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Effectively integrating research argumentation in syllabus learning: a case study of reading journal articles in four fourth-year engineering fluid mechanics courses

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Abstract

In an emerging trend in engineering education students are engaged in the scientific discovery process through reading about research published in articles rather than textbooks. A research-based and curriculum-oriented intervention in an undergraduate course was designed to elucidate whether students can progressively gain reading skills when provided with selected articles explicitly related to fluid mechanics research. The aim was also to monitor student awareness of their own progress. A questionnaire was designed to evaluate how fourth-year fluid technology students perceived their reading skills during the teaching intervention. A progressive strategy was applied, including warm-up readings, in- and out-of-class assignments, and best practice lectures. Two parallel test-exams and test readings were associated and quantitatively analyzed. Each cohort was randomly divided into two groups, and each group was assigned a different test reading before the lectures; the readings were then switched for the post-lecture assignment. The results demonstrate that the students acquired selective reading skills and awareness of accomplishment. The analyses indicated that learners gained understanding of the core concepts and gave positive feedback on the teaching materials and schedule. These findings may serve as a guide for engineering educators to improve preparation of undergraduate students.

KEYWORDS

research argumentation, undergraduate research, course design, syllabus learning, STEM, fluid mechanics

1 INTRODUCTION

Engineering education transmits a fundamental body of knowledge to serve society. To maintain this role, it must adapt to a wide range of divergent global factors, both in the present and future. Indeed, doubts have been expressed if the teaching of engineering can keep pace with the rapidly expanding range of knowledge, skills, abilities, competences, and attitudes the field requires in today's world.[1,2] Changes in higher education need to be implemented quickly and with agility to equip students with a solid, discerning, and perceptive understanding of engineering practice for the challenges ahead[3,4], in accordance with how engineering educators conceptualize research and scholarship.[5]

Promisingly, over the past two decades, this adjustment is evident in a growing body of research focused on linking teaching and research in higher education and exploring how students benefit from research experiences[6–8], and how research supports teaching in a research-based framework.[9,10] There is little doubt that activities such as reading and evaluating articles, data analysis, assessment, model construction, critical observations, and research planning[11–15] constitute a valuable opportunity for academics to work collaboratively with undergraduate scientific and engineering students.[16,17]

Engineering educators, as a complementary part of their activities, spend a great deal of time reading research literature. However, incomprehensibly, this skill is rarely taught, especially to undergraduate students, leading to a waste of expertise and knowledge[18]. In particular, a major challenge in course design is how to balance and integrate research-based and curriculum-oriented perspectives. Hence, to provide insight into these constraints, the research objectives of this study of an undergraduate engineering course are threefold: a) to create a teaching strategy, including lectures and assignments, that promotes critical reading of journal articles; b) to link research argumentation with fluid technology course topics through selected reading material explicitly related to the syllabus; and c) to assess the effects of the intervention in each cohort using assessment instruments and qualitative analysis.

To date, there is only a limited body of literature that discusses a teaching intervention in which the guided and supervised reading and evaluation of journal articles is included as part of the core syllabus of an engineering course. The hypothesis to be contrasted and validated in the present work is that during the intervention students will be able to perceive improvements in their own reading performance, which this study aims to measure and analyze in a quantitative manner. Thus, three research questions are explored:

RQ1: Can students progressively learn how to read research articles as a key part of an undergraduate course?

RQ2: How aware will students be of their progress through this teaching strategy?

RQ3: To what extent is reading research articles an effective way for students to learn the content of their course?

The course instructor designed an aligned active learning program that places research journal reading at the forefront of the course. The tailor-made methodology is a progressive guide based on warm-up readings and assignments and provides a catalog of best practices on how to analyze, evaluate, and critique research articles.

As a collateral benefit, this intervention may prevent students from experiencing frustration in the learning process by transmitting the 'value of learning'. Additionally, it promotes thinking and understanding from an engineering perspective and conveys the 'roles of engineers'. Students are encouraged to start taking responsibility for their learning, become self-directed learners, align their strengths, and gain awareness of the relevance of learning for their own futures.

2 BACKGROUND

This section reviews the growing interest in combining class-based experiences, research-based approaches, and student-friendly learning tools in engineering education, including in the discipline of fluid mechanics.

2.1 Engineering education

The traditional lecturing approach, focused on the teacher-student transmission of syllabus content, is less efficient and achieves worse learning outcomes than the active learning approach, with student endeavor as the central concept.[19] However, this statement cannot be justified by an imperfect implantation of the traditional mode by an inexperienced lecturer, as shown by [20].

The redesign of traditional lecturing, with emphasis on the nexus between teaching and research, is a growing tendency.[9,21] A significant number of studies with undergraduates in different types of institutions have reported clear evidence that students value learning in a research-based environment [2,22], including passive and active research processes.[23] The knowledge generated by research is viewed as the objective of active learning with a research-oriented/tutored approach, and it requires a separately conceptualized teaching process for transmission and engagement with students.[24]

The advent of digital technology has changed the conception of educational technology, and the complex relationships between content, pedagogy, and technology must be understood by instructors.[25] Additionally, this shift in perception may benefit from taking into account the emerging field of neuroeducation as an effective teaching methodology to enhance reading skills.[26]

Research in science, technology, engineering, and mathematics (STEM) undergraduate courses shows that students benefit from an inquiry-discovery approach[27,28] , regardless of their background, culture, gender, and school status.[29,30] However, extra efforts are required to address the underrepresentation of females in STEM fields.[31]

2.2 Fluid mechanics education

Fluid mechanics courses in engineering education, despite usually having a large enrollment, can be one of the most disliked subjects in the course, with students tending to obtain poor results.[32–34] It is critical for students to effectively learn the key concepts involved and for any misconceptions to be corrected at an early stage to ensure a successful performance in more advanced courses.[35,36]

In this regard, as a flexible educational approach, blended learning integrates the best face-to-face and online course delivery modes to achieve the desired learning objectives for students within the fluid mechanics class.[37,38] The flipped or inverted classroom is increasingly gaining ground in STEM courses[39] , with students showing positive perceptions of factors such as flexibility, guidance, engagement, and feedback.[40] Unfortunately, to date, fluid mechanics has not captured the interest of STEM educators to the same extent as other scientific subjects, despite the excellent benefit-to-cost ratio.[41,42] It should be noted that with this approach, instructors cannot assume that all learners will watch or read the core content before coming to class.[43]

2.2.1 Complementary student-friendly learning tools

In recent years, efforts to boost student engagement in fluid mechanics have increasingly turned to in-class activities, such as using an in-house low-cost prototype to practically analyze the modeling of compressible flow[44] , open source tools[45] , in-lab simulation and virtual experiments[46,47] , as well as out-of-class tasks, such as at-home experiments that can serve as an alternative to video lectures.[48]

Gamification, the design of activities centered on game principles in non-game contexts, has experienced a rapid growth in engineering education.[49,50] The employment of "paper&pencil" didactic games can be successful in terms of understanding and cognition processes, as proven in hydraulic courses.[51]

2.2.2 Assessment methods

An interesting non-assessment practical intervention in a second-year fluid mechanics course was reported by [52]. The authors confirmed that non-assessment-driven learning reduced student perceptions of workload, anxiety, and time pressure, and assessment proved unnecessary to drive or enforce learning. The concern was that attendance and engagement are often poor for non-assessment-based work, but imposing a small penalty on non-attendance of in-class activities (a small percentage toward their final mark) proved effective in ensuring student participation.

3 DESIGN

The present work explores the importance of actively engaging students in the practice of scientific exploration and communication, focusing on the mutual relationship between academic reading skills and learning success. The outlined research questions were addressed in a case-based study in which an educational strategy was designed and implemented in an undergraduate fluid technology course, followed by a quantitative and comparative analysis of the generated data.

3.1 Reading primary literature

Primary literature, also referred to as research papers, or scientific or journal articles, are the official documents that scientists use to communicate their research to each other.[53] Teachers and researchers read this literature to gain professional knowledge.[54,55]

The beneficial effects of reading primary literature were observed in a research survey on undergraduate science education.[56] In an assessment of a primary literature-based teaching program from 1999 to 2005, Kozeracki et al.[57] concluded that "[…] the program increases student confidence and scientific literacy during their undergraduate years and facilitates their transition to postgraduate study", with positive results also observed in first-year courses.[58]

Since academic educators spend a great deal of time reading primary literature, these reading skills may be taught and transferred. Efforts to strengthen the undergraduate research-teaching nexus cannot be based on undergraduate research experiences[8] , but is rather guided and thematically linked by topic.[59] A possible methodology can take the form of three ascending steps. The first is to explore ways that best support students in developing their literacy skills using a series of papers in a particular discipline.[60–62] This can be followed by the identification of rhetorical structures in research articles that play an important role in an author's argument.[63,64] The final step would be to measure student reading skills and their ability to organize, analyze, and interpret quantitative data and information.[27,65] This methodology, put into practice to different extents in the present case-based study, aims to build student confidence, and helps them focus their attention and accept responsibility for their own learning.

3.2 Strategies for reading primary literature

Owing to the variety of disciplinary structures and audiences, research articles come in different formats and lengths across disciplines and there is no standardized criterion to establish the relevance of a particular published paper.[66,67] In addition, they are written in a very condensed style, and it can be hard to find the content you are interested in.[68,69]

Therefore, reading primary literature efficiently can be challenging, and instructors should not assume that students have academic reading skills.[70,71] Several books are available to help introduce this discipline.[53,68,69] In the present study, the "three-pass" approach proposed by Keshav[72] was followed to design the teaching strategy: (i) obtain a general idea about the article; (ii) grasp the article's content (but not its details); and (iii) understand the article in depth.

3.3 Intervention design

A practical intervention in fluid technology, a fourth-year undergraduate course, was implemented in four consecutive semesters. In- and out-of-class activities aligned with the course syllabus were designed to study the acquirement of reading skills and their impact on learning, and students were encouraged to use higher-order cognitive skills to construct meaning.[12,58]

The research presented here was inspired by previous studies, above all the research-oriented/tutored approach of Healey and Jenkins[21] , the research on the self-assessed ability to read and analyze journal articles of Hoskins et al.[61] , and the teaching strategy to improve primary literature reading skills of Van Lacum et al.[64] The practical intervention design is characterized by:

- A progressive structure, moving from secondary to primary literature, for optimum effectivity.
- Providing specific answers to well-designed questions.
- Actively developing student discipline and professional literacy.
- The development of an effective reading style for research papers in general without forgetting the targeted research area.
- Its aim to be a scholarly research contribution on the effectiveness of integrating primary literature reading in a fluid technology course.
- An emphasis on the course syllabus and teaching students about the processes of knowledge construction in the subject by blending traditional lecturing with active research-based learning.
- Constructing results based on a literature review and the study findings.

4 METHODS

This intervention method was developed in-house to be aligned with the course characteristics and to address the research questions posed in Section 1. Oral communications, individual presentations, or tutorial group meetings were not included. The first author, as a single instructor, was in charge of all the course material and teaching strategy, without the support of teaching assistants.[64]

4.1 Course context

The course was given in the city of Terrassa (Spain) by the Department of Fluid Mechanics at the School of Industrial, Aerospace and Audiovisual Engineering of Terrassa, part of the Universitat

Politècnica de Catalunya (UPC). All engineering students have to enroll in the subject, which is worth 4.5 European Credit Transfer and Accumulation System (ECTS) credits (one credit corresponds to 25 hours of the student's work, 10 hours of lecturing activities, and 15 hours of self-study).

This compulsory course is programmed each semester and encompasses two periods of six weeks each, or twelve sessions in total (see Figure 1). The course typically has 50–60 students and is taught once a week with two hours of lectures and one hour of problem-based sessions.

4.2 Subject context

The subject under intervention was fluid technology, which is taught in the fourth year of a Bachelor's degree in engineering. The educational content of the fluid technology course is divided in three main frameworks: (i) fluid engineering concepts: applying sound scientific and technical foundations in fluid engineering; (ii) fluid application skills: analyzing and evaluating each fluid application by the appropriate analytical, theoretical, experimental and numerical studies; and (iii) professional and personal development: integrating engineering and technical terminology, organizing multidisciplinary abilities, reading and critiquing primary literature, synthesizing capabilities, and boosting motivation and self-confidence.

All three frameworks are described in terms of Bloom's revised taxonomy to consolidate the 'higher order thinking skills'[73] : applying (implementing, carrying out, using, executing); analyzing (comparing, organizing, deconstructing, attributing, outlining, finding, integrating); and evaluating (checking, hypothesizing, critiquing, judging). Furthermore, the intervention was scrutinized in accordance with the seven principles for good practice in undergraduate education.[74]

The subject covers fluid technology applications, with the unifying thread being the basic physical laws of fluid mechanics and state relations. Three basic approaches are used to analyze arbitrary flow problems: integral analysis (large-scale), differential analysis (small-scale), and dimensional analysis (experimental). At the end of each period, the students take an examination with two parts: a problem-solving multiple-choice question test and a problem-solving exercise.

Fluid technology is habitually one of the hardest courses in the engineering degree. It involves a complex interaction between understanding concepts and applying them to resolve cases, which also requires the development of a set of skills.

4.3 Positional statement

The two authors of this study have distinct academic careers and research backgrounds, but they are united by a research interest in pedagogic innovation in engineering education to promote student learning through a high-quality teaching experience.

Each author contributed their viewpoint, savoir-faire, and expertise to the study. The first author, who has taught the fluid technology courses for eight semesters, designed the teaching strategy and data collection for the intervention. Both authors analyzed the data and reported the results, and their engagement with the course content and class activities allowed them to assess changes in participant learning outcomes. The findings could form the basis of a project to develop a taxonomy for the field of engineering education research.

4.4 Course outline

The intervention was planned for the 2021 spring semester (S2021) and was extended to three consecutive semesters: the 2021 fall semester (F2021), the 2022 spring semester (S2022), and the 2022 fall semester (F2022).

When this teaching strategy was first introduced in 2021, face-to-face or in-person activities were prohibited due to the global sanitary circumstances. Thus, the S2021 course took place interactively through distance learning technologies and students attended remotely. In the subsequent semesters, all activities were on-site.

The fourth-year undergraduate students taking the course were randomly divided into two groups, labeled RPL_A and RPL_B. The students were between 21 and 24 years old and proficient in both official languages, Spanish and Catalan. The textbooks and slides were written in Spanish, the lectures were taught in Catalan, and the assignments were in English. The course material, activities, and assignments were stored in the teaching support platform ATENEA (Moodle) on servers at the UPC.

The course outline, including lectures, activities, and assignments, is presented in Figure 1. The course encompasses two six-week periods, with twelve sessions in total. The course schedule was planned before each semester, sent to students one week in advance, and explained in the introductory lecture of the first week. In total, the teaching intervention involved 100 minutes of lectures per week, 30 minutes of in-class activities per week, and 180 minutes of pre/ and post/out-of-class activities per week (see Figure 1). Since the course has 3 hours of teaching per week (4.5 ECTS), 4.5 hours per week ought to be assigned to students as self-study, and the total time scheduled for activities represents 66% of these hours. The course utilizes its own open-access book.[75]

	First period						
Week	1	2	3	4	5	6	7
Lecture&Application (50'+50'*)	Introduction	Fluid/Pressure	Mass/Concentration	Linear/Angular momentum	Energy	Dimensional/Similarity	
Best practices in Reading Primary Literature (50'*)					**Lecture 1/3 (S2022&F2022)**	**Lecture 2/3 (S2022&F2022)**	
Pre/Out-of-class activity: inverted teaching (60')	"La biblioteca de Babel" Jorge Luís Borges	Slides,Videos&Examples	Slides,Videos&Examples	Slides,Videos&Examples	Slides,Videos&Examples	Slides,Videos&Examples	
In-class activity (30')	Pre-questionnaire	Computer-based gamification "common fluid mechanics mistakes"	paper&pencil: "fluid properties crossword puzzle"	paper&pencil: "the buoyancy dilemma"	paper&pencil: "spotting the twelve differences between the two sets of conservation laws"	paper&pencil: "fluid mechanics eleven celebrities word search"	**Midterm exam**
Reading assignment (60')		**Paper 1: Secondary source RPL_A&B: (Courty et al. 2013)**		**Paper 2: Research article RPL_A: (Ransegnola et al. 2018) RPL_B: (Hussain et al. 2010)**		**Paper 3: Conference paper RPL_A&B: (Ortega et al. 2008)**	
Post/Out-of-class activity (60')		**Paper 1: multiple-choice question quiz RPL_A&B: Fluid properties**	Other assignments	**Paper 2: Pre-test exam RPL_A: Viscous flow RPL_B: Energy/Pump to system**	Other assignments	**Paper 3: multiple-choice question quiz RPL_A&B: Linear momentum**	

	Second period						
Week	8	9	10	11	12	13	14
Lecture&Application (50'+50'*)	Newtonian viscous flow	Pump to system (1/2)	Pump to system (2/2)	Nonnewtonian flow	Inviscid flow	Case studies	
Best practices in Reading Primary Literature (50'*)	**Lecture 1/3 (F2021)**	**Lecture 2/3 (F2021)**	**Lecture 1/1 (S2021 - 100'*) Lecture 3/3 (F2021&S2022&F2022)**				
Pre/Out-of-class activity: inverted teaching (60')	Slides,Videos&Examples	Slides,Videos&Examples	Slides,Videos&Examples	Slides,Videos&Examples	Slides,Videos&Examples		
In-class activity (30')	paper&pencil: "spotting the eleven differences between the Bernoulli's equation"	paper&pencil: "Navier-Stokes's terms matching game"	paper&pencil: "Power density mismatch"	Computer-based gamification "fluid technology applications"	Post-questionnaire		**Final exam**
Reading assignment (60')	**Paper 4-Part 1: Research paper RPL_A&B: (Saadat et al. 2017)**	**Paper 4-Part 2: Research paper RPL_A&B: (Saadat et al. 2017)**	Selected papers examples	**Paper 5: Research article RPL_A: (Hussain et al. 2010) RPL_B: (Ransegnola et al. 2018)**			
Post/Out-of-class activity (60')	**Paper 4-Part 1: multiple-choice question quiz RPL_A&B: Dimensional analysis**	**Paper 4-Part 2: multiple-choice question quiz RPL_A&B: Similarity**	Other assignments	**Paper 5: Post-test exam RPL_A: Energy/Pump to system RPL_B: Viscous flow**			

FIGURE 1 Outline of the course, teaching strategy, and lectures on best practices in reading primary literature.

Each course was evaluated by means of a standard course evaluation form used in previous courses and with an additional weighted grade that focused on this teaching intervention, which was worth 6% of the total course marks.

4.5 Teaching strategy

The intervention is outlined in Figure 1 and described in the following subsections, which match the rows of the figure. At the start of the intervention, the instructor went through the outline of the course with the students and informed them about the programmed pre-, post-, and in/out-of-class activities.

4.5.1 Lectures and application

The lectures are shown in Figure 1. The syllabus includes an introductory lecture (week 1), nine main topic lectures (weeks 2–6, 8–9, and 11–12), and a review lecture with case studies (week 13). The application outlines how much class time is dedicated to a variety of learning activities. The total in-class activities are scheduled for 100 minutes per week (50' + 50'). An asterisk indicates that this class time is devoted to the lecture on best practices in reading primary literature.

4.5.2 Best practices in reading primary literature

The teaching strategy was supported by lectures entitled "Best Practices in Reading Primary Literature". Their purpose was to explain how to identify different sections, research argumentation and questions, contents, and results in research articles. In the first intervention in semester S2021, the 100-minute lecture was given in week 10, between the pre- and post-test exams, as shown in the cell “Lecture 1/1 (S2021 100’*)” in Figure 1. The table of contents of the designed lecture is:

1. Introduction: a guide and notes on how to read, critique, and evaluate a research article.
2. Objective, motivation, and justification.
3. What are ‘Primary Research Articles’?
4. Why read primary literature?
5. The 'anatomy' of the paper.

    a. Title, citation, publication dates, and abstract: read nonlinearly.
    b. Take your time and focus on methods and results.
    c. Methodological details: reproducibility.
    d. Convincing findings: be fair and expect to be challenged.
    e. Dealing with variability: accept uncertainty.
    f. Be skeptical about descriptive and inferential statistics.
    g. Visualizing results: consider the big picture.
6. Bear in mind: best practices.
7. Innovation: a word.
8. Finding research articles: authors and journals.

After analyzing the results of the first intervention, the teaching strategy for the following semester (F2021) was developed further in two major directions. Thus, in the second period (weeks 8, 9, and 10 between the pre- and post-test exams), new contents were added and broken down into three lectures (150 minutes in total), which were given over three consecutive weeks, as shown in the cells "Lecture 1/3 (F2021)", "Lecture 2/3 (F2021)" and "Lecture 3/3 (F2021)" in Figure 1. The new content was presented as “Research Argumentation” and “Contents and Results”. New in-class activities based on four research articles were prepared by the instructor to help students consolidate their understanding of the content of this new lecture, which was as follows:

1. Research Argumentation
    a. What was the researchers’ motive for conducting this research? Why the research was done.
    b. What was the objective? What the authors pursue.
    c. What is the main conclusion drawn by the researchers from the results? The main outcome of the research.
    d. What are, according to the researchers, the implications of the research? The justification and consequences of the research.

e. Which factors do the authors mention that weaken the results or conclusion? What weakens the results or the main conclusion.

2. Contents and Results
    a. Identify the key features of the presented work. Theoretical, analytical, numerical simulation, and experimental studies.
    b. Identify the "tools" used by the authors in their work. Basic physical laws of fluid mechanics and state relations.
    c. Identify the key and most essential table and figure. The information and results are presented in table and figure formats.
    d. Evaluate the results. Numerical results are to be calculated from the data in the paper.
    e. Reliability of the data. Are the data reproducible?

Based on the experience gained in the initial year, a third edition of the teaching strategy was developed and carried out in the S2022 course. In this intervention, two of the three lectures were programmed in the first period (weeks 5 and 6) in the week after the pre-test, as shown in the cells "Lecture 1/3 (S2022)" and "Lecture 2/3 (S2022)" in Figure 1. The third lecture (week 10) was given a week before the post-test exam, as shown in the cell "Lecture 3/3 (S2022)" in Figure 1. This teaching strategy was repeated in the final semester (F2022) for its consolidation and to be able to compare the results and draw conclusions in terms of the proposed research questions (see Section 1).

4.5.3 Pre/Out-of-class activity: inverted teaching

The pre-class activities are out-of-class tasks of 60 minutes per week to be carried out by the students prior each topic lecture.

- *Pre-prepared presentation slides selected by the instructor to be read in advance.* As a pre-reading activity, the instructor's prepared slides (maximum of 10 slides per lecture) are accessible in the teaching support platform ATENEA (Moodle).

- *Textbook-style readings selected by the instructor to be read in advance.* Assigned reading outside of class is not only for having discussions in class afterwards, which could tempt students to not complete the task, but for complementing instructor's prepared slides.
- *Technical videos selected by the instructor to be watched in advance.* Before class, students watched very short online videos about a course-related subject selected by the instructor according to technical criteria. These videos were not recorded from his own lectures, but H5P open technology was used to create and edit interactive videos with embedded questions.
- *Examples.* The problem statement is set out clearly and is designed to promote self-knowledge. The instructor's scanned handwritten solution is posted in the corresponding folder in PDF format in the teaching support platform ATENEA as a pre- or post-class problem.

The first out-of-class task in week 1 deserves special attention: a voluntary task dedicated to reading Jorge Luis Borges' short story "The Library of Babel" (*La Biblioteca de Babel*), in which the universe is imagined as a vast library containing all possible 410-page books of a certain format and character set. As a metaphor for the universe of learning, it also helps students identify the differences between literary and scientific writing.

4.5.4 In-class activity

Two types of in-class activities were designed: two questionnaires and seven didactic games. The aim of the questionnaires was to monitor student perceptions of their ability to read and evaluate research articles before (pre-questionnaire) and after (post-questionnaire) the intervention. In other words, to assess their self-awareness of conceptual cognition and its accomplishment over a significant period of time. The total time scheduled for the self-evaluation questionnaire in class is 20 minutes.

The questionnaire is in Spanish, and its English translation is presented in Table 1. It has 20 questions divided into 4 blocks:

- 'Capability' in reading: Block (A) with eight questions, from 1(A) to 8(A).
- 'Ability' in reading: Block (B) with seven questions, from 9(B) to 15(B).
- 'Skills' in reading: Block (C) with three questions, from 16(C) to 18(C).
- 'Background' in reading: Block (D), with question 19(D) on experience and question 20(D) on the significance of reading research articles.

Each question has five possible answers. The students answer on a 5-point rating scale precisely defined for each block. No grade or mark is assigned for the completion of the questionnaire.

The other in-class activity consists of didactic games, which are student-friendly learning tools that complement each other. In the present case study, seven in-house-designed "paper&pencil" didactic games were used as in-class activities, all of them in Spanish. No mark was allocated for the completion of this task and brief feedback was provided in light of the answers. The total scheduled time for in-class activities per week is 30 minutes. The slogans of the didactic games are listed as follows:

1 "Fluid properties crossword puzzle" related to 'Fluid'.

2 "The buoyance dilemma" related to 'Pressure'.

3 "Spotting the twelve differences between the two sets of conservation laws" related to 'Mass/Linear/Angular momentum/Energy'.

4 "Fluid mechanics eleven celebrities word search" related to 'Dimensional analysis'.

5 "Spotting the eleven differences between the Bernoulli’s equation" related to 'Pump to system'.

6 "Navier-Stokes's terms matching game" related to 'Newtonian viscous/inviscid flow'.

7 "Power density mismatch" related to all concepts.

TABLE 1 Questions and answer options in the questionnaire: in-class self-evaluation.

Questionnaire: 4 Blocks, 20 questions and 5 answer options **(A) 'Capability', (B) 'Ability', (C) 'Skills' and (D) 'Background' in reading**
(A) Right now, when reading a research article, I am able to …
1(A). ... read the article in a structured way.
2(A). ... identify the key research question(s).
3(A). ... understand the choice of materials and methods used.
4(A). ... understand experimental design and development.
5(A). ... identify the results and their discussion.
6(A). ... identify the conclusions and their arguments.
7(A). ... identify the arguments used that justify the conclusion.
8(A). ... read selectively, choosing which parts of it to read.
Answer options (A): 1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree
(B) Rate your current ability to adequately read the following sections of a research article …
9(B). ... Abstract
10(B). ... Introduction and References
11(B). ... Materials and Methods
12(B). ... Results
13(B). ... Discussion
14(B). ... Conclusion
15(B). ... Figures and Tables
Answer options (B): 1 = Not; 2 = Unsatisfactory; 3 = Satisfactory; 4 = Good; 5 = Very Good
(C) At this moment, when reading a research article …
16(C). ... I need to use a dictionary to translate into English.
17(C). ... I need a textbook to understand the concepts.
18(C). ... I do a sequential reading, following the order from beginning to end.
Answer options (C): 1 = Always; 2 = Frequently; 3 = Occasionally; 4 = Rarely; 5 = Never
(D) Finally, please, answer these two questions …

19(D). How many research articles have you read so far?

Answer options question 19(D): 0; 1-2; 3-5; 6-8; >8

20(D). What impact, if any, do you believe reading research articles has on your professional development or career?

Answer options question 20(D): None; A little; Neutral; Quite a lot; A lot

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4.5.5 Reading assignment and post/out-of-class activity

During both periods, students received a new reading assignment (article to read and a multiple-choice quiz) and instructions from the instructor. The reading materials are stored in the ATENEA teaching support platform and are accessible via the library service. The reading assignments allow students to become more familiar with the concepts discussed in the preceding lectures, promoting the connection between prior knowledge and the text.

4.5.5.1 Warm-up readings

For a successful implementation, it was important not to overload and discourage students at the beginning of the intervention before the lectures on best practices in reading articles. Hence, a progressive approach based on warm-up readings was designed. The warm-up reading plan is presented in Table 2. The three readings are intended to guide the student in the reading process, the first being a secondary source paper, followed by a conference paper, and finally a research article. The secondary source paper (Paper 1 in Table 2) is two-pages long, is in Spanish, and is to be read in full. In contrast, specific sections of the conference paper (Paper 2 in Table 2) are selected to guide the students, matching syllabus-related concepts. Continuing with this progressive approach, the selected research article (Paper 3 in Table 2) is divided in two parts (Part 1 and Part 2), to be assessed separately, with different sections selected as assignments. The instructor, by concealing several parts of the article, has reduced the amount of reading without loss of readability.

TABLE 2 Warm-up reading plan.

	Paper 1	**Paper 2**	**Paper 3** **Part 1 and Part 2**	
Type	Secondary source, scientific dissemination	Conference paper	Research paper	
Language	Spanish	English	English	
Title	“Cuando el vidrio fluye.”	"A numerical model about the dynamic behavior of a pressure relief."	“On the rules for aquatic locomotion.”	
Reference	Courty and Kierlik[76]	Ortega et al.[77]	Saadat et al.[78]	
Syllabus related concepts	'Fluid/Pressure'	'Mass/Concentration' and 'Linear/Angular momentum'	'Dimensional analysis'	'Similarity'
Assignment by sections	Full reading	Abstract 1. Introduction, 2. Mathematical Model 2.1. Dynamic characteristic 2.2. Initial and Boundary Conditions	Abstract I. Introduction	II. Dimensional and Scaling Arguments IV. Experimental results V. Conclusion
Figures in assignment	0	3	0	3
Assessment	Online multiple-choice quiz with text and numerical answers. The online multiple-choice quiz is a computer-based individual activity delivered via the ATENEA platform. It is available for five days (120 hours), opening on Thursday and			

	closing on Monday the following week. During this period, students can attempt the quiz once within the 60-minute scheduled time and a specific mark is allocated as part of the associated final course mark. The results are not visible to students until they have finished the quiz, when the correct answers are displayed, and the errors are underlined.
Group	Groups A and B have the same assignment and schedule. (Code: RPL_A&B)

There was no distinction between groups: group A and group B carried out the same assignment following the same plan (code: RPL_A&B). The total scheduled time for post/out-of-class activities per week is 60 minutes.

4.5.5.2 Test readings

The two last readings are intended to assess student ability to read research articles before and after the lectures on 'Best Practices in Reading Primary Literature' and thus evaluate their progress. To measure the effectiveness of the teaching intervention, a single field experiment was carried out in which the variables were isolated and controlled using a pre-experimental design with one group for the pre- and post-test exams.[64,79] As is often the case in educational research, control groups were not included, given that withholding assignments or expecting students not to read a research article was not an acceptable option.

The main characteristics of the two test readings are presented in Table 3. The two articles were selected with care, as different contents and syllabus-related concepts were used to generate the pre- and post-test exams. The "readability" score of both articles was assumed to be fairly equivalent, with a similar number of figures and level of difficulty: a readability score between 30 and 50 is regarded as "difficult" in the academic area.[80]

The pre- and post-test exams were implemented as a parallel test. As mentioned, the student cohort was randomly divided into two groups, RPL_A and RPL_B, which had an even distribution, the group size differing by only one member.

The test reading design is presented in Table 4. In the pre-test exam, paper 4 was 'Ransegnola et al.[81] ' for group RPL_A and 'Hussain et al.[82] ' for group RPL_B. In the post-test exam, the test readings were switched: for paper 5, group RPL_A received 'Hussain et al.[82] ' and group RPL_B received 'Ransegnola et al.[81] '. The articles were switched to eliminate the possibility that any measured improvement was due to the post-test article being easier to read and understand than the pre-test article.

4.5.5.3 Test-exam questions

The questions in the test-exam are summarized in Table 5. Eleven questions were devised and categorized as article comprehension ("Research Argumentation" and "Contents and Results") and personal opinion about the contents ("Opinion").

The short answers written by the students for the five questions about "Research Argumentation" (1-(RA) to 5-(RA) in Table 5) were manually graded as correct (1 point), semi-correct (0.5 point) and incorrect (0 point). This scoring model is based on the instructor's rubric, with grading criteria based on the elements that should be present in a student's answer. To ensure continuity in the scoring model, the numerical answers related to the five questions about "Contents and Results" (6-(C&R) to 10-(C&R) in Table 5) were also prepared and graded as correct (1 point), semi-correct (0.5 point) and incorrect (0 point). Question 11-(O) was not graded and was used to obtain the student's personal view of the article, its convincing findings, and the "anatomy" of the paper.

The aim of the pre- and post-test exams was to unveil the tangible progress made by undergraduate fluid technology students in their ability to identify research arguments and the contents and results in articles after completing the intervention. The teaching strategy was not based specifically on rhetorical moves, and no oral examination was given.[64]

TABLE 3 Test readings: design and main characteristics of the selected research articles.

Type	Research article	Research article
Language	English	English
Title	"An Investigation on the Leakage Flow and Instantaneous Tooth Space Pressure in External Gear Machines."	"Discharge characteristics of sharp-crested circular side orifices in open channels."
Reference	Ransegnola et al.[81]	Hussain et al.[82]
Key features	Analytical and Numerical Simulation work (Integral & Differential analysis)	Analytical and Experimental work (Integral & Dimensional analysis)
Sections	Abstract I. Introduction II. Leakage modelling in lumped parameter approach III. Flow turbulence at tooth tip IV. Results from the proposed model V. Conclusion References	Abstract Nomenclature 1. Introduction 2. Analytical considerations 3. Experimental work 4. Analysis of data 5. Conclusions References
Main body word count	≈ 4000 words	≈ 3500 words
Figures	14	6
Tables	2	2
Readability "reading ease" score[80]	39 (Difficult - Academic)	45 (Difficult - Academic)

TABLE 4 Test reading design: pre-test exam (paper 4 entitled "An Investigation on the Leakage Flow and Instantaneous Tooth Space Pressure in External Gear Machines.") and post-test exam (paper 5 entitled "Discharge characteristics of sharp-crested circular side orifices in open channels.").

	Pre-test exam		**Post-test exam**	
	Paper 4 (RPL_A)	**Paper 4 (RPL_B)**	**Paper 5 (RPL_A)**	**Paper 5 (RPL_B)**
Test exam	PRE-		POST-	
Reference	Ransegnola et al.[81]	Hussain et al.[82]	Hussain et al.[82]	Ransegnola et al.[81]
Syllabus related concepts	Newtonian viscous flow	Energy/Pump to system	Energy/Pump to system	Newtonian viscous flow
Assignment by sections	Full reading		Full reading	
Assessment	Online multiple-choice quiz with numerical and short answers. The short answer format allows students to write at length and is manually graded by the instructor with three possible grades: correct, semi-correct and incorrect. The online multiple-choice quiz is a computer-based individual activity delivered via the ATENEA platform. It is available for five days (120 hours), opening on Thursday and closing on Monday next week. During this period, students can attempt the quiz once within the 60-minute scheduled time and a specific mark is allocated as part of the associated final course mark. Results are not visible to students until they have finished the post-questionnaire in week 12.			
Group	(Pre-) RPL_A	(Pre-) RPL_B	(Post-) RPL_A	(Post-) RPL_B

TABLE 5 Test-exam questions.

	Question	**Related to**
"Research Argumentation" (RA): short answer manually graded (correct 1 point, semi-correct 0.5 points and incorrect 0 points)	1-(RA). What was the researchers' **motive** for conducting this research? In which section did you find the **motive**?	Why the research was done.
	2-(RA). What was the **objective**? In which section did you find the **objective**?	What the authors pursue.
	3-(RA). What is the **main conclusion** drawn by the researchers from the results? In which section did you find the **main conclusion**?	The main outcome of the research.
	4-(RA). What are, according to the researchers, the **implications** of the research? In which section did you find the **implications**?	The justification and consequences of the research.
	5-(RA). Which factors do the authors mention that **weaken** the results or main conclusion? In which section did you find the **weak factors**?	What weakens the results or the main conclusion.
"Contents and Results" (C&R): multiple-choice specific/numerical answer (correct 1 point, semi-correct 0.5 points and incorrect 0 points)	6-(C&R). Identify the key features of the presented work.	The key features (theoretical, analytical, numerical simulation, experimental studies).
	7-(C&R). Identify the "tools" used by the authors in their work.	Related to the basic physical laws of fluid mechanics and state relations.
	8-(C&R). Identify and choose the key and most essential table and figure.	The information and results are presented in table and figure formats.

	9-(C&R). Calculate the coefficient of discharge for run no. 24 (Table 1) (Hussain et al., 2010)	Numerical results are to be calculated by the students from the results of the paper.
	9-(C&R). What is the source of the unexpected rise in Figure 9(a)? (Ransegnola et al., 2018)	
	10-(C&R). Reliability of the data. Are the data reproducible?	Reproducibility as a marker of research progress.
'Opinion' (O): short answer	11-(O). What do you think is missing in the reported work?	Personal opinion about convincing findings and the 'anatomy' of the paper.

4.6 Limitations

The intervention method is limited by a number of boundary assumptions inherent to the case study. First, the groups of participants were selected based on the semester enrollment and, consequently, restricted by matriculation size. In addition, the students were all from a specific engineering degree program at a single institution. No background information was collected, which excludes other indicators from the study, such as previous academic performance, research practice, or industry experience.[83] In fact, it was decided that collecting demographic, race, ethnic and gender data would not be a part of the study. Finally, since the teaching strategy is designed for a specific context, the results and findings may only be analyzed in a comparative sense within the data collected from the intervention.

5 RESULTS AND DISCUSSION

The data represent four student cohorts from four consecutive semesters: the 2021 spring semester (S2021), 2021 fall semester (F2021), 2022 spring semester (S2022), and 2022 fall semester (F2022).

The enrolment figures in each course are presented in Table 6. The participants included male and female students, and it was decided not to collect data on race, ethnicity, or gender.

The student population was randomly divided into two groups: RPL_A and RPL_B (Table 4). To maintain the comparability of the data, all the administered assignments, tests, exercises, and examinations were identical or had a comparable level for both groups. The students who were repeating the subject, having failed it the previous semester, represented just under 10% of the enrolled students for all semesters, and it can be postulated that they had no significant influence on the outcomes. The Minitab® 19 software package (State College, PA, USA) was used for data processing.

TABLE 6 Enrolment figures, questionnaire, test-exam participation, and survey.

Semester	S2021	F2021	S2022	F2022
Enrolment	55	55	54	57
Pre-questionnaire	52 (95%)	54 (98%)	52 (96%)	53 (93%)
Post-questionnaire	55(100%)	53 (96%)	45 (83%)	54 (95%)
Pre-test exam RPL_A	28 (100%)	24 (96%)	27 (100%)	25 (93%)
Post-test exam RPL_A	27 (100%)	23 (92%)	26 (96%)	25 (93%)
Pre-test exam RPL_B	26 (93%)	29 (97%)	25 (93%)	29 (97%)
Post-test exam RPL_B	27 (100%)	29 (97%)	25 (93%)	27 (90%)
Survey	-	-	50 (93%)	54 (95%)

5.1 Student responses to questionnaires

The number of students participating in the pre- and post-questionnaires can be seen in Table 6. The level of participation was high, being above 90%, except in one cohort, where it was 83%.

The pre- and post-questionnaires were used to assess the student perceptions of their own improvement in capability, ability, skills, and background in research article reading. The data of all the students in S2021 and F2021 were combined in a non-parametrical Mann-Whitney test, with alpha equal to 0.05 as the significance level. As the responses to both questionnaires were anonymous, an individual match could not be performed. To carry out a paired comparison, both questionnaires in S2022 and F2022 courses were non-anonymous, and a non-parametrical Wilcoxon signed-rank test was used with an alpha equal to 0.05 as the significance level.

Questions were grouped into blocks and are listed in Table 7, which shows the statistically significant differences in scores: a higher post-questionnaire score than pre-questionnaire score represented a positive trend. The results provide insights into the effectiveness of the proposed teaching methodology in helping students achieve competence in reading research articles. Significant positive differences in capability (block A) and background (block D) scores were obtained in all courses. Particularly noteworthy is the positive shift in perceptions of reading ability during the intervention, apparent in the response to questions 11(B): “Materials and Methods”, 12(B): “Results”, and 13(B): “Discussion”. This can be attributed to the evolution of the teaching strategy based on the experience gained by the instructor during the period of implementation. Thus, the learning curve is a factor that impacted the effectiveness of strategy execution.

The results of the last intervention in F2022 are depicted in Figures 2–4. Reading capability, ability, and skills improved substantially in all three blocks according to the difference in pre- and post-questionnaire results. The improvement in response to question 15(B), regarding perceived ability to read figures and tables, with a *p*-value between 0.05 and 0.1, is considered to have practical significance in this context. The results for question 16(C), which rates reading skills without needing to use a dictionary to translate English words, indicate a gain in confidence in language skills after reading five research papers in a 14-week period. Assisted by the high level of participation, it was possible to measure the objective learning outcomes, which were supported by an increase in student confidence in reading and analyzing research articles, as revealed by self-assessment. These findings provide insights into the first two research questions outlined in Section 1.

TABLE 7 Student perceptions of capability (block A), ability (block B), skills (block C) and background (block D) in reading a research article. Blocks and questions of the questionnaire are shown in Table 1.

Semester	S2021		F2021		S2022		F2022	
Question (Block)	Significant difference?	*p*-value	Significant difference?	*p*-value	Significant difference?	*p*-value	Significant difference?	*p*-value
1(A)	Yes	0.006	Yes	0.003	Yes	0.009	Yes	0.000
2(A)	Yes	0.001	Yes	0.000	Yes	0.000	Yes	0.002
3(A)	Yes	0.000	Yes	0.002	Yes	0.001	Yes	0.000
4(A)	Yes	0.000	Yes	0.000	Yes	0.000	Yes	0.000
5(A)	Yes	0.001	Yes	0.004	Yes	0.001	Yes	0.000
6(A)	Yes	0.000	Yes	0.000	Yes	0.000	Yes	0.000
7(A)	Yes	0.031	Yes	0.001	Yes	0.003	Yes	0.000
8(A)	Yes	0.000	Yes	0.000	Yes	0.000	Yes	0.000
9(B)	Yes	0.000	Yes	0.000	Yes	0.000	Yes	0.000
10(B)	Yes	0.000	Yes	0.000	Yes	0.000	Yes	0.000
11(B)	**No**	**0.311**	**Yes**	**0.014**	Yes	0.000	Yes	0.001
12(B)	**Yes**	**0.001**	**No**	**0.168**	**Yes**	**0.001**	Yes	0.000
13(B)	Yes	0.010	**Yes**	**0.001**	**No**	**0.161**	**Yes**	**0.000**
14(B)	Yes	0.000	Yes	0.000	Yes	0.000	Yes	0.000
15(B)	Yes	0.026	Yes	0.026	Yes	0.032	**Yes***	**0.064**
16(C)	**No**	**0.445**	**No**	**0.448**	**Yes**	**0.017**	Yes	0.050
17(C)	Yes	0.004	Yes	0.003	Yes	0.014	Yes	0.004
18(C)	Yes	0.018	Yes	0.000	Yes	0.000	Yes	0.000
19(D)	Yes	0.000	Yes	0.000	Yes	0.000	Yes	0.000

η_1: pre-quest. median η_2: post-quest. median Difference: $\eta_1 - \eta_2$

Null hypothesis: H_0: $\eta_1 - \eta_2 = 0$ Alternative hypothesis H_1: $\eta_1 - \eta_2 < 0$

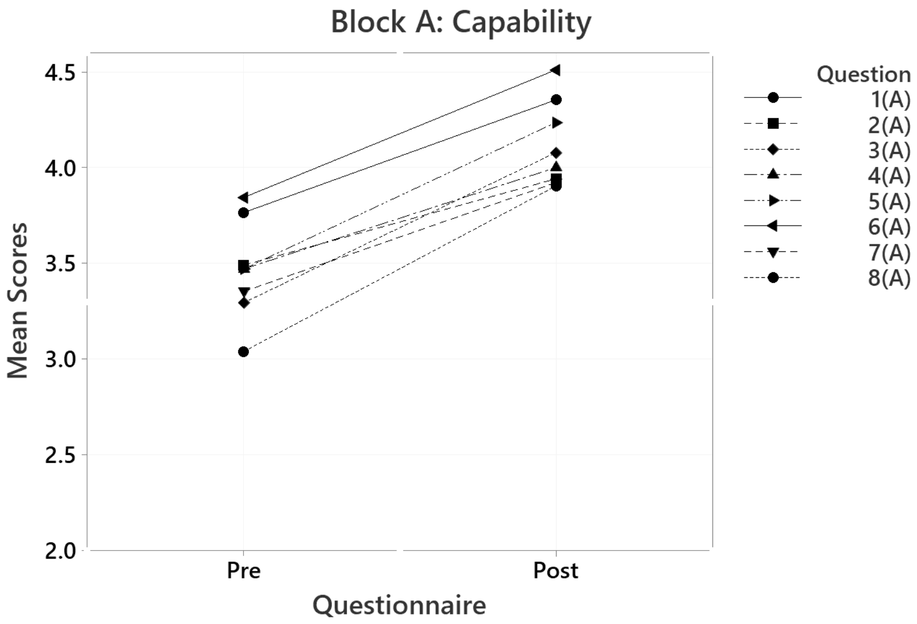

FIGURE 2 Capability in reading: changes in F2022 student perceptions from the pre- to post-questionnaire. Answer options block (A): 1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree. (Questions in Table 1).

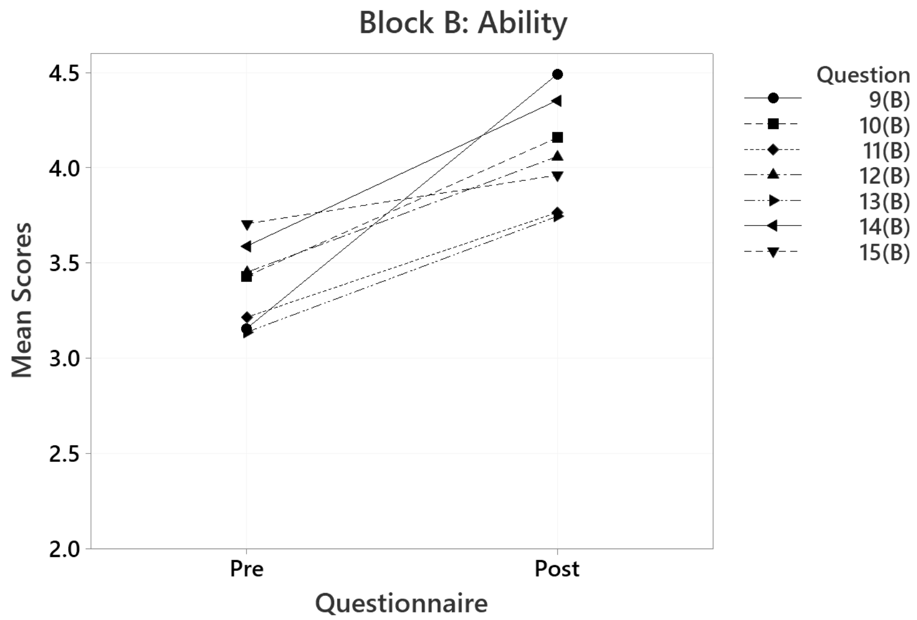

FIGURE 3 Ability in reading: changes in F2022 student perception from the pre- to post-questionnaire. Answer options block (B): 1 = Not; 2 = Unsatisfactory; 3 = Satisfactory; 4 = Good; 5 = Very Good. (Questions in Table 1).

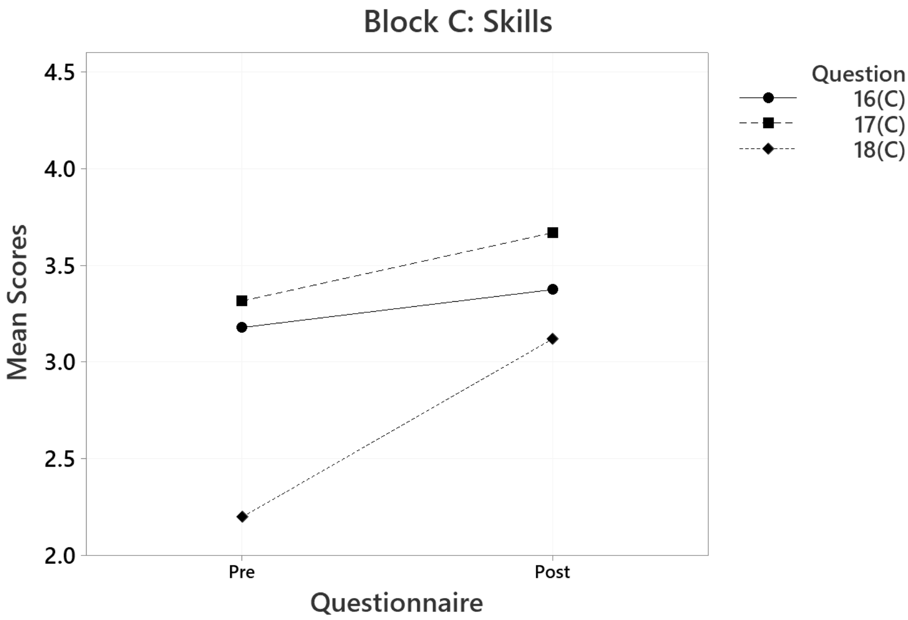

FIGURE 4 Skills in reading: changes in F2022 student perception from the pre- to post-questionnaire. Answer options block (C): 1 = Always; 2 = Frequently; 3 = Occasionally; 4 = Rarely; 5 = Never (Questions in Table 1).

The relationship between the response to question 19(D), concerning the number of research articles the student has read to date, and the response to the questions of block (A): "capability in reading" and block (B): "ability in reading" is of particular interest, and is depicted in a bivariate plot in Figure 5. Notably, the average score for the four readings increased significantly from the pre- to the post-questionnaire. In both blocks, a clear displacement of the responses to the upper right corner is noticeable: right-displacement means a higher score for capability and ability, whereas up-displacement indicates an increment in the number of research articles read by the students. These findings allow us to conclude that almost all the students carried out all six assignments, read all five papers, and perceived an improvement in both reading capability and ability. The interest and dedication of the students is further corroborated by the fact they answered all twenty questions of the questionnaire.

A Chi-square test, with an alpha of 0.05 as the significance level, was carried out to see if the response profile to question 20(D), regarding the relevance of reading research articles, differed between pre- and post-questionnaires. The results of the test were S2021 (*p*-value 0.316), F2021 (*p*-

value 0.231) and S2022 (p-value 0.932). The results of the F2022 course, collected in Table 8, reveal no statistically significant changes, showing that the student opinion remained steady throughout the intervention. This could be attributed to the perception that reading research articles is an important task in academic and scientific careers as opposed to industrial, professional, and business careers.

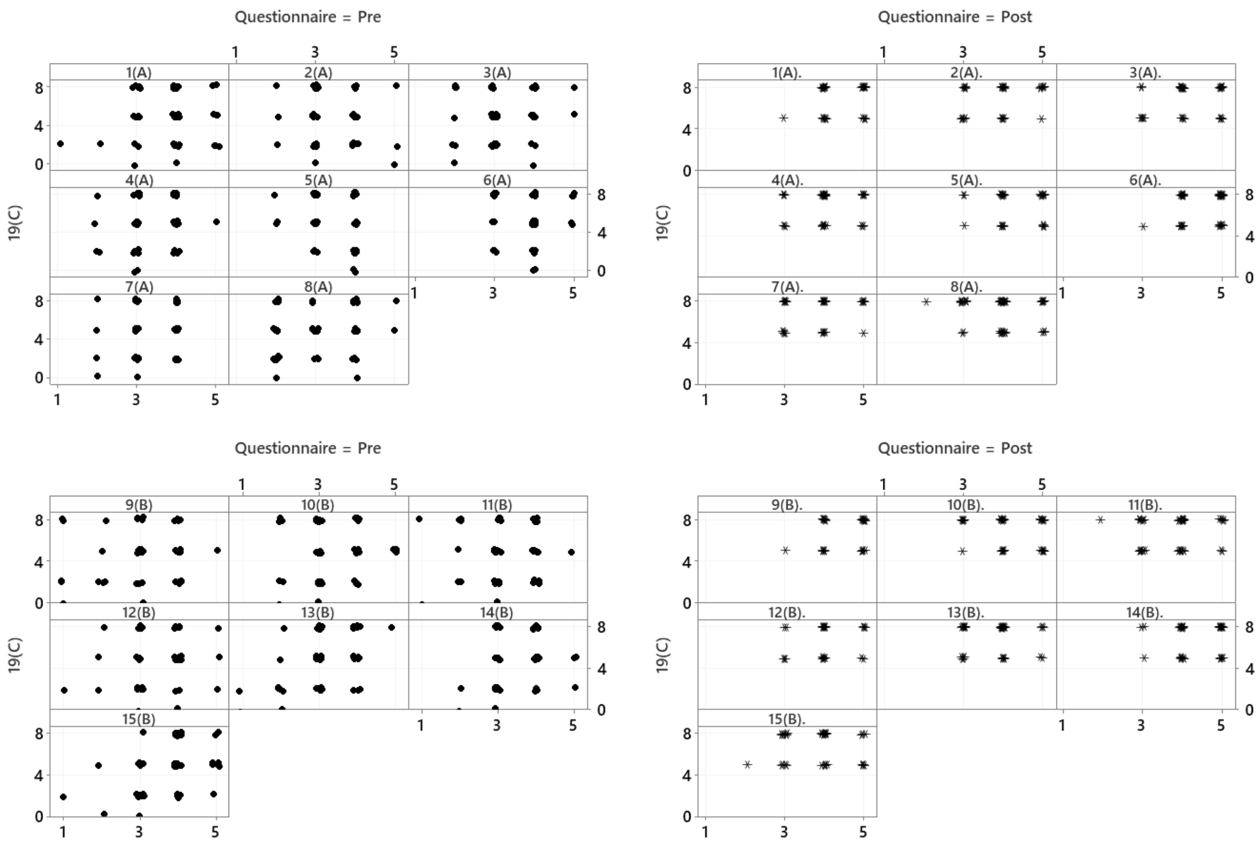

FIGURE 5 Responses of F2022 students: comparison of block (A) "Capability in Reading" questions 1(A)÷8(A) and block (B) "Ability in Reading" questions 9(B)÷15(B) with question 19(D) from pre- to post-questionnaire in Table 1: "How many research articles have you read so far?". Answer options block (A): 1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree. Answer options block (B): 1 = Not; 2 = Unsatisfactory; 3 = Satisfactory; 4 = Good; 5 = Very Good. Answer options question 19(D): 0; 1-2; 3-5; 6-8; >8.

The student responses to Table 1 questions 8(A) and 18(C) regarding whether they read the articles sequentially or non-sequentially were used to determine the extent to which they read selectively. The results are provided in Figures 6–8, where the highest columns and percentages are on the left, indicating a significant number of students strongly agreed that they read selectively (question 8(A)), and never read a paper sequentially (question 18(C)).

TABLE 8 F2022 student responses to question 20(D) regarding the importance of reading research articles.

Question 20(D)	"What impact, if any, do you believe reading research articles has on your professional development or career?"				
Answer options	None-A little	Neutral	Quite a lot	A lot	Chi-square test*
Pre	1	16	24	10	$p = 0.505$
Post	4	18	21	8	

* $\alpha = 0.05$

The results in Figures 6 and 7 point to a clear and positive evolution between the pre- and post-questionnaire. Figure 6 depicts an increase in the percentage of students who "strongly agree" with this gained capability (question 8(A)), indicating that students assimilated the competence of selectively reading a research paper from pre- to post-test exam, with a significant increase in the pre/post ratio, ranging from 3-fold in S2021 and F2021 to 5-fold in S022 and F2022. In addition, question 18(C) in Figure 7 shows a positive trend toward claiming to "rarely" reading a paper sequentially, which in the last three cohorts doubled from the pre- to post-questionnaires. Furthermore, the answer "always" for never reading a paper sequentially increased from 0% to 4% in S2022 and up to 13% in the last intervention in F2022.

These results are supported by the average of the percentiles of the four cohorts presented in Figure 8 and demonstrate that our teaching strategy may be used to improve undergraduate reading skills, thus addressing the first research question of Section 1.

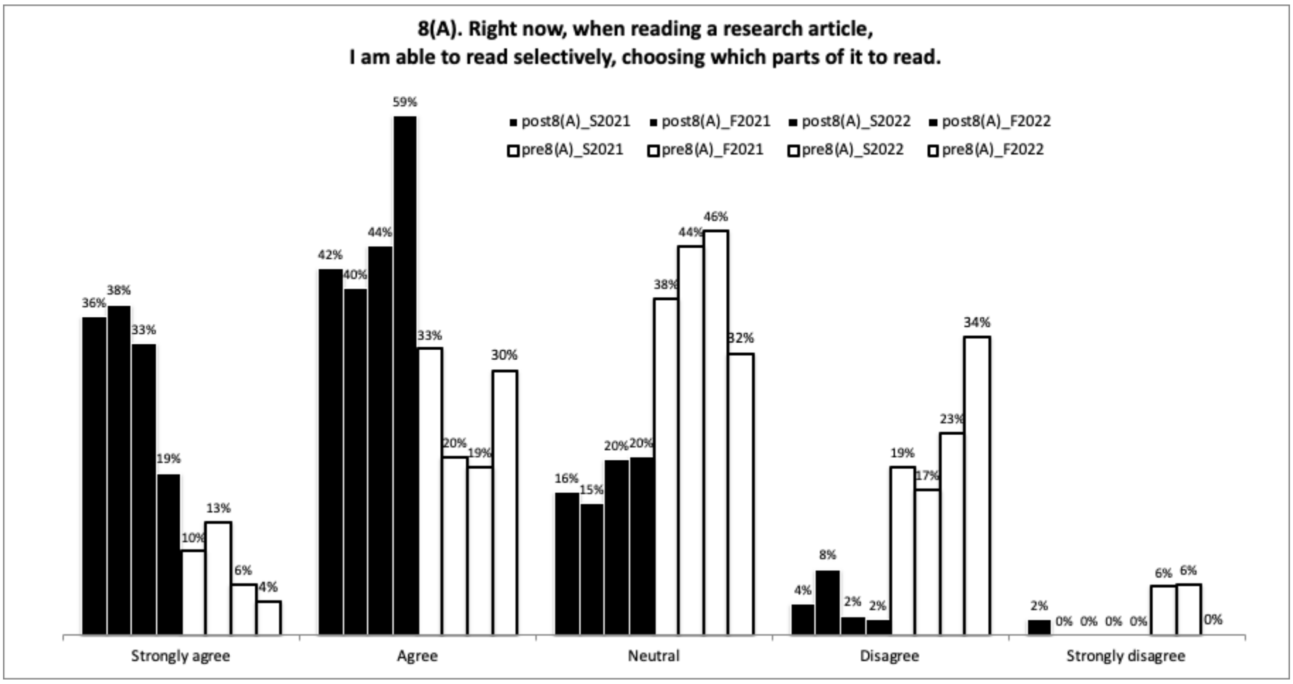

FIGURE 6 Student perception, expressed as a percentage, of whether they read the articles sequentially or not. Question 8(A): "Right now, when reading a research article, I am able to read selectively, choosing which parts of it to read." Answer options 8(A): 1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree.

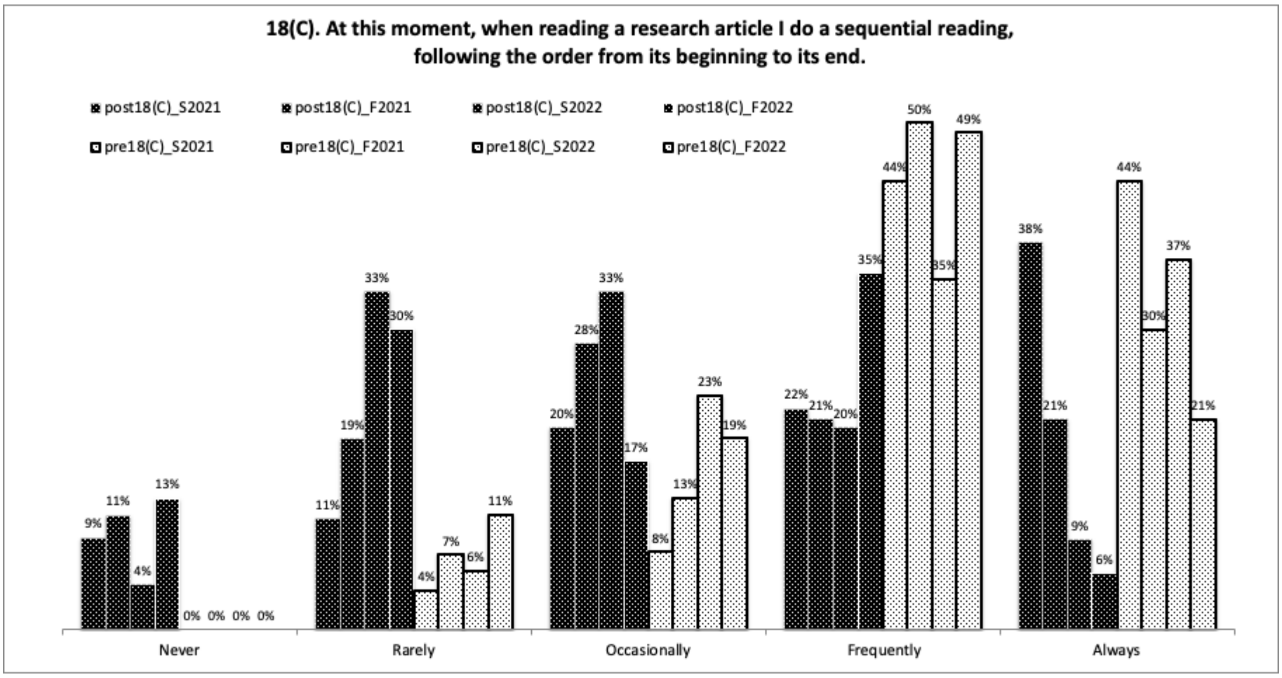

FIGURE 7 Student perception, expressed as a percentage, of whether they read the articles sequentially or not. Question 18(C): "At this moment, when reading a research article I do a sequential reading, following the order from its beginning to its end." Answer options 18(C): 1 = Always; 2 = Frequently; 3 = Occasionally; 4 = Rarely; 5 = Never.

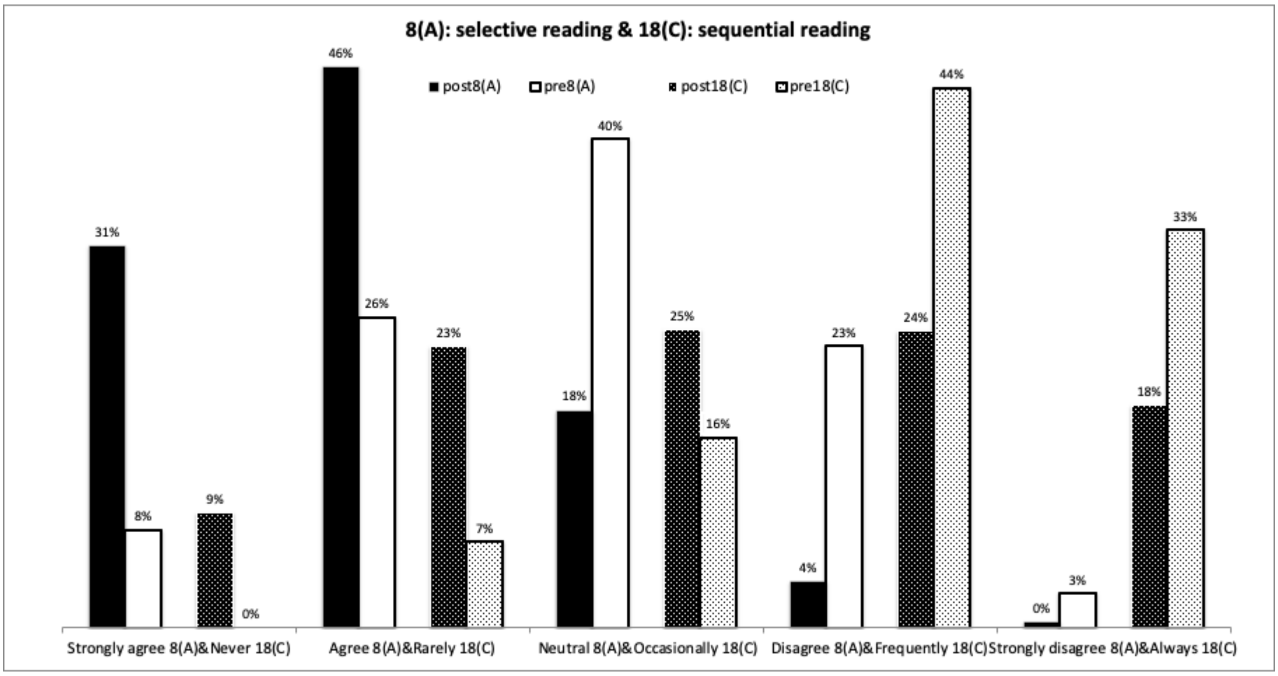

FIGURE 8 Student perception of whether they read the articles sequentially or non-sequentially. Average percentage for the four cohorts for questions 8(A) and 18(C).

5.2 Student performance in the test-exams

The data of students participating in the pre- and post-test exams are summarized in Table 6. As the responses to both tests were non-anonymous, the results could be matched to extract individual effects.

With the intention of calculating student progress after the lectures on best practices in reading primary literature, a non-parametrical paired-test was run on the data of pre- and post-test exams for each student. In each case, the score difference was calculated (post-test minus pre-test) to elucidate the efficacy of the methodology. Also, a Wilcoxon signed-rank test was performed to check if the difference was statistically significant (alpha equal to 0.05 as the significance level), that is, if the post-test score was significantly higher than the pre-test score. The same test was run to simultaneously check whether there were differences between the two groups, RPL_A and RPL_B. The results are listed in Table 9, in which the questions of Table 5 are grouped into two blocks: Research Argumentation and Contents and Results. The results reveal a considerable difference in the scores in both blocks before and after the lectures.

Focusing on the F2022 students, both groups improved their performance regarding Contents and Results, as shown in Figure 9, with a median difference of 0.5 points in the total score for these questions. The improvement is clearly apparent in the RPL_B group, which would also have been the case in the RPL_A group but for two individuals with an anomalously negative difference (the two asterisks). In contrast with group RPL_A, the RPL_B group improved their overall performance in Research Argumentation, and questions 2-(RA) and 9-(C&R). This minor but noticeable difference could be explained by the fact that the lecture on the 'Newton viscous flow' concept was taught in week 8 (see Figure 1), and the assignments related to this concept were given in week 4 for the RPL_A group (paper 2) and week 11 for the RPL_B group (paper 5). Therefore, the RPL_B group completed the assignment shortly after all the lectures on reading primary literature and had more time to assimilate the course information. This difference in schedule could also explain the statistically significant difference in the response to question 9-(C&R) (see Figure 10), which requires the students to calculate results based on the article content using the concepts learned in the previous lectures. When comparing the pre- and post-test scores, 50% of the overall cohort and the RPL_B group showed a positive difference and 25% neither positive nor negative. The worse results obtained by the RPL_A group for question 9-(C&R), observed in the distribution of the differences on the negative side of the figure, supports the plausibility of the previous explanation. The students were non-native speakers of English, but there is no reason to suppose this had a noticeable influence on the results.

TABLE 9 Analysis of student improvement after the lecture on best practices in reading primary literature, comparing the results of pre- and post-test exams. (RA): "Research Argumentation" and (C&R): "Contents and Results". Questions from the test-exam are listed in Table 5.

Semester	S2021		F2021		S2022		F2022	
Block and question	Significant difference? (Group difference)	*p*-value	Significant difference? (Group difference)	*p*-value	Significant difference? (Group difference)	*p*-value	Significant difference? (Group difference)	*p*-value
{1÷5-(RA)}	Yes (B)	0.046	Yes (B)	0.000	No (None)	0.096	**Yes (B)**	**0.007**
{6÷10-(C&R)}	No (B)	0.147	No (None)	0.552	No (B)	0.064	**Yes (Both)**	**0.006**
1-(RA)	Yes (B)	0.048	No (None)	0.309	No (None)	0.594	Yes (A)	0.047
2-(RA)	No (None)	0.504	Yes (B)	0.021	Yes (B)	0.030	**Yes (B)**	**0.070**
3-(RA)	No (A)	0.313	Yes (None)	0.039	No (A)	0.136	No (A)	0.341
4-(RA)	Yes (A)	0.038	No (None)	0.061	No (A)	0.518	No (None)	0.257
5-(RA)	No (None)	0.223	Yes (B)	0.001	No (B)	0.441	No (B)	0.097
6-(C&R)	No (A)	0.422	No (A)	0.265	No (A)	0.096	No (A)	0.450
7-(C&R)	No (B)	0.933	No (None)	0.294	No (None)	0.064	No (None)	0.608
8-(C&R)	No (None)	0.505	No (None)	0.826	No (B)	0.594	No (None)	0.663
9-(C&R)	Yes (B)	0.000	No (None)	0.928	Yes (B)	0.030	**Yes* (B)**	**0.081**
10-(C&R)	No (None)	0.581	No (A)	0.228	No (None)	0.136	Yes (Both)	0.006

η_1: post-test **median** η_2: pre-test **median** Difference: $\eta = \eta_1 - \eta_2$

Null hypothesis: H_0: $\eta = 0$ Alternative hypothesis H_1: $\eta > 0$

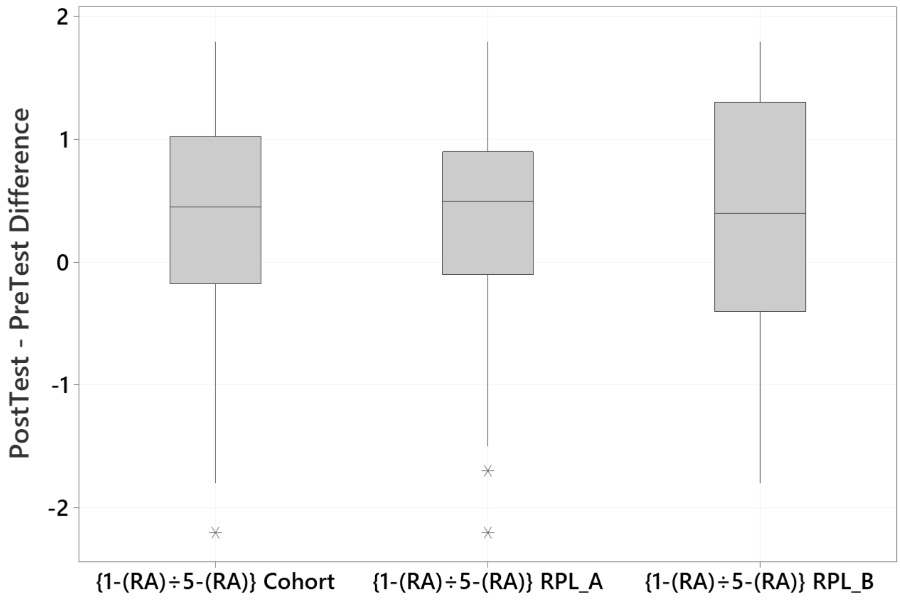

FIGURE 9 Difference in F2022 student pre- and post-test performance in the block "Research Argumentation". Groups: RPL_A and RPL_B. Questions block {1÷5-(RA)} in Table 5. Range (−5.0: minimum ÷ +5.0: maximum).

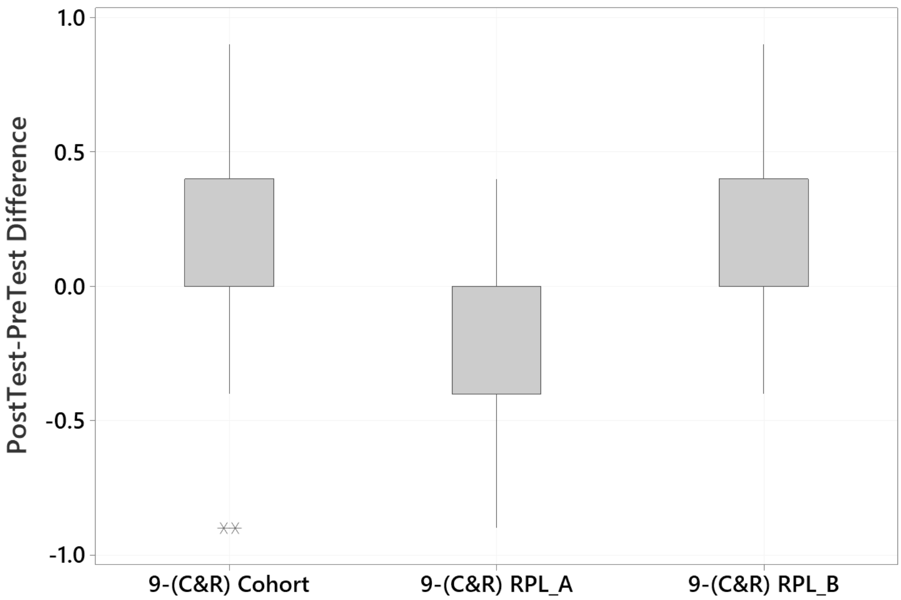

FIGURE 10 Difference in F2022 student pre- and post-test performance in question 9-(C&R) of Table 5 related to the numerical results calculated by the students from the data of the pre- and post-assigned paper. Groups: RPL_A and RPL_B. Range (−1.0: minimum ÷ +1.0: maximum).

5.3 Student performance in the final examination

The effect of the intervention on student performance was also evaluated by means of the grade obtained in the final course examination. Their performance sheds light on the third research question of Section 1 of whether reading research articles favors learning of course material. The final examination was based on two fluid-dynamic applications: a problem-solving multiple-choice question test and a problem-solving exercise (performed by each student on their own), and the grade for the problem-solving exercise ranged from 0 (minimum) to 10 (maximum). The problem-solving exercise was based on the syllabus concept of 'Newtonian viscous flow', the subject of the research article by Ransegnola et al.[81]

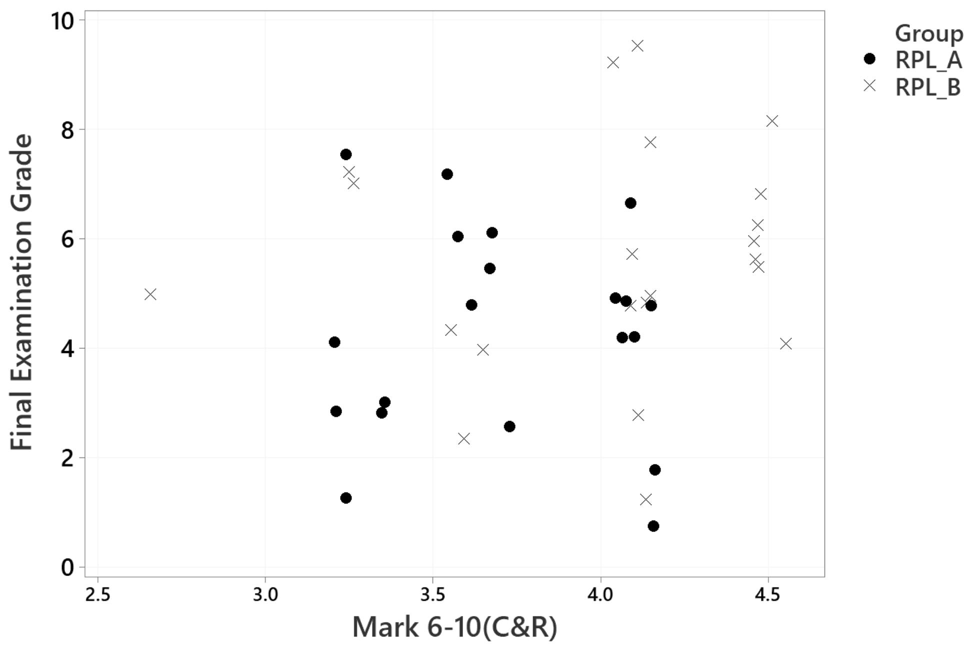

FIGURE 11 F2022 individual and group comparisons in the post-test exam scores for "Contents and Results" questions versus the final examination grade. Groups: RPL_A and RPL_B. Questions&block {6-10(C&R) range (0: minimum ÷ +5.0: maximum)} in Table 5. Final examination grade range (0: minimum ÷ +10: maximum).

Figure 11 only depicts the relationship between the final exam grade and the post-test exam scores, as the pre-test exam did not exhibit any correlation. The Pearson correlation was calculated to quantify the relation between the final examination grade and the post-test exam scores. There is significant correlation between the scores of questions {6-(C&R) ÷ 10-(C&R)} in Table 5 related to Contents and Results and the final examination grade, $r = 0.311$ (95% CI = (0.008,0.562)). The grade in the final examination was slightly higher among the students in the RPL_B group compared to the RPL_A group, although the difference was only marginally significant.

5.4 Student evaluations of the teaching strategy

Students evaluated the teaching strategy with a survey filled out at the end of the semester, which was introduced in the last two courses. The data of students participating in the survey are summarized in the last row of Table 6. The results presented in Table 10 show that the students generally gave a positive evaluation for the different parts of the teaching strategy (items (a)-(e) in Table 10). The response to the last item (f), ranging between "Neutral" and "Bad", deserves special attention, as it indicates that the students perceived the lecture program to be sufficient for learning the content. This result supports the successful evolution of the teaching strategy and its effectiveness.

To capture student opinions about what they found lacking in both test readings, the short answer to question 11(O) of Table 5 about convincing findings and the 'anatomy' of the paper was used. A selection of the comments is presented here (translated from Spanish into English):

- "I think that the work presented misses the hypothesis. Acknowledgment section is missing."
- "More images from the experimental analysis are needed to understand where the values in the tables come from, as well as some examples where we can study it in a real-world application."
- "It lacks repeatability as they use their own software. It also lacks experimental data that can be compared to their simulation results."
- "A Discussion section is missing in this work, so the authors can explain their findings."

- “I would have explained the purpose of the research more clearly and drawn clearer conclusions.”

TABLE 10 Student evaluations of the teaching strategy. Items are translated from Spanish to English. Mean score (Standard deviation). Answer options 1 = Very bad; 2 = Bad; 3 = Neutral; 4 = Good; 5 = Very good.

Item	Mean score (SD)	
	S2022	F2022
(a) Please rate the quality of the content of the articles that you have read as assignments.	4.0 (0.6)	3.9 (0.7)
(b) Please rate the order in which the readings of the articles have been scheduled.	3.9 (0.7)	4.1 (0.6)
(c) Please rate the quality of the preparation and explanation of the contents to be worked on in each article.	4.4 (0.6)	4.2 (0.7)
(d) Please rate the quality of the questionnaires associated with reading the articles.	4.2 (0.7)	3.9 (0.7)
(e) Please rate how useful you found the lectures on best practices in reading scientific articles.	4.1 (0.7)	3.8 (0.9)
(f) Please rate how convenient it would be for you to have one more lecture on best practices in reading scientific articles.	3.2 (1.3)	2.6 (1.2)

An unexpected outcome was the opinion that a research paper should be accompanied by a video prepared by the authors. It was felt that videos would improve explanations given in each paper:

- “A video is missing to make the flow behavior through the gears more visual.”
- “Too much text; I need videos to know how the system works.”

These comments are understandable given the tech-savvy nature of the new generation of undergraduate students. Finally, according to the results of the official survey carried out by the university, student feedback on the overall subject was very positive.

6 CONCLUSIONS

In fluid technology, an advanced course related to fluid mechanics, it is strategically important to actively engage fourth-year undergraduate engineering students in a two-way link between the discovery process of scientific research and the course topics. This complex interaction helps students understand core concepts and boosts the development of a skill set required in real-world engineering applications. In the present case-based study, a post-hoc analysis was conducted of an in-house teaching strategy based on reading journal articles as an unconventional student-centered method and an intermediate step between education and industry.

The scores achieved by all four cohorts in the post-intervention questionnaire were statistically significantly higher than in the pre-intervention questionnaire, indicating an improvement in student perceptions of their capability and ability to read and evaluate a research article. These positive changes are aligned with the reading skills analysis, which suggested that students improved in their ability to read selectively from assignment to assignment. Even though the mark allocated to the assignments in this teaching strategy contributed to only 6% of the final course mark, the students carried out all six assignments and read all five papers, a sign of commitment and motivation.

The objective learning outcomes were assessed using a quantitative analysis of two parallel test exams and test readings, administered before and after the specific lectures on best practices in reading primary literature. By switching the articles, the risk of false estimations was minimized. The scores for questions about research argumentation increased significantly, indicating the successful development of the teaching strategy. Increasing the time devoted to the lectures and their division into three sessions contributed to this result. The slight positive correlation between the final examination grade and the scores for questions about article contents and results points to an association between the test-exam articles and the course syllabus. Overall, the results indicate that students gained an understanding of the core concepts of the subject during the semester, a very satisfactory trend.

The intervention can be considered effective, as it resulted in the gaining of knowledge by students. The positive experience in terms of benefit-cost outcomes, without having to sacrifice any of the course syllabus, favors its continuous implementation in future semesters. Addressing limitations and gauging the instructor's learning curve could improve the methodological approach in further research. The findings from this study are transversal and applicable to other engineering disciplines to help students learn, and engineering educators may make use of them.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare that there is no conflict of interest.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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