into lab-based instruction shifts students from passive procedural execution toward deeper conceptual engagement and flexible problem-solving (Zhao & Kan, 2024). Furthermore, the intentional synthesis of theoretical and experimental instruction enhances learning by reinforcing concepts through practice, ultimately promoting a more integrated and comprehensive educational experience (Garcés et al., 2024).

This study examines the effects of implementing the flipped classroom model—delivered via instructor-produced video content—in an introductory university-level Chemistry course within a Engineering degree program. Previous assessments revealed significant deficiencies in students' foundational knowledge of laboratory equipment and experimental procedures, which negatively affected academic performance. In response, a shift toward more active instructional strategies was initiated. The integration of the flipped classroom approach was intended to enhance the teaching–learning dynamic while simultaneously supporting the development of transferable competencies relevant to professional practice, particularly within STEM disciplines. This investigation centers on the premise that such an active and innovative pedagogical framework can facilitate more participatory learning experiences and foster greater autonomous motivation among students. During the intervention, learners engaged with multimedia materials designed by faculty and benefitted from continuous formative feedback. Data collected through student surveys and academic performance metrics reveal a notably positive impact, characterized by improved achievement levels and heightened student engagement.

2. Methodology

2.1 Objectives

The primary objective of this project is to implement an active flipped classroom methodology within laboratory settings by utilizing instructor-generated video content. The initiative is designed to enhance the learning process and support the development of essential 21st-century competencies relevant to professional STEM environments. The intervention targets first-year Chemistry students enrolled in the Chemistry Engineering Degree program at the School of Experimental Sciences and Technology, Rey Juan Carlos University (Madrid).

2.2 Study description

This educational innovation project implemented formative assessment within laboratory sessions using a flipped classroom model, incorporating instructional videos and digital learning tools. This activity contributed 30% to the final course grade and was designed to promote active student participation. It also enhanced engagement through continuous self-assessment and feedback.

Students completed initial and final surveys assessing their familiarity with the flipped methodology and expectations for the course. The surveys, along with informed consent procedures, were managed via the Moodle platform. 64 enrolled students participated as the activity formed an integral part of a 6 ECTS course during the second semester of the 2024/25 academic year.

Instructors created the laboratory content, including video materials and practice guides, and designed pre- and post-surveys referencing established flipped classroom literature. Students accessed these materials prior to lab sessions, which were structured around preparatory quizzes (10%), lab reports (60%), and post-session tests (30%). These components collectively aimed to encourage proactive learning and deeper conceptual understanding of experimental procedures.

Throughout the laboratory sessions, instructors facilitated student learning through direct supervision and clarification of pre-lab content. The practical work emphasized skill development in applying theoretical knowledge in experimental contexts. Data collected during the process was subjected to statistical analysis to evaluate learning outcomes and compare performance with results from the previous academic year, in which no flipped methodology had been applied.

Following the completion of all activities, a final survey was administered to gather student feedback on the methodology and measure perceived learning gains, satisfaction, and alignment with initial expectations. Both surveys employed a 5-point Likert scale to capture levels of agreement.

The main goal was to evaluate the flipped classroom's effect on student achievement and their perceptions of the learning process. Key milestones included familiarization with the task, self-assessment of prior knowledge, guided engagement with instructional content, monitored laboratory execution, reflective feedback, and comprehensive performance evaluation. The initiative was approved by the university's ethics committee, ensuring compliance with academic research standards in educational settings.

3. Results

3.1 Effects of the Activity on Students' Academic Achievement

Student performance data from the formative activity were gathered for both the current academic year (2024/25), in which the flipped classroom methodology was applied in the laboratory sessions, and the previous academic year (2023/24), when this innovative strategy had not yet been introduced. Figure 1 presents a comparative distribution of student scores, categorized by grade ranges, at the end of the activity in both academic periods.

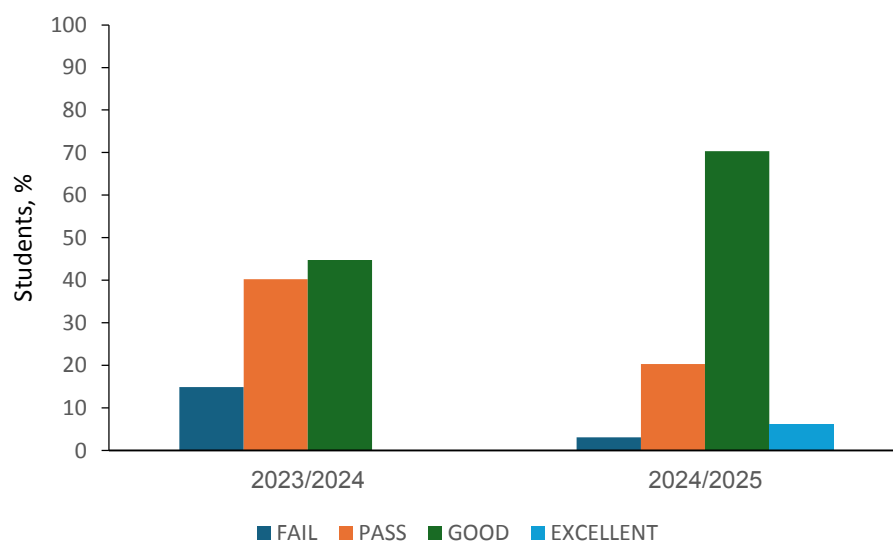


Figure 1: Grade Distribution of Student Activity by Academic Year

As illustrated in Figure 1, the majority of students in the 2023/24 academic year achieved grades within the 'pass' (40.29%) and 'good' (44.78%) categories. Notably, in the 2024/25 academic year, there was a substantial increase in the proportion of students attaining a 'good' grade, rising to 70.31%. Examining the distribution at both ends of the performance spectrum, 14.93% of students fell into the 'fail' category and no students reached the 'excellent' level in 2023/24. In contrast, with the implementation of the innovative activity in 2024/25, these figures shifted markedly: only 3.13% of students failed, while 6.25% achieved an 'excellent' grade. These outcomes highlight the effectiveness and pedagogical value of the methodology, showing that it fosters both conceptual understanding and laboratory proficiency, as well as transferable skills relevant to professional practice.

3.2 Student Perception Analysis of the Implemented Activity

In this study, a diagnostic survey tool was created to assess student perceptions related to the innovative instructional activity. The surveys, developed by the teaching team, addressed four key areas: teaching methodology, learning outcomes, assessment criteria, and attitudes toward educational innovation. Each area included statements rated on a five-point Likert scale, generating quantifiable data. Two surveys were conducted: one before students engaged with the flipped materials and one after completing the lab sessions and assessments. Figure 2 illustrates mean values per dimension across both surveys.

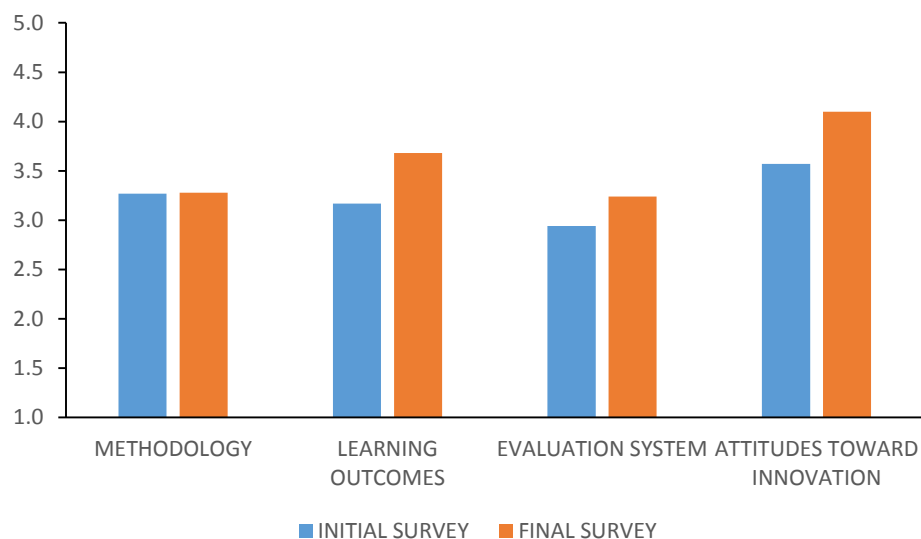


Figure 2: Analysis of Student Feedback from Pre- and Post-Surveys.

As shown in Figure 2, initial responses were highly positive, with Likert scores above 3, reflecting students' interest in synthesizing information and clarity about evaluation. Moreover, results reflected a general improvement across the initial to final surveys in all dimensions, although similar values were achieved in methodology, possibly due to end-stage fatigue. The outcomes showed strong student involvement, reflected in their enthusiasm and sustained motivation, with a notable 0.5-point increase in the final survey, particularly in learning outcomes and attitudes toward innovation. The majority of participants evaluated the experience very favorably, noting notable gains in their self-assurance when engaging in experimental procedures that required practical laboratory abilities. They also highlighted development in cross-disciplinary skills such as collaboration and analytical reasoning. Although some difficulties arose due to unfamiliarity with certain materials and lab instruments, students collectively acknowledged the value and efficiency of the flipped classroom model enhanced by instructional videos. This method provided the opportunity to

revisit video content multiple times before executing the experimental tasks in the laboratory setting, thereby reinforcing their preparedness and understanding.

4. Conclusion

This study evaluated the effects of a flipped classroom model using instructor-made videos in a first-year Chemistry course for Engineering Chemistry students at Rey Juan Carlos University during 2024/25. Student perceptions were assessed via a survey, and grades were compared to the previous year without the flipped approach. Initial survey scores ranged from 3.00 to 3.50, with slight improvement by the end. Students reported better understanding, motivation, engagement, and confidence in lab work, along with growth in teamwork and critical thinking. Despite minor technical issues, reviewing videos before labs was valued. Academic performance improved, with an 11.8% decrease in failing grades, a 25.53% increase in mid-to-high grades, and a 6.25% rise in top grades. These results support the flipped model's effectiveness in enhancing conceptual knowledge and practical skills. Future research will explore variables like subject and gender, and analyze common lab procedure errors to improve teaching strategies.

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