A teaching-learning sequence to develop epistemic thinking in engineering students at master's educational level

Journal of Applied Research in Higher Education

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Received 6 October 2023
Revised 18 March 2024
27 May 2024
28 June 2024
Accepted 29 June 2024

Abstract

Purpose – This research work had been a double objective, to help the students achieve the learning outcomes, scientific skills and on the other hand, to develop specific scientific sub-competences, all of these related not only with the conceptual knowledge but also with the knowledge of procedurals and epistemology.

Design/methodology/approach – A didactic sequence has been designed and applied with students of the University Catholique of Louvain (Belgium) in collaboration with teachers from the University of Zaragoza (also researchers in the knowledge areas of Electronics, Applied Physics and the Didactics of Experimental Sciences). Several methodologies were applied thorough the teaching-learning sequence as the flipped classroom is. A varied sample of assessment instruments was used.

Findings – The results suggest this sequence produces a more significant learning than a more conventional teaching, however there is no increase in the number of students who passed. The students explaining phenomena scientifically, evaluating and designing experiments and making researchable questions and interpreting data and scientific evidence, which are a consequence of the development of scientific knowledge (content, procedural and epistemic). In addition, the students kept motivated by this methodological change and maintained the perception of having achieved the expected learning according to the objectives of the course.

Originality/value – Until a few years ago, research in the didactics of experimental sciences, and the application in the classroom of the results obtained, was limited to education in non-university stages. The opportunity of this work is to expand knowledge in relation to the application of didactic strategies in physics education at a higher level.

Keywords Epistemic thinking, Physics education, Higher education, Flipped class, Activity sequence

Paper type Research paper

Introduction

Didactics of experimental sciences has a relatively short history in Spain, starting in the 1970s with Lucrecia Fernández's inaugural doctoral thesis (Fernández, 1975). Since then, research in this field has grown significantly, making a considerable impact, particularly

The authors thank the support of the Group of Electronics Didactics with ICT Technologies (DIELTIC) from the University of Zaragoza.

Conflicting interests: The authors declare no conflict of interest during the research or the preparation of this manuscript.

Journal of Applied Research in Higher Education

2050-7003
DOI 10.1108/JARHE-10-2023-0464

within education degrees and teacher training. In 2007 Spain introduced new educational programs to train secondary school teachers, emphasizing pedagogy, sociology and didactics (RD 1396/2007 and Order ECI/3858/2007, n.d.). Nowadays, graduates with scientific backgrounds pursuing teaching careers are exposed to methodologies that enhance student learning. Consequently, all teacher education programs for students aged 3 to 17 in Spain draw on research findings in didactics of experimental sciences.

The question arises concerning students in higher levels of scientific education. Currently, research in didactics of experimental sciences has limited impact on higher education, specifically on the training of students pursuing scientific and technological degrees, which often rely on traditional masterclass formats (Almudí *et al.*, 2016). A notable conclusion from science education research suggests that students exclusively exposed to masterclasses do not achieve significant learning outcomes (Justi and Gilbert, 2002). Therefore, aligning with the principles of didactics of experimental sciences, teaching sequences should be thoughtfully designed to foster the development of scientific competences.

University lecturers from the Universidad de Zaragoza (Spain) collaborated with counterparts from the Université catholique de Louvain (Belgium) in designing a teaching-learning sequence. The primary objective was to cultivate competences and achieve the learning outcomes.

Theoretical framework

Higher scientific education emphasizes conceptual understanding to connect content, laws and principles. However, research faces challenges (Duit, 2009) due to insufficient focus on constructing and validating knowledge through research-based models (Ceberio *et al.*, 2014). Current higher education curricula prioritize acquiring diverse skills through active teaching and learning (Gatica-Saavedra and Rubí-González, 2021). Concepts like didactical science were introduced by researchers like Artigue (2015) and Barquero and Bosch (2015).

Assessing scientific skill acquisition is challenging, yet instructors can develop strategies to evaluate them (Gilbert, 1991; Gobert and Buckley, 2000; Oh and Oh, 2011). These skills are fostered through teaching and assessment targeting conceptual, procedural and epistemic contents (OECD, 2016). Evaluating teaching methodologies in science is crucial for achieving expected learning outcomes (Ferrés Gurt *et al.*, 2015). According to the OECD (2016), science teaching should enhance specific learning outcomes and students' scientific skills. These skills include evaluating and designing experiments, formulating research questions (SC1), explaining phenomena scientifically (SC2) and interpreting data and scientific evidence (SC3). These align with developing scientific knowledge at content (knowing that), procedural (knowing how) and epistemic (knowing why) levels (Kind and Osborne, 2017; Osborne, 2014), reflecting goals of science education: learning science (content knowledge), understanding science (epistemic knowledge) and practicing science (procedural knowledge) (Hodson, 2014).

(1) Explaining phenomena scientifically: students must recognize, offer and evaluate explanations of a specific range of natural and technical phenomena. To a large extent, this depends on the knowledge of these ideas and theories, this is, knowledge of the content. However, it also requires an understanding of the route to gain this knowledge, the methods used (procedural knowledge) and the role played by knowledge itself in its justification (epistemic knowledge).

(2) Evaluating and designing scientific research: students must describe and evaluate scientific investigations and offer scientific approaches to certain questions. According to PISA (OECD, 2016, 2019, 2022), rather than knowledge of the content of science, it requires an understanding of how scientific knowledge is established

and its confidence, this is, a procedural and epistemic knowledge of science. Ferrés-Gurt (2017) argued that students must be capable of designing researchable questions that allow the development of scientific practices (enquiry, argumentation and modeling).

(3) Interpreting data and scientific evidence: students must analyze and evaluate data and arguments to offer adequate scientific conclusions. As with the previous sub-competence, knowledge of content is necessary, but procedural and epistemic knowledge are of major importance. Thus, scientifically literate citizens must understand how to represent experimental data and grasp the uncertainties inherent in data collection and measurement (procedural knowledge). Students must also assess whether data are appropriate, with argumentation and criticism playing a significant role on the process (epistemic knowledge). In short, this competence includes access to information and evaluation of arguments and scientific evidence (Kuhn, 2010; Osborne, 2010).

We introduce the design and evaluation of a teaching-learning sequence that incorporates the flipped classroom as a significant instructional strategy. The aim is to facilitate students in attaining the specified learning outcomes and foster developing the scientific sub-competences described above while generating epistemic thinking.

The flipped classroom methodology is widely used across higher education disciplines such as engineering, healthcare, business and statistics (Aronson *et al.*, 2013; Chen *et al.*, 2014; Deslauriers *et al.*, 2011; Gilboy *et al.*, 2015; O'Flaherty and Phillips, 2015). It enhances learning environments (Ruiz-Jiménez *et al.*, 2022) by shifting specific activities outside class, allowing more interactive sessions in class to apply and implement ideas (Pierce *et al.*, 2012). Instructors move from a "sage on the stage" to a "guide on the side," facilitating student interaction and optimizing class time for learning and practice (Deslauriers *et al.*, 2011; Gilboy, 2015).

A successful flipped classroom goes beyond just assigning videos to watch at home (Abeysekera and Dawson, 2015; Deslauriers *et al.*, 2011). The goal is to use the flipped classroom model not merely as a delivery format change but as a strategy to improve student learning experiences.

Classroom activities take an innovative approach to promote skills such as autonomy and multidirectional learning (Aronson *et al.*, 2013). Lectures are repurposed to implement active learning activities to reinforce concepts learned outside the classroom. Indeed, some authors (Verdonck *et al.*, 2022) have recognized the opportunity of promoting active learning through flipped classes. While various patterns exist for developing flipped classroom activities (Wood *et al.*, 2016), successful applications should support the whole learning cycle. The integration of direct instruction and constructivist methods proves valuable in guiding model acquisition effectively.

Recent research shows that connecting instructions to students' social and technological environments enhances knowledge acquisition (Sánzhez-Azqueta *et al.*, 2020). This emphasizes the role of information and communication technologies (ICTs) in developing new training methods. This shift requires methodological changes in teaching and assessing learning processes. Technologies are recognized for supporting individual work, autonomy, collaboration and interactive evaluation between instructors and students. However, selecting the right methodology for each educational need remains crucial.

Here, we examine the outcomes derived from the implementation of a teaching-learning sequence based on active methodologies within the domain of Master's studies. Educators from the Université catholique de Louvain (UCL) collaborated with counterparts from the areas of Electronics, Applied Physics and Didactics of Experimental Sciences at the

Universidad de Zaragoza to design a teaching sequence incorporating the flipped classroom methodology to substantiate or challenge the following hypotheses.

H1. The sequence facilitates students achieving the prescribed learning outcomes.

H2. The flipped classroom promotes the development of the three scientific sub-competences.

Method

Sample

Participants were students enrolled in the course "Design and Architecture of Analog Electronic Systems (ELEC2532)," offered as elective in the Master's studies of Electromechanical Engineering and Electrical Engineering at the UCL. It comprised 22 students, predominantly graduates, with an equal distribution between genders and an internationalization around 20%. Before the study, participants underwent an informed consent process outlining the procedures for data collection and analysis. All evidence collected was anonymized to maintain confidentiality.

The course is offered in the second semester of the masters' degrees, following a course on digital electronics and concurrently with a project involving the creation of an electronic system. It precedes courses on synthesis of integrated circuits. Its primary objective, thus, is to familiarize students with fundamental analog circuits and systems within the functionality of an embedded system. It encompasses the definition and comparison of various component families, their implementations and figures of merit.

All participants hold Electronic Engineering degrees, demonstrating solid understanding of key electronics concepts, mathematical methods and relevant lab experience.

Type of study

Qualitative research using Case Study (CS) methodology was conducted to analyze student scientific competence development within their learning context, examining input, support and engaged activities (Justi and van Driel, 2005).

To ensure clarity and legitimacy in our research, we provide contextual information about the project design and methodology. The CS method validates research with a small sample over an extended period, as argued by Simons (2011), emphasizing criteria such as credibility, transferability, dependability and confirmability in research design, data collection and analysis.

Methodology of the teaching-learning process

To attain the objectives of this research (analyzing the learning outcomes and the development of scientific competences) a teaching sequence spanning four phases was designed and executed over one academic year. Various methodologies were integrated into each phase, with a focus on ICT-based activities, since recent research indicates that knowledge acquisition is more effective when students receive instructions integrating social and technological advancements. This underscores the importance of favoring tools based on ICTs to create new training areas and modes. Consequently, ICTs have been employed to encourage collaboration among students, enhance their motivation, and improve the acquisition of individual knowledge competences. A description of the four phases is given below.

Phase 1 introduces the theoretical concepts at the start of each topic by traditional classes on general analog electronics. Here, the instructor provides theoretical explanations and students solve exercises and problems with his/her assistance.

Phase 2 develops the epistemic content through the three scientific sub-competences (Falicoff *et al.*, 2014): identifying scientific questions (students recognize issues suitable for scientific investigation and identify key terms to search for scientific information), evaluating, designing experiments and formulating researchable questions (students pose relevant questions that can be scientifically investigated and design experiments for that purpose) and interpreting data and scientific evidence (applying scientific knowledge to a situation). This empowers students to generate their own knowledge, granting them autonomy in learning more applied topics. The objective is mirroring the future demands of engineering jobs, where individuals need to explore topics not fully covered during their training.

Phase 3 involves the development of theoretical and procedural contents through dynamic activities where students engage in friendly competition, enhancing the understanding of topics introduced in the flipped classes. The activities include solving real engineering problems using SPICE simulations and participating in quiz activities.

In Phase 4, the focus is on developing epistemic content through seminars delivered by experts in various industrial areas. These seminars aim to motivate students and provide them with a realistic perspective on potential future challenges in their professional careers. A summarized representation of the content covered in each phase is shown in Figure 1.

A set of teaching resources has been employed to facilitate this learning experience, incorporating a blend of face-to-face (F2F) synchronous activities and virtual teaching. In the following sections, we describe the methodologies, learning sequence and supporting materials utilized throughout the course. Emphasis will be placed on detailing the phases where new activities or methodologies have been applied, particularly Phase 2, which involved a series of flipped classes on typical analog applications and their associated system architectures.

During this phase, students actively participate in generating their own knowledge. In the flipped class activity, students are grouped in teams of 3 or 4, depending on the total enrollment. Each group is responsible for preparing a comprehensive class activity covering one topic in the course. This includes presenting simulation results to help other students

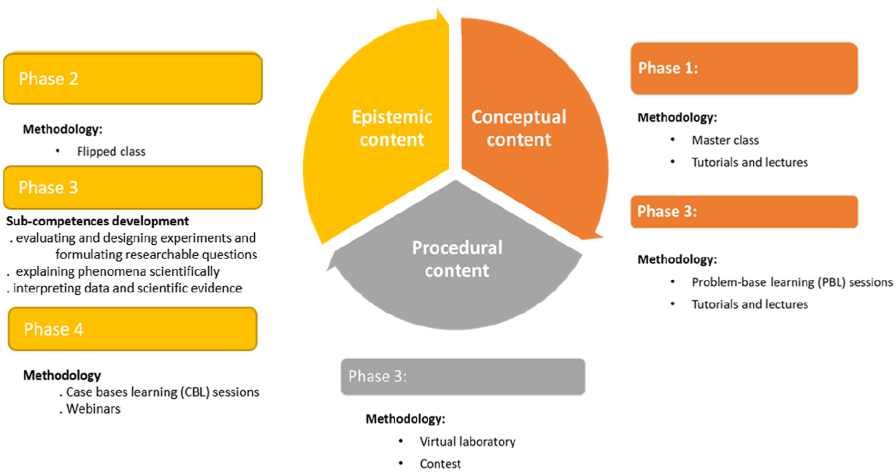

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Figure 1. Relationship of each phase with the methodologies

grasp the concepts visually, for which students have access to LTSPICE software, a high-performance SPICE simulator, along with tutorials, explanatory videos and manuals.

The flipped class session includes before-class and in-class activities. Before class, students access materials and references such as books and journal papers from repositories like the UCL library. Key study topics are explained, and students connect these with prior learning. Specific references help identify key metrics for the system under study. Students are encouraged to seek additional information and request full papers from instructors. This phase develops competencies in scientific information retrieval, hypothesis formulation and causal relationship establishment, aligning with SC1: evaluating and designing research, and SC2: explaining phenomena scientifically.

In preparation for the class activity, student groups were given access to the materials two weeks before the presentation, which allowed instructors to assume the role of mentors, overseeing and evaluating the preparation of the flipped class. At least one week before the classroom session, instructors met the groups to assess their progress, assist in organizing the flipped class and address any doubts that arose during the bibliographic search (SC1). This fosters collaboration, ensures adequate preparation and supports students in delivering a successful presentation.

During F2F sessions, the roles of instructor and students are interchanged in a structured manner. On the day of the class, instructors randomly select a student to present each part of the material, promoting collaboration in preparation and ensuring comprehensive mastery of the entire presentation by all students. These presentations go beyond simple exposition; students are encouraged to deliver comprehensive sessions involving specific activities and simulations to demonstrate system operation.

As part of the instructor's role during these sessions, the student group is expected to address questions from other students or the instructor. At the end of each session, the instructor clarifies any insufficiently explained topics and corrects any mistakes made by students. This practice aims to prevent errors or misunderstandings, supporting the objective of scientific data interpretation and evidence (SC3).

Phase 3 consists of two parts. The first part involves a case study where students tackle a real engineering problem using SPICE simulations. The second part is a quiz conducted over two classroom sessions, allowing students to earn extra points towards their overall course grade (1.5 out of 10 points). Both activities occur in an interactive classroom equipped with five TV screens at cooperative tables and one main screen with a projector. Using the MirrorOp Sender application, students can connect their devices to the screens. This setup encourages collective work and information sharing among group members (Ellis and Bliuc, 2019). The instructor can access all screens and highlight specific groups' work on the main screen, fostering a collaborative and informative learning environment.

For the case study, students were organized into groups of six, promoting collaborative problem-solving and cooperative engagement. Group composition was meticulously arranged, ensuring representation from each flipped class group and maintaining equitable distribution of skills and knowledge. The objective was to leverage the collective expertise within each group.

Students integrated flipped class knowledge and conducted SPICE simulations for a case study, with 1:45 h allotted for analysis and discussion. They utilized tools, course Moodle resources, and the Internet. Each group created a slide summarizing their solution, presented and defended in a 5-min session. Evaluation, including extra points, focused on solution quality, presentation effectiveness and articulation of their approach, recognizing exemplary performances.

The second part included a quiz with questions tied to flipped class content. Students accessed course materials and the Internet, answering questions one at a time to encourage collaboration. After completing the quiz, students received their scores but not specific incorrect answers. They could opt to retake the quiz. The phase lasted 1 h and 30 min, with the leading group determined by correct answers within the first hour. The final 30 min involved instructors explaining answers, fostering discussions and enhancing clarity (Figure 2).

In summary, both parts of the activity effectively addressed all three scientific sub-competences. The experience proved to be highly engaging, showcasing collaboration, meaningful discussions and a palpable interest among students. The added incentive of extra points for the winning group further motivated their active participation. In addition, the final session allowed students to compare procedures and solutions reached by their peers and, on the other hand, those proposed by the experts who participated in the seminars (Phase 4).

Data analysis

As highlighted in the section covering the teaching-learning process, the emphasis extends beyond the acquisition of content knowledge. Integral to the learning objectives is the development of procedural and epistemic knowledge, this is, understanding not just what ideas entail but how they are generated. The goal is to impart information to students and to actively stimulate their capacity for critical thinking and engagement in reasoned discourse. This approach seeks to stimulate not only the absorption of facts but also the development of skills and insights for thoughtful participation and analytical reasoning.

The learning sequence includes topics such as OpAmp-based circuits, voltage regulators, power management, memory arrays, peripherals, memory bit cells, CMOS imagers, phase-locked loops, clock generation, digital IOs and serial links. It aims to introduce basic concepts while deepening understanding and developing students' epistemic knowledge. Students learn to differentiate between observations, facts, hypotheses, explanations, models and theories. By validating these models through procedures, they enhance their understanding of the scientific process, formulate hypotheses, use specific tools for testing, gather evidence and draw conclusions. This approach fosters scientific sub-competences, critical thinking and systematic inquiry.

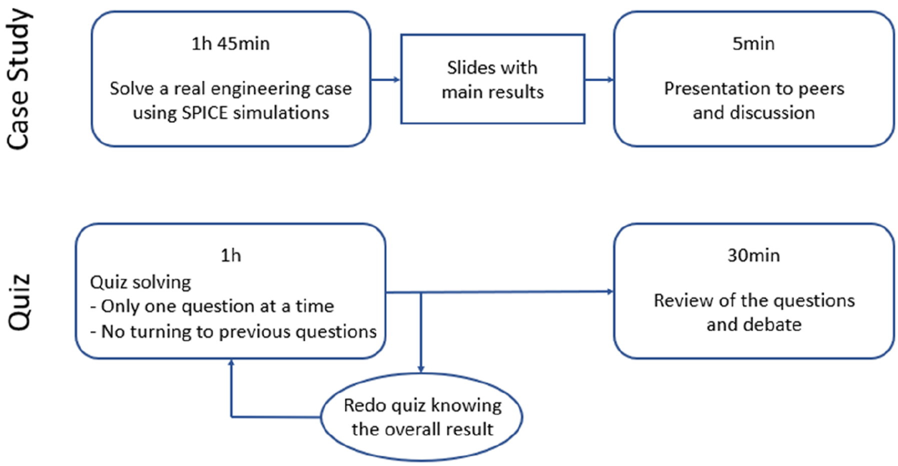

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Figure 2.
Flow diagram of the realization of Phase 3 of the activity

Initially, OpAmp-based circuits, voltage regulators, phase-locked loops and clock generation systems were selected. For instance, in Phase 1, students explore concepts like frequency response and stability, focusing on OpAmp-based circuits in filtering stages. They develop technical hypotheses, selecting specific configurations and conducting tests using simulation software to analyze circuit behavior and validate feasibility, considering stability and frequency response. During Phases 2 and 3, student questions are analyzed, with evidence showing proficiency in explaining observed phenomena scientifically.

The flipped classroom plays a crucial role in facilitating the construction of knowledge models. Classical model-based learning involves students iteratively constructing mental models of phenomena through comparisons, integrating information, inductive processes and simplifications. While students must engage in this process independently, instructors can employ strategies to facilitate and assess model acquisition. Various learning materials play crucial roles in supporting this construction process. The flipped classroom enhances student engagement and satisfaction, correlating with improved performance and deeper learning outcomes.

The sequence is enhanced by a series of seminars (Phase 4) that offer a broader and applied perspective on the electronic circuit design process. These seminars contribute to the generation of new knowledge, including understanding transistors as basic building blocks (Phase 1). They also prompt reflection on scientific knowledge, emphasizing its continuous review and the utilization of sophisticated tools and empirical evidence to propose new models. Students demonstrate their ability to communicate conclusions, articulate assumptions and evidences, support their findings, and reflect on the societal implications of scientific-technological advancements. This multifaceted engagement reinforces technical expertise and also critical thinking and an awareness of the broader implications of scientific exploration.

Table 1 shows the sequence on OpAmp-based circuits (F1). It identifies distinct tasks and elucidates their contribution to implementing the teaching-learning methodology. It also shows specific contents corresponding to the three phases of the activity and its final assessment.

Figure 3 shows realizations of the materials elaborated by the authors to assess the tasks done by students in the different phases, particularized for contents of another topic: voltage-controlled oscillator circuits (VCO) for phase-locked loops and clock generation (F7-F8).

Table 1. Sequence of the activity on circuits based on the OpAmp (in blue, before-class activities and in red, face-to-face activities)

Activity	Filter design for an optical receiver signal equalization system
Topic	OpAmp-based circuits
Tasks	T1.- OpAmp. Use in circuits with negative feedback T2.- Key concepts of frequency response and stability T3.- Figures of merit/performance criteria and non-idealities T4.- Active filters T5.- Choice of the desired topology and the components T6.- Verification of the behavior of the chosen architecture T7.- Preparation of the technical report
Methodology	T1-T2-T3-T4: Master class, tutorials, lectures, Baf-flipped class T5-T6: PBL sessions, Virtual laboratory, F2F flipped class
Phase and content	T1-T2-T3-T4: Phase 1–2 (conceptual and epistemic) T5-T6: Phase 2–3 (epistemic and procedural) T7: Phase 2–3 (epistemic and conceptual)
Assessment	T1-T2-T3-T4-T5-T6: Test and contest T7: Rubric

Source(s): Table created by authors

Assessment aims to analyze knowledge construction and learning impact through methods like systematic instructor annotations, questionnaires, exams and oral presentations. These track student progress, refine knowledge models and aid work planning (García-Carmona *et al.*, 2014; McWilliam *et al.*, 2003; Roca *et al.*, 2013). Evaluation focuses on written exams, resource quality and performance in flipped classes and contests, assessing application context, performance metrics, circuit architecture, LTSpice simulations, design techniques and typical performance.

Besides content knowledge, the course aims to develop skills aligned with three scientific sub-competences (Falicoff *et al.*, 2014): identifying scientific questions, explaining phenomena scientifically and reflecting on the social implications of scientific and technological advances. These competences are evaluated using a rubric (Table 2) adapted from Pozuleo Muñoz and Cascarosa Salillas (2024) during Phases 2 and 3.

The evidence gathered across the sequence is evaluated using the rubric, providing insights into whether the flipped classroom sequence effectively contributes to developing the three sub-competences. Additionally, the results can be compared with the previous academic year, when the strategy was not employed, allowing for an assessment of its impact. Furthermore, a specific questionnaire focused on student motivation was administered to capture insights into student perception, attitude and motivation related to the flipped classroom approach. By analyzing these results, the effectiveness and reception of the flipped methodology can be gauged, providing feedback for future implementations.

Results

The collected results aimed to validate the initial hypotheses. A comprehensive evaluation of student achievement, compared to the preceding academic year, was conducted. The

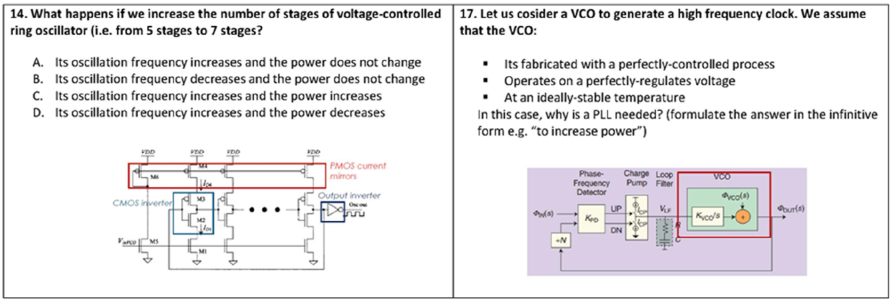

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Figure 3. Examples of the materials elaborated to assess the tasks carried out by the students

SC1. Explain phenomena scientifically	Scientific knowledge of the problem
	Models or explanatory representation of knowledge and implications for society and people
	Predictions, hypotheses and causal relationships or simple correlations
SC2. Evaluate and design the research	Objectives of a study and methodology
	Researchable issues
	Scientists work
SC3. Interpret data and evidence scientifically	Data and representation
	Data validity

Source(s): Table created by authors

Table 2. Rubric to evaluate the three sub-competences along the sequence

analysis focused on student performance in the skills assessed during the flipped class sessions. Overall, the results showed an improvement, particularly in the contest, likely due to the collaborative nature of the new methodology. Notably, further improvement was observed in the second round, attributed to more in-depth discussions on challenging topics. These findings suggest that the flipped classroom contributes to more significant learning compared to conventional teaching methods, as evidenced by an upward shift in grades.

Figure 4 compares grades for the operational amplifier topic (F1) between the implementation year and the previous academic year, based on assessments detailed in Table 1. The previous year had a higher global average of 73.5%, compared to 68.9% in the implementation year out of a maximum of 20 points. Despite the lower overall average, flipped classes and contests in the implementation year showed significantly improved results, attributed to collaborative methodologies fostering deeper student understanding. Increased discussions on challenging topics further enhanced outcomes (see Figure 5), suggesting the methodology enhances topic comprehension.

Regarding the second hypothesis, evidence shows that students took time to understand the assigned task before starting it (Table 3). Initially, they worked as a group and then prepared individually outside the classroom. Some students sought clarification from instructors to deepen their understanding. The tasks involved constructing models or explanatory representations of knowledge, which align with the sub-competence "explaining phenomena scientifically." This suggests that the activity effectively contributes to this objective.

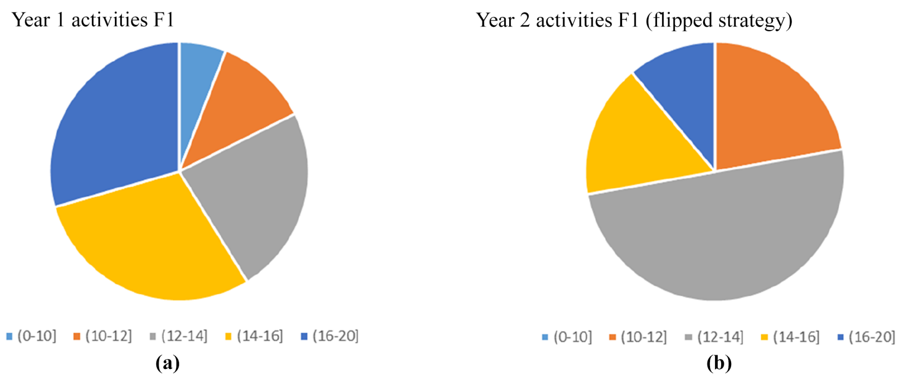

Figure 4. Grades obtained in the consecutive courses (maximum of 20 points) in the activities evaluated in phases 2 and 3 of the topic F1. OpAmp-based circuits (a) no flipped and (b) flipped applied

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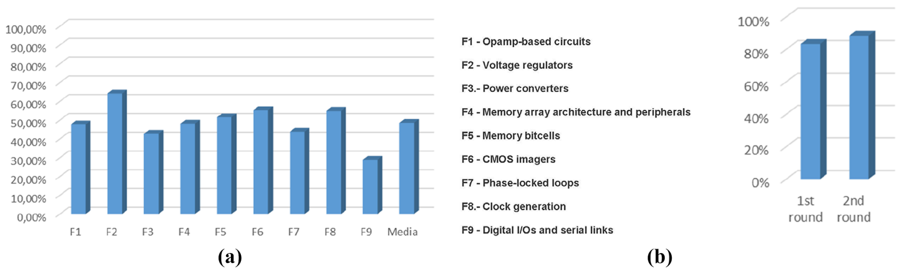

Figure 5. (a) Grades obtained in the student contest of the topic F1-9 (b) comparative between the best results of each of the two rounds of the contest

Source(s): Figure created by authors

SC1. Explain phenomena scientifically	Scientific knowledge of the problem Models or explanatory representation of knowledge and implications for society and people Predictions, hypotheses and causal relationships or simple correlations	Students assessed the scientific knowledge they had of the problem and expanded it, combining their explanatory models with others to formulate hypotheses to be subsequently confirmed based on experimental evidence. These results, evaluated by the rubric in Table 1, indicate that the three dimensions developed as part of sub-competence SC1 were fulfilled
SC2. Evaluate and design the research	Objectives of study and methodology Researchable issues Scientist work	Students designed a research methodology according to the objectives, evaluating whether the questions were scientifically researchable. They carried out the tasks assigned taking into consideration the workflow that would be followed in a real situation
SC3. Interpret data and evidence scientifically	Data and representation Data validity	Students collected data according to all simulation variables, guaranteeing that they were replicable. Through initial condition variations, they assessed the validity of the data. Also, they performed graphical representations to facilitate interpretation and comparison with the theory. They drew conclusions based on the data collected and presented them to the instructors and peers

Source(s): Table created by authors

Table 3. Evidences collected about the three sub-competences developed

The second sub-competence, "evaluate and design research," appears to be the most positively influenced. This is evident as students set objectives, develop methodologies, identify researchable questions and approach tasks consistently with scientific practices. In the final phase of the flipped activity, students share their individual work with peers and instructors, emphasizing the third sub-competence, "working with and validating data", and using arguments and evidence for presentations. Therefore, the results indicate that the flipped activity significantly promotes the development of all three sub-competences within the outlined framework.

Another crucial aspect to assess the activity is student experience and motivation. Research suggests a robust correlation between motivation, satisfaction and success of virtual learning activities (Regueras *et al.*, 2009). A specialized survey was created to collect information on the activity. Students rated their satisfaction levels using a Likert scale ranging from 1 (strong disagreement) to 5 (strong agreement) based on a series of statements.

This aims to capture feedback regarding student experiences and motivation, providing essential information for the evaluation of the effectiveness of the activity.

Among the aspects of interest, it was sought to known whether.

(1) The integration of multimedia content enhances the efficient utilization of class time.

(2) Multimedia resources provided facilitate collaboration.

(3) The methodology fosters motivation, leading to improved outcomes.

Students expressed satisfaction with the instructional resources, noting their usefulness for individual work and self-directed learning. The impact of the flipped classroom reveals a distinction between descriptive subjects like integrated circuit fabrication and analytical/

mathematical subjects such as device operation. Overall, students show a strong preference for the flipped classroom approach, describing its difficulty as fair yet effective in fostering deep understanding.

Students showed motivation by aiming to improve contest scores, demonstrating commitment despite challenges. Encouragingly, two-thirds of groups improved their scores.

Discussion and conclusion

It is still not common to find research on improvements in student learning at the higher level, especially in the field of higher engineering education. Thus, it is noteworthy that through this research we expand the existing knowledge on the topic at the higher educational level.

This study investigated how a specially designed sequence of activities enhances students' epistemic knowledge in scientific learning. It focused on three competencies: explaining phenomena scientifically, evaluating and designing experiments and research questions, and interpreting scientific data and evidence. The activities covered topics such as OpAmp-based circuits, voltage regulators, power management, memory arrays, CMOS imagers, phase-locked loops, clock generation, digital IOs and serial links.

In terms of epistemic content, students actively engaged in formulating hypotheses, designing experiments, selecting verification tools, gathering evidence and drawing conclusions. Procedurally, students conducted simulations to validate hypotheses, processed data from Phase 2, and conducted research to prepare for the flipped classroom sessions.

Students effectively posed scientific questions, demonstrating their ability to identify research issues and use scientific terms for retrieval. They explained phenomena and applied scientific knowledge practically. Consequently, the activities developed scientific competencies (Kuhn, 2010; Osborne, 2010), enriched knowledge across dimensions (Hodson, 2014) and promoted scientific practices like inquiry and modeling (Ferrés-Gurt, 2017). Overall, this sequence enhanced students' mental models and significantly boosted their epistemic knowledge.

In conclusion, the designed methodology centered on the flipped classroom proved successful in achieving educational objectives in our specific case study (methodology that covers the research contextualized in the framework described in this work according Justi and van Driel, 2005).

Notably, students remained motivated by this methodological shift and maintained a perception of having attained the expected learning outcomes aligned with the course objectives. As such, this work contributes to advancing the study of didactics in experimental sciences, particularly in the domain of electronics at higher education.

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Further reading

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