Approach with Active-cooperative, Flipped and Hands-on Learning: A Case Study in Transport Phenomena

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Abstract

This study reports the implementation and evaluation of an active learning strategy in an undergraduate Chemical Engineering course. The course was redesigned using a flipped classroom model, incorporating active-cooperative learning method. The weekly structure included three main components: (1) asynchronous video lectures to introduce core concepts, (2) in-class group work utilizing structured worksheets and small cooperative teams, and (3) hands-on simulations. The course Transport Phenomena served as the case study. Traditionally perceived as a mathematically challenging and abstract subject, Transport Phenomena often struggles to engage students effectively. To address this issue, the approach combined inverted classrooms, experiential learning, and the use of ANSYS Fluent in a computer lab setting. Student feedback was overwhelmingly positive: 90% of students rated the new methodology as adequate or highly effective, 93.3% preferred the guided study format over traditional lectures, and 73.3% found both the feedback process and the use of the computational fluid dynamics (CFD) tool beneficial for their learning. Additionally, academic outcomes improved, with the average final grade rising from 5.4 to 6.2, and there was a significant reduction in failure and remediation rates, even amid rigorous summative assessments. These results suggest that integrating flipped learning with active-cooperative and hands-on activities can enhance student engagement and support deeper learning in challenging engineering subjects.

Keywords: flipped learning, active cooperative learning, CFD tool, fluid mechanics

1. Introduction

Traditional lecture-based teaching often fails to sustain student attention, with engagement typically dropping after just thirty minutes (Keith, 2005). In addition, instructors are no longer the sole source of knowledge. With the rise of the internet, smartphones, and tablets, students now have constant access to vast amounts of information.

These developments highlight the need to rethink traditional teaching methods to ensure meaningful learning. The emphasis should shift from teacher-centered instruction to student-centered learning, where the goal is not simply to transmit content but to foster active engagement. This leads to a key question: how can we design learning experiences that support deep and lasting understanding?

Active learning addresses this goal by placing students at the center of the learning process (Felder, 1995; Felder & Brent, 2009). It shifts the emphasis from content delivery to student engagement and autonomy. Felder demonstrated the benefits in his Introductory Chemical Engineering Course (Felder, 1996), stating that he became convinced it was more effective than traditional approaches because it led to deeper learning and more confident student attitudes.

Recent studies have introduced new discussions on active teaching strategies. Nguyen et al. (2021) conducted a systematic analysis focusing on how to address students' emotional and behavioral responses. Their work suggests a variety of strategies to support teachers, including explanation, facilitation, and action planning, and recommends that these approaches be integrated into pedagogical practice. The authors found that 23 of the 29 studies they evaluated reported positive results for their active learning interventions.

Lombardi et al. (2021) provided a review of active learning specifically in the fields of science, technology, engineering, and mathematics (STEM). Their findings resulted in a new, coherent definition of active learning that is intended to be more applicable in practice.

Doolittle et al. (2023) aimed to refine the definition of active learning by emphasizing the need for clearer theoretical models. They highlighted which active learning strategies are effective and under what circumstances they should be used. Thus, undergraduates should be active participants, with their learning enriched by the social construction of meaning that extends beyond individual cognition.

Collaborative group work plays a central role, fostering peer collaboration and critical thinking. Hands-on activities further reinforce understanding by connecting theory to practice (Lavor et al., 2024).

Educators in Transport Phenomena have tested various innovative strategies to improve student engagement and learning. For example, Keith (2005) used a gamified approach in which student teams competed in classroom challenges called The Stanley Cup of Transport Phenomena. Teams answered randomly selected questions and earned points for accuracy and completeness. This format promoted active participation and helped reinforce core concepts through engaging activities.

Integrating laboratory experiments into the curriculum has proven to be an effective strategy for active learning. Augusto et al. (2019) implemented a new methodology in which student teams perform the concept, design, and development of practical demonstrations of mass transfer phenomena. Hansen et al. (2022) developed Active Learning Research Projects (ALRPs) inspired by ongoing research that sparked authentic questions and insights in the context of Transport Phenomena.

Virtual laboratories have greatly enhanced the learning experience. Some experimental scenarios are challenging to replicate in a traditional lab setting, making virtual laboratories a valuable alternative. For instance, De Jong et al. (2013) simulated transport phenomena scenarios, such as mass transfer in packed columns and non-Newtonian fluid flow. Pirola (2021) utilized a virtual immersive Crude Distillation Unit, allowing students to manage the unit operation by manipulating parameters and PID control. A survey conducted among the students confirmed a high level of interest and very positive feedback.

Zárate-Navarro et al. (2024) implemented several approaches to teaching Transport Phenomena, including interactive simulations using MATLAB’s PDEtool and Arduino-based experimental setups. MATLAB was used to visualize analytical solutions of conservation equations, while COMSOL supported the modeling and simulation of transport phenomena. The new approaches proved more effective for learning than theory by itself.

Flipped learning (FL) has proven effective across different educational settings (Amarilla et al., 2022). For instance, Torio (2019) applied this approach in a university-level course on physics and technology, combining video lectures with project-based learning. Students reported high satisfaction with the method.

Flipped learning is a well-established theme in engineering education. Karabulut-Ilgu et al. (2018) conducted a review of 62 studies in this field and concluded that flipped learning generally leads to higher learning outcomes compared to traditional instructional approaches. Similarly, Al-Samarraie (2020) evaluated several studies and found that, when combined with active learning, flipped learning can enhance skills such as student engagement, attitude, metacognition, performance, self-efficacy, and understanding.

In higher education, research has increasingly investigated flipped learning in combination with active and cooperative learning, since the flipped model creates classroom time that can be used for collaborative, problem-based, and interactive activities.

Li et al. 2020 evaluated around 435 studies and concluded that the link between flipped learning and active learning is “rarely explicitly addressed or operationalized. The theoretical and conceptual underpinnings are generally only vaguely described”. A strong growth in publications in FL is observed, with many applications, but a limited foundation.

Galindo-Dominguez (2021) evaluated 61 studies on flipped learning (FL) and revealed that the approach is more effective than conventional approaches. Some advantages are higher-order thinking skills, a more personalized teaching and learning process, and constructs such as self-efficacy, cooperativeness, and engagement.

Bredow et al (2021) found that active learning yields better results than lecture-based learning. It is more effective for various academic and personal outcomes, as well as satisfaction. However, these benefits are less pronounced in engineering and mathematics classes.

In the context of Transport Phenomena, Valero et al. (2019) applied a flipped learning model by assigning video materials before class sessions, allowing in-class time to be dedicated to participatory discussions and collaborative problem-solving.

Building on this foundation, the present study examines the combined use of flipped learning, active-cooperative, and hands-on strategies to increase student engagement in a traditionally challenging course. Drawing inspiration from established models in the literature, the approach aims to create a more interactive and student-centered learning environment.

2. Literature Review and Theoretical Background

2.1 Avtice Learning

A wide range of tools and approaches has been developed to support the evolving landscape of teaching and learning. The shift from "teaching" to "learning" itself reflects a change in focus: the emphasis is now on the learner. While teaching does not always result in learning, learning implies a measurable outcome for the student.

To support this learner-centered perspective, educators have adopted diverse pedagogical approaches, including active learning, flipped learning, hybrid models, collaborative and cooperative learning, case-based instruction, lean learning, interdisciplinary strategies, gamification, and structured methodologies such as CDIO and Problem-Based Learning (PBL), along with its variants: Project-Based, System-Based, and Puzzle-Based Learning (Vianna Jr. & Vianna, 2023).

An example of Problem-Based Learning (PBL) in Chemical Engineering is the work of Hmelo-Silver (2004), which focused on a heat exchange scenario for troubleshooting a distillation column. Similarly, Tuson (2007) approached the topic by examining both historical and contemporary engineering disasters or successes. In this context, students analyzed situations involving Transport Phenomena, such as the Challenger disaster, from the perspective of heat transfer.

But what exactly is active learning? According to Prince (2004), active learning encompasses any instructional method that directly involves students in the learning process. Rather than passively receiving information, students engage in meaningful activities and reflect on their actions, typically during class time. Similarly, Felder and Brent (2009) define active learning as any course-related task that requires students to go beyond passive behaviors like listening, watching, or note-taking.

When applied in group settings, these strategies form the foundation of active cooperative learning. Cooperative learning is an instructional method in which students work together toward shared goals while being individually assessed (Prince, 2004). It can also be understood as a collaborative process in which students support one another's learning, working alongside peers and instructors (Menezes, 2021).

This model is grounded in five core principles (Menezes, 2021): individual accountability, positive interdependence, high levels of simultaneous interaction, development of interpersonal skills, and team self-assessment—the ability to evaluate group dynamics and address challenges collectively. The emphasis is on cooperation rather than competition, with the ultimate goal of fostering deeper learning (Prince, 2004).

2.2 Designing a Course

Course design can follow the framework proposed by INSPER (Gianesi et al., 2020). In the Planning phase, instructors define the intended learning objectives for the course or module. Course Dynamics refers to the chosen instructional strategy that supports students in reaching those objectives, for example, Problem-Based Learning (PBL), the flipped classroom model, or the CDIO approach.

Assessment measures the extent to which students achieve the learning objectives. Its function goes beyond assigning grades; it serves to verify whether the desired outcomes have been met. Assessments can be formative (ongoing and developmental) or summative (final and evaluative).

Feedback is closely linked to formative assessment and should be provided consistently throughout the course. Timely feedback enables students to learn from mistakes and make adjustments before summative evaluations.

Flipped learning redefines how time and space are used in the classroom. This concept is discussed extensively in Flipped Learning: A Guide for Higher Education Faculty by Robert Talbert (2019), a book praised by Professor Eric Mazur (2015), who described it as "a must-have reference," whether one is new to flipped learning or an experienced practitioner.

In a flipped model, students first encounter new content outside of class, typically through video lectures, shifting the initial learning to an individual setting. As a result, in-class time can be used for more meaningful activities such as applying concepts, discussing results, and engaging in collaborative or creative tasks (Talbert, 2019).

Professor Talbert defines flipped learning as:

" [...] a pedagogical approach in which first contact with new concepts moves from the group learning space to the individual learning space in the form of structured activity, and the resulting group space is transformed into a

dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter."

3. Local Context

Two items are addressed here: the proposed research plan for the Department of Chemical Engineering, supported by a Capes-Fulbright project (PMG-2018981270P), and the evaluation of a course that served as the case study for this work.

3.1 Research Plan - Modernizing Chemical Engineering Education

3.1.1 Rationale

Chemical Engineering education must adapt to rapid technological, social, and environmental transformations. Traditional teaching, strongly centered on content transmission, has proven limited in engaging students and preparing them for complex and interdisciplinary contexts.

The plan provides an opportunity to rethink curricula, teaching methods, and external partnerships. This research aims to systematize, evaluate, and improve PIM's actions within the Chemical Engineering program, generating scientific evidence on its effectiveness and offering insights for replication in other engineering courses.

3.1.2 Objectives

The general objective is: To investigate the impacts of implementing innovative teaching and learning methodologies in Chemical Engineering education, focusing on course integration, interdisciplinarity, active learning, and partnerships with industry and society.

The specific objectives are:

(1) To evaluate the effects of course integration and interdisciplinary approaches on student learning.

(2) To analyze the contribution of active methodologies (PBL, flipped classroom, TBL) to student engagement and academic performance.

(3) To examine how adequate physical spaces (teaching laboratories, collaborative classrooms) influence pedagogical practices.

(4) To assess the role of industry and other partner institutions in shaping contextualized teaching experiences.

(5) To map the development of socioemotional, entrepreneurial, and leadership skills among students.

(6) To produce recommendations for institutional policies on curriculum modernization in engineering.

3.1.3 Methodology

(1) Type of Research

Quasi-experimental, mixed-methods approach (quantitative and qualitative).

(2) Data Collection

1) Quantitative: academic performance (grades, pass/fail rates), structured questionnaires, metrics of participation in practical activities and cooperative projects.

2) Qualitative: student and faculty interviews, classroom and laboratory observations, documentary analysis of lesson plans, reports, and projects.

(3) Procedures

1) Initial assessment of the traditional teaching model.

2) Gradual implementation of initiatives (course integration, interdisciplinarity, active methodologies, innovation, and partnerships).

3) Continuous monitoring of indicators related to learning, engagement, and professional placement.

4) Comparison between cohorts exposed to the traditional model and the innovative model.

(4) Expected Outcomes

1) Improved approval rates, higher average grades, and reduced dropout/remediation.

2) Increased student satisfaction and engagement.

3) Stronger integration between courses and closer collaboration with industry.

4) Consolidation of a replicable model for curriculum modernization in engineering.

5) Scientific output (articles, reports, conference presentations).

3.2 Study Case Course

The activities described in this study are part of the course PQI-3202: Transport Phenomena I, a core component of the undergraduate Chemical Engineering curriculum at the University of São Paulo, Brazil. The course has a total workload of 90 hours and is offered during the second semester of the program's second year. This study focuses specifically on the final third of the course, which introduces students to complex fluid systems, turbulence modeling, and particulate transport.

The overall learning objective of the course is for students to understand and apply momentum transport principles to industrial processes. For the final third of the course, specific learning goals include:

(1) Understand, apply, and evaluate turbulence.

(2) Use computational fluid dynamics (CFD) software.

(3) Characterize solid materials.

(4) Understand, apply, and evaluate particulate systems.

(5) Understand, apply, and evaluate solid handling.

(6) Analyze and interpret simulation results.

To support these objectives, the flipped classroom model was adopted. Each weekly cycle was structured into three stages: (1) asynchronous study through video lectures, (2) guided group work with theoretical and algorithmic exercises, and (3) practical CFD simulations in the computer lab.

The course has continuously evolved over the years. Before 2019, the weekly format consisted of two sessions. The first session featured an expository lecture, where key concepts and fundamental ideas were presented using chalk and a board. The second session was a practical class, during which exercises were solved on the board, and students were encouraged to participate through instructor-led questions. However, over time, there was a noticeable decline in student attention and engagement. Despite these efforts, only about one-third of the students consistently maintained their interest throughout the classes.

In 2019, we began incorporating hands-on activities into the course. Traditional exercise sessions on turbulence were replaced with practical activities using Ansys Fluent. To support students in learning the software, we provided Portuguese-language tutorials focused on simple geometries, such as a pipe bend and a backward-facing step. These activities were completed in groups of three students, and a report was submitted through USP's virtual learning environment at the end of each session. This component was introduced as a formative assessment, allowing for timely feedback and reinforcing students' understanding of the topic.

In 2020, we began implementing a flipped learning approach. Instructional videos were created and made available through USP's virtual learning environments. The methodology was thoroughly explained to students during class sessions and through recommended readings and articles on the topic.

When the COVID-19 pandemic began, we redesigned the summative assessment at the end of the course as a project-based assignment. Students worked in groups of four to five and had a minimum of 20 days to complete the task. This shift aimed to promote a problem-based learning (PBL) approach, encouraging deeper engagement with the course content through real-world applications.

In 2021, active-cooperative learning was introduced, based on the model proposed by Professor Richard Felder. Activity sheets outlining the tasks were distributed in class to guide student engagement. Initially, these activities took place in a traditional lecture hall rather than in a space designed for flipped learning, similar to the setting depicted in Professor Felder's instructional videos.

At first, not all students watched the assigned videos before class. To address this, we included brief expository lectures - lasting up to 30 minutes—before the active learning sessions. However, by 2023, we phased out these introductory presentations, and students gradually adapted to the flipped learning approach. Although some students still arrive unprepared, the group-based structure (groups of three) encourages peer instruction, which helps ensure that learning continues effectively during the activities.

To evaluate student performance in the course, a combination of formative and summative assessments was employed. Detailed formulas are provided in Section 5.4.

4. Method

The instructional approach adopted in this course was based on the model proposed by Professor Talbert (2019). Each week was divided into three distinct phases (Figure 1). The course combined synchronous and asynchronous activities, providing flexibility in terms of time and learning environment.

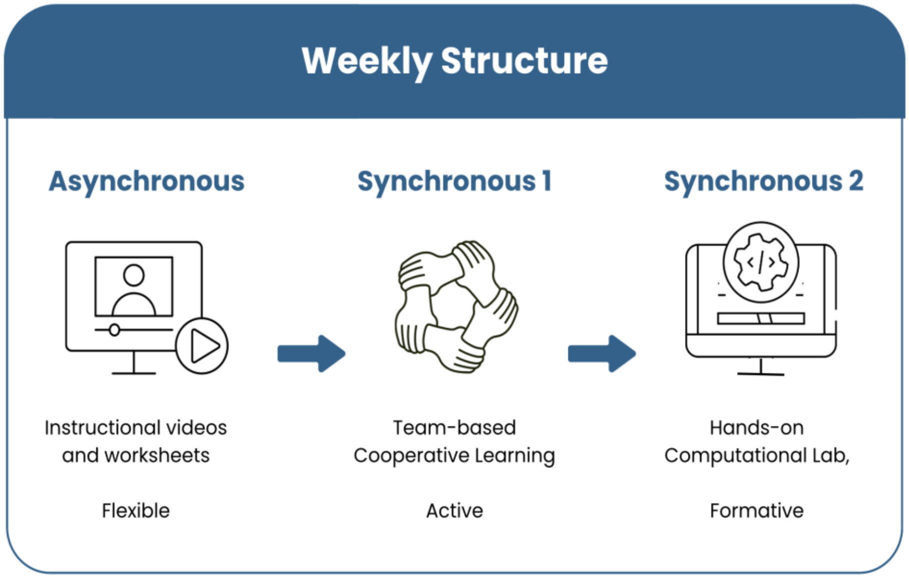


Figure 1. The three distinct phases of the instructional approach

The flipped learning structure was implemented over a one-week cycle, divided into three stages. The first stage is asynchronous, where students watched a set of short instructional videos prior to the theoretical class. To support their learning and highlight essential concepts, each video was accompanied by a guided study worksheet that outlined the core content to be understood. The videos, ranging from 8 to 12 minutes in length, were made available on the virtual learning environment (VLE), e-disciplinas. Depending on the topic, 2 to 5 videos were assigned each week. The topics covered the key concepts from the final third of the course, ranging from introductory CFD to particulate systems.

The first weekly synchronous session, which is the second stage, was dedicated to team-based cooperative learning, drawing on the active cooperative learning approach proposed by Felder (1995, 1996), with some adaptations. Students were divided into groups of three and worked collaboratively on a guided study worksheet (Appendix A), designed to reinforce the content covered in the pre-class instructional videos. Each worksheet consisted of 6 to 10 questions that included both conceptual topics and algorithmic exercises, particularly those necessary for solving calculation-based activities.

The instructor actively facilitated the session by circulating among students in a specially designed active learning environment, informally referred to as the “colorful classroom” (Figure 3). This classroom is designed for collaboration and active engagement, featuring round tables, colorful seating, and students using laptops. It embodies a modern educational approach where discussion and teamwork are central. This dynamic setting promoted interaction, allowing students not only to clarify doubts but also to engage in deeper discussions that extended beyond the planned curriculum. For instance, during a session on industrial fluidized beds, a spontaneous and insightful conversation emerged about Fluid Catalytic Cracking (FCC) technology, an outcome unlikely to occur in a traditional lecture format.

Figure 2. “Colorful Classroom” – A classroom designed for flipped learning activities

The second weekly synchronous session consisted of a hands-on computational lab, designed to consolidate theoretical knowledge through active, practical applications. The software used was ANSYS Fluent, a commercial computational fluid dynamics (CFD) tool developed by ANSYS (https://www.ansys.com/). Adopted in both academia and industry, Fluent offers robust simulation capabilities. For this course, students used the free Student License (https://www.ansys.com/academic/students/ansys-student), which allows for the solution of moderately complex problems.

These lab sessions were carried out in groups of three, reinforcing collaborative learning. At the end of each session, one member of the group was responsible for submitting the completed activity to a Virtual Learning Environment (VLE). At the University of São Paulo, commonly used platforms for this purpose include Sakai (TIDIA) and Moodle (e-disciplinas).

This practical assignment also served as a formative assessment, with weekly feedback provided before the subsequent task was due. The purpose of the feedback was to inform students of areas for improvement and to promote continuous learning.

The summative assessment consisted of two final exams and a group project developed by teams of four to five students. Unlike the formative assessments, the group project was more complex and demanding, requiring greater collaboration and extended deadlines. This project closely aligned with the principles of Project-Based Learning (PBL). Students submitted their projects through the VLE, including all executable files and supporting documentation. Each project required an in-depth discussion and thorough analysis of the results. Examples of final projects included:

(1) Fluid flow through a Y-duct: analysis of turbulence models

(2) Venturi flow simulation

(3) Tank discharge modeling

(4) Flow over a cylinder: von Kármán vortex street

(5) Turbulent flow over a backward-facing step

(6) Fluid dynamics in an elbow pipeThese components provided a comprehensive framework for evaluating both conceptual understanding and practical application of transport phenomena.

5. Results

This section presents the outcomes of the three instructional components implemented in the course: instructional videos, active-cooperative learning sessions, and hands-on CFD activities. Additionally, student feedback and final grade report are discussed to assess the perceived effectiveness of the approach.

5.1 Instructional Videos

The asynchronous phase of the course consisted of a carefully structured weekly schedule that centered around video-based instruction. Each week, students were provided with between two and five short films, each lasting from eight to twelve minutes, which were made available through the university's virtual learning environment, e-disciplinas. These videos offered a dynamic and accessible means for students to engage with essential concepts and theories, especially those covered during the final third of the course syllabus.

The content of these weekly videos spanned a range of advanced topics, including introductory Computational Fluid Dynamics (CFD) and particulate systems. Care was taken to ensure that each video broke down complex technical material into manageable segments, with clear explanations and visual aids that supported different learning styles. In addition to theoretical knowledge, the films often incorporated practical demonstrations, real-world case studies, and problem-solving sessions to help bridge the gap between abstract concepts and tangible applications.

Throughout this asynchronous module, students were encouraged to manage their own learning pace while adhering to suggested completion timelines to stay aligned with the course's overall progression. To facilitate active participation and reinforce understanding, each video was supplemented by discussion prompts, and reflective exercises posted on the e-disciplinas platform. These resources allowed learners to test their comprehension in real time and provided instructors with valuable feedback on student progress and engagement.

Furthermore, the asynchronous structure was thoughtfully designed to complement synchronous course elements such as virtual office hours and collaborative group projects. By combining the flexibility of on-demand video content with opportunities for real-time interaction, the course ensured a holistic learning experience that supported diverse student needs and maximized the potential for deep, sustained mastery of the challenging subject matter.

Topics covered:

Topic 1: Introduction to Computational Fluid Dynamics (CFD)

Video: Lesson 22 – Fluent Introduction

Topic 2: Turbulence

Video: Lesson 23.1 – Introduction to Turbulence

Video: Lesson 23.2 – Turbulence Scales

Topic 3: Turbulence and RANS Models

Video: Lesson 24.1 – RANS Fundamentals

Video: Lesson 24.2 – RANS Applications

Topic 4: Turbulence in Fluent

Video: Lesson 26 – Implementing Turbulence Models in Fluent

Topic 5: Solid Particles

Video: Lesson 27.1 – Experimental Planning

Video: Lesson 27.2 – Particle Size

Video: Lesson 27.3 – Particle Shape

Video: Lesson 27.4 – Force Balance

Topic 6: Particulate Systems

Video: Lesson 28.1 – Bed Properties

Video: Lesson 28.2 – Industrial Beds

Video: Lesson 28.3 – Model Derivations

Video: Lesson 28.4 – Turbulent Flow in Beds

Video: Lesson 28.5 – Ergun Equation

Students showed good engagement with the videos, and the guided worksheets helped focus attention to the most relevant concepts. This pre-class exposure allowed students to arrive better prepared for the synchronous sessions, resulting in more productive in-class discussions and fewer foundational doubts. The variety and pacing of the videos were frequently cited by students as helpful for comprehension.

5.2 Guided Active-Cooperative Sessions

The guided in-class sessions, structured around team-based cooperative learning, were effective in deepening students' understanding of the material. Students worked in groups of three on 6–10 questions that covered both conceptual knowledge and algorithmic reasoning based on the video content (see Appendix A).

The classroom dynamic encouraged sustained engagement as predicted. Sessions lasted approximately 90 minutes, during which students worked through the full set of questions without interruption. Unlike traditional question-by-question guidance, the tutor moved among the groups, offering spontaneous feedback and enriching discussions. This approach led to deeper reflection and extended conversations, including emergent topics beyond the core curriculum.

Notably, students actively discussed and justified their reasoning during group work, which strengthened their ability to articulate technical concepts and collaborate effectively, skills often unseen in conventional lectures.

5.3 Hands-on CFD Activities in Fluent

The practical lab sessions were used to consolidate theoretical learning through applied simulations. Figure 3 shows the velocity vector fields for the backward-facing step. From there, it is possible to observe how the velocity behaves on the step, forming vortices, including the small whirlpool that forms next to the sharp edge. In Fluent simulations, the following are also available: mesh quality, evolution of the residuals for each variable, computational time, etc.

(a)

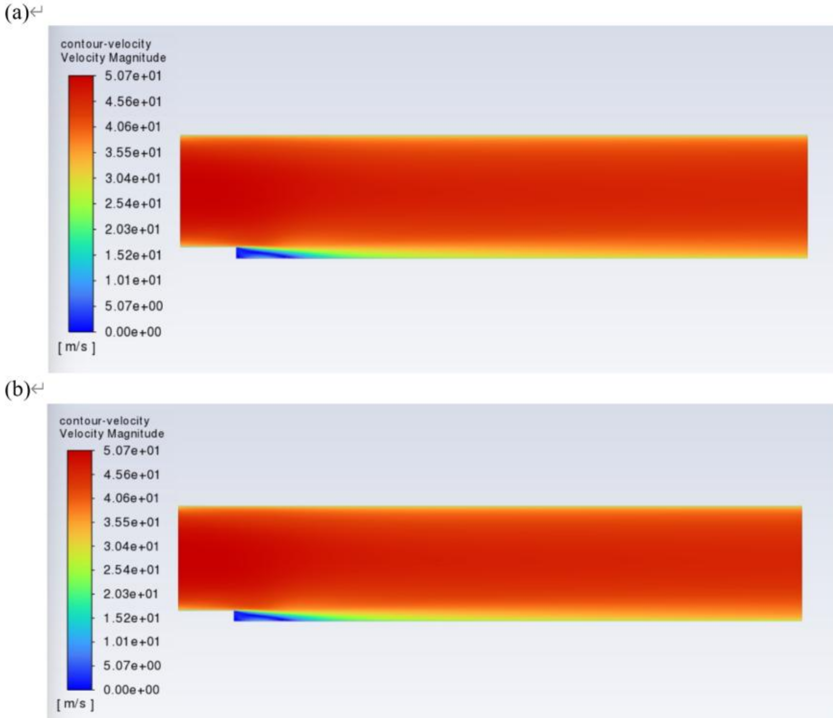
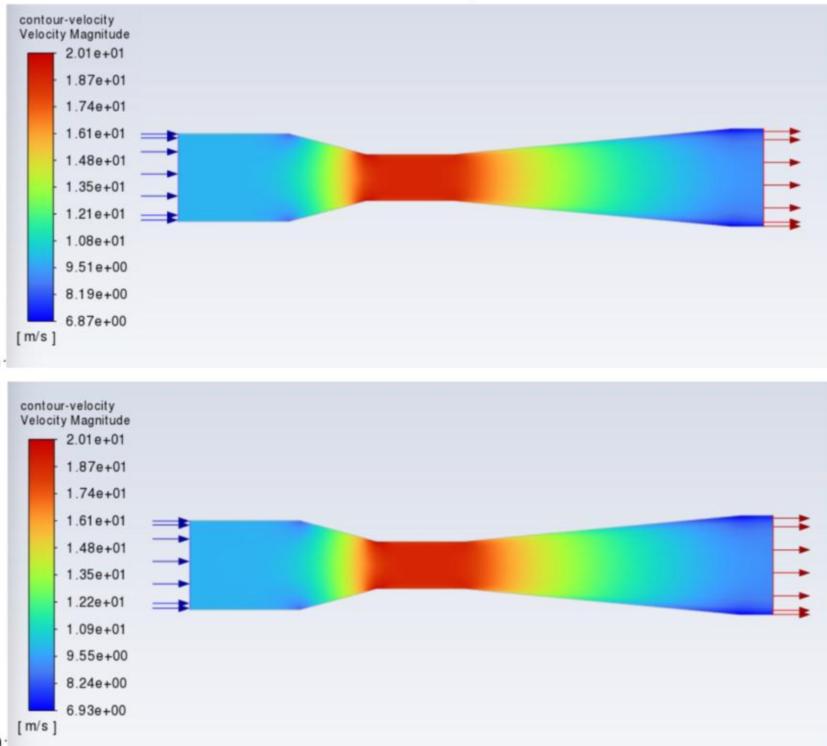


Figure 3. Velocity profiles in a backward-facing step using two different turbulence models for comparison purposes (a) k–ε; (b) k–ω SST turbulence models

This comparison emphasizes how each model captures the size, shape, and intensity of the recirculation zone, which is critical for accurately representing separation and reattachment phenomena in complex flow regions.

(a)



(b)

Figure 4. Velocity profiles in a Venturi tube simulated using: (a) the k–w; (b) RSM turbulence model

The k–ω model tends to be more accurate in near-wall flows and captures boundary layer effects well. As a result (Fig. 4(a)), the velocity gradient appears more abrupt near the entrance of the throat. In contrast, the velocity gradients (Fig. 4(b)) near the throat entrance and exit are smoother, indicating more turbulent mixing.

5.4 Students' Conclusions

For experimental and quasi-experimental designs, there must be a description of the flow of participants (human, animal, or units such as classrooms or hospital wards) through the study. Present the total number of units recruited into the study and the number of participants assigned to each group. Provide the number of participants who did not complete the experiment or crossed over to other conditions and explain why. Note the number of participants used in the primary analyses. (This number might differ from the number who completed the study because participants might not show up for or complete the final measurement.)

The survey was conducted using Google Forms, ensuring all responses are anonymous to prioritize data access security. A total of 30 responses were collected from a class of 61 students.

(1) Each weekly class followed a three-stage structure: (1) viewing pre-assigned instructional videos, (2) attending a synchronous session, and (3) completing exercises in groups of three. Is that?

30 answers

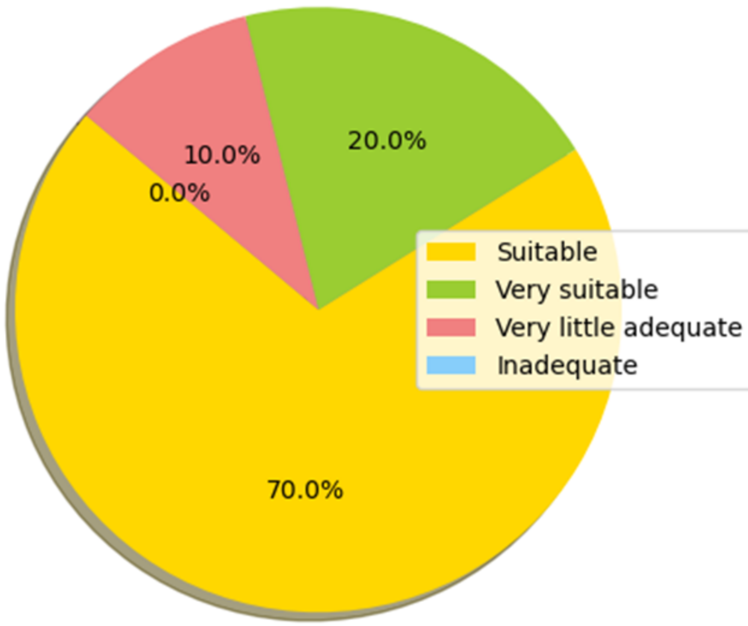


Figure 5.

The flipped learning approach was rated as "adequate" or "highly adequate" by 90% of respondents, indicating strong acceptance of the method.

(2) The quizzes, questions about the class in a directed study format, are:

30 answers

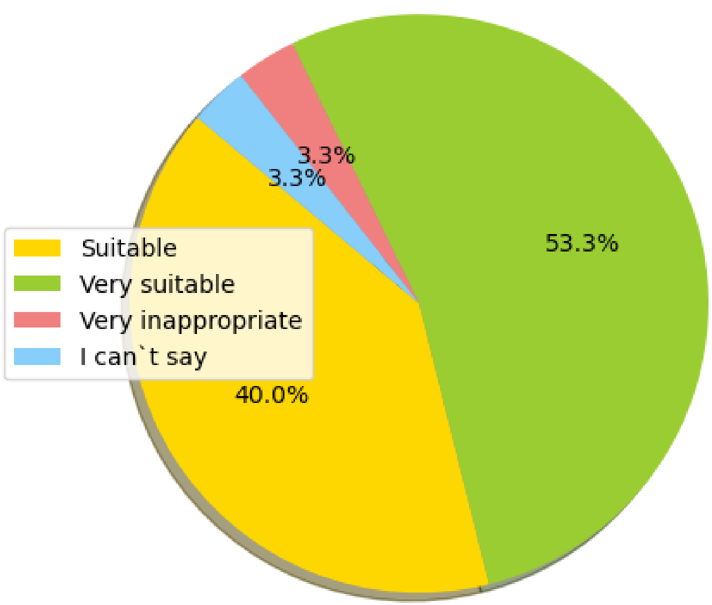


Figure 6.

A significant majority, 93.3%, expressed a preference for the guided study format over traditional lecture-based classes. Notably, students remained actively engaged in these sessions for over 90 minutes, an attention depth rarely sustained during conventional lectures.

(3) The class of November 1st had in its first part a conventional exhibition and, in the second part, an activity, with the completion of the list of questions (quiz). You learn more with:
30 answers

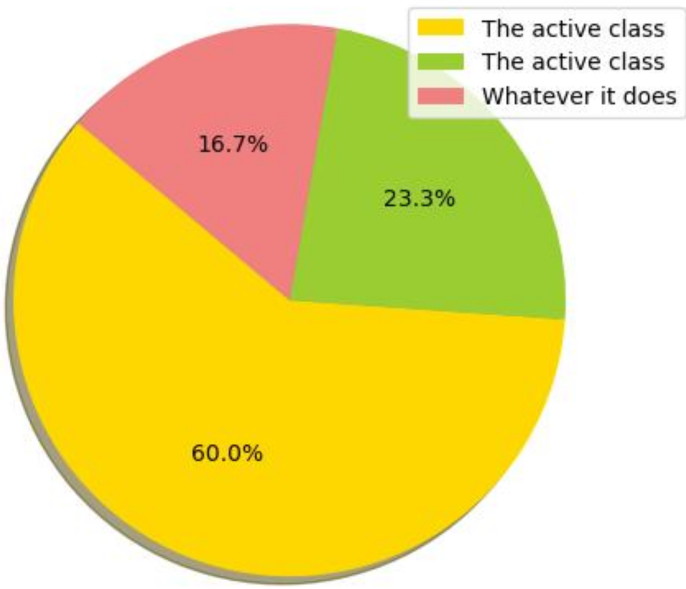


Figure 7.

Regarding learning effectiveness, 60% of students reported learning more through the active learning approach, while 23.3% stated a preference for traditional instruction. As noted by Professor Talbert, it is expected that some students may not adapt well to flipped learning environments, and this was reflected in the responses

(4) Was the feedback of the practical activities effective for the learning process?

30 answers

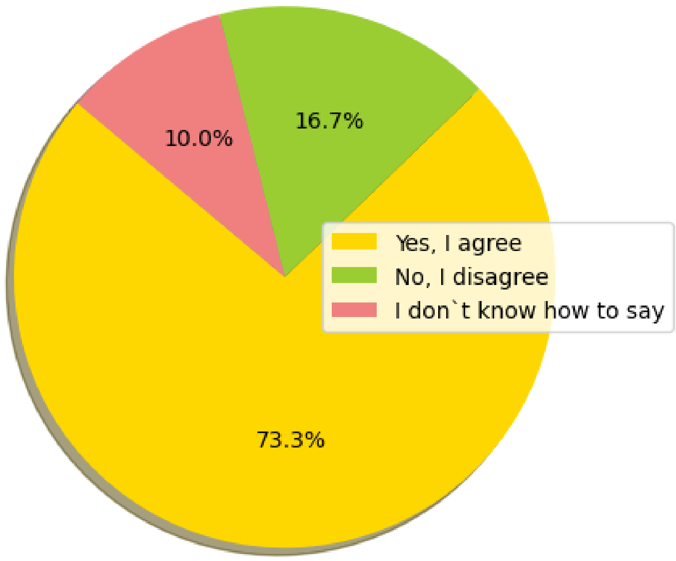


Figure 8.

Weekly feedback was considered effective in supporting the learning process by 73.3% of the class, highlighting the importance of timely, formative assessments.

(5) The activities in the room related to the videos (the quizzes) were written by hand. In this regard, you prefer:

30 answers

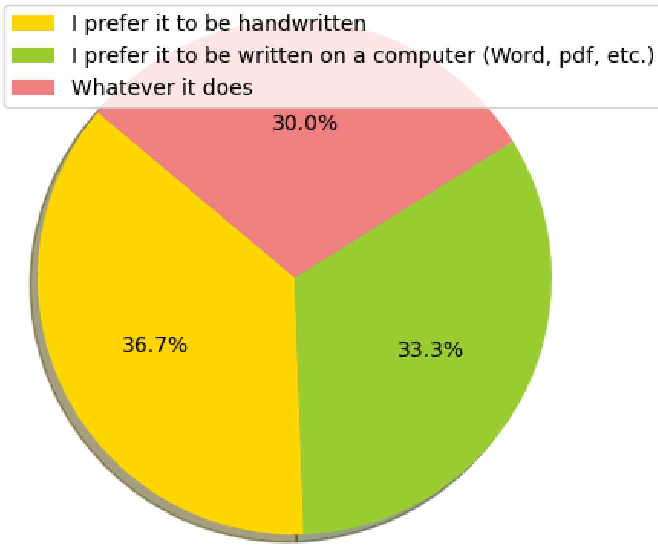


Figure 9.

When asked about the format of the guided worksheets, responses were mixed. Although the handwritten format was designed to encourage empathy and focus, a slight majority preferred digitally completed assignments, indicating a potential area for future adjustment.

(6) The use of a Transport Phenomena application tool, Fluent, was:

30 answers

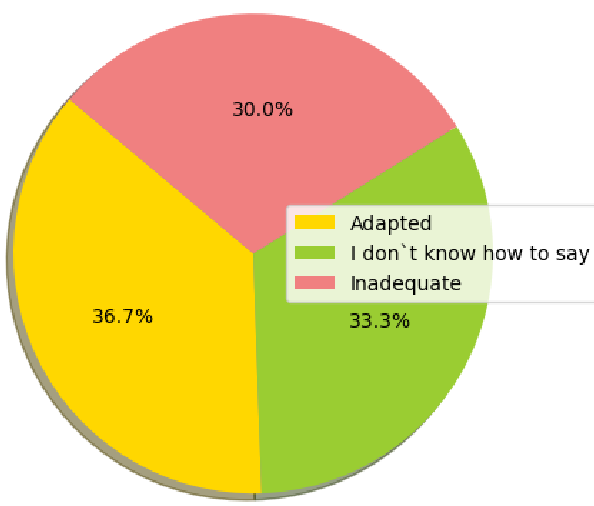


Figure 10.

The use of ANSYS Fluent as a computational tool was rated as effective for learning by 73.3% of students. This suggests that the integration of professional software significantly contributed to conceptual understanding.

(7) Was your level of engagement on the course?

30 answers

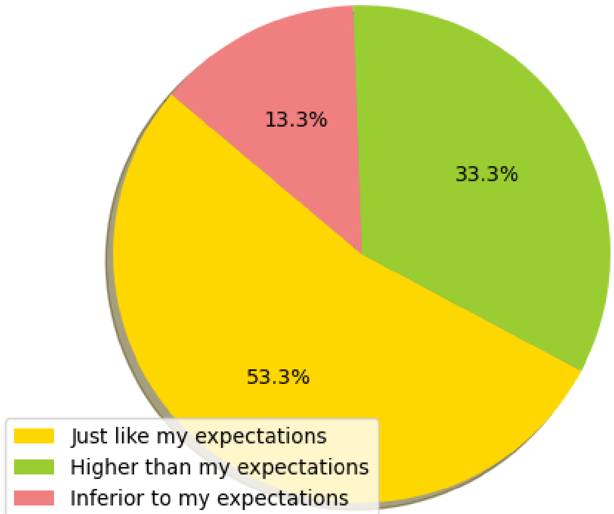


Figure 11.

Finally, the course achieved strong engagement levels: 86.6% of students reported that their engagement was equal to or higher than expected. In terms of overall learning, 79.3% rated their learning experience as good or excellent, with only one student rating it as poor, and 17.2% selecting average.

(8) Regardless of your grades, as was your learning, on a scale of 1 to 5 (5 Great, 1 terrible)

29 answers

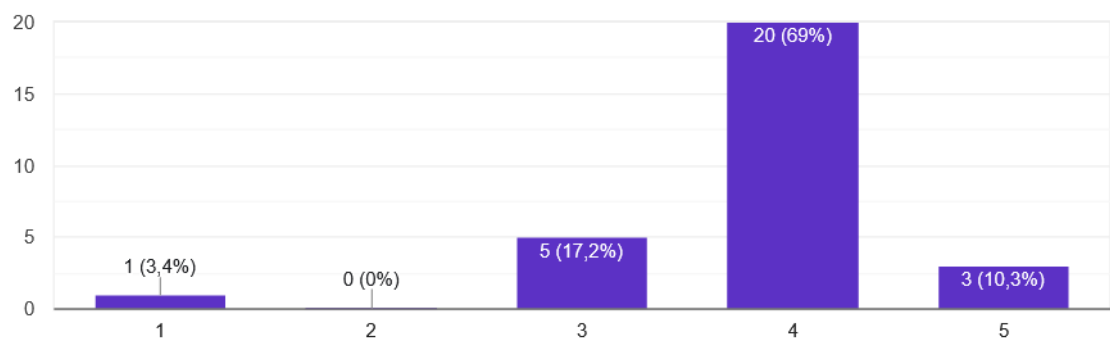


Figure 12.

This feedback may be assumed to be positive. Most students perceived their learning experience as above average, even if that didn't necessarily reflect in their grades. This suggests that the approach was effective and engaging for most learners.

(9) Do you self-declare neurodivergent or neuroatypical?

30 answers

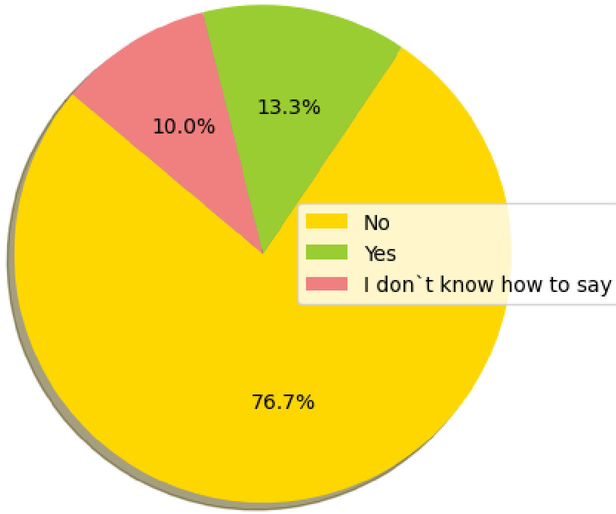


Figure 13.

If interventions or experimental manipulations were used, provide evidence on whether they were delivered as intended. In basic experimental research, this might be the results of checks on manipulation. In applied research, this might be, for example, records and observations of intervention delivery sessions and attendance records.

It is also worth noting that 10% of students self-identified as neurodivergent or neuroatypical, which underscores the importance of flexible and inclusive teaching approaches in future course designs.

These simulations stimulated critical scientific evaluation. Students were required not only to produce computational results but to analyze and discuss them. Selected student comments reflect this depth:

"We concluded that combining experimental methods and computational simulations offers a detailed and complementary view of the Venturi tube's behavior. This not only validates the use of these tools in engineering studies but also highlights the importance of selecting models aligned with project goals."

"Although Fluent can carry out the calculations, the results may be physically incorrect if the mesh is too coarse—especially near the walls. This highlights the need to refine the mesh for improved accuracy."

"The graphs allowed us to identify potential recirculation zones or strong gradients that require attention, and to verify the convergence of the k-epsilon model."

These reflections show that students moved beyond simple execution of tasks and into meaningful interpretation, which is one of the central goals of active learning.

Thirty responses were collected from a class of 61 students, which should be considered a small sample size. Critically reflecting on the statistics of small samples of student grades involve assessing the implications of using limited data sets in educational evaluations. Small sample sizes can lead to various issues, particularly regarding reliability and generalizability.

Results from small samples are often less reliable than those derived from larger groups. This unreliability can arise from outliers or anomalies that disproportionately affect the mean, median, and other statistical measures. For example, if a few students perform exceptionally well or poorly, their grades can skew the overall results, leading to potentially misleading conclusions about the performance of the entire class.

Small samples typically have lower statistical power, which increases the risk of Type II errors—where one fails to detect a genuine effect or difference when it exists. While small samples of student grades can offer some insights, they come with significant limitations that must be critically assessed. Additionally, complementing quantitative data with qualitative insights can provide a more nuanced understanding of student performance and learning needs.

5.5 Hands-on CFD Activities in Fluent

To evaluate student performance in the course, a combination of formative and summative assessments was employed. The final grade (M) was calculated using structured formulas that evolved from 2023 to 2024, reflecting a shift in pedagogical priorities and assessment strategy.

In 2023, the final grade was determined through a weighted average of formative and summative components. Formative assessments focused on learning activities and included:

A: Scores from cooperative activities and quizzes (worth 25% and allowed for occasional absences)

R: Performance in laboratory activities

These components were averaged to produce the formative grade (Eq. 1):

$$L= (A + R) / 2 \tag{1}$$

The summative component (P) was calculated using the following weighted formula (Eq. 2):

$$P = (2\ P1 + 3\ P2 + PJ) \tag{2}$$

where P1 and P2 are theory tests, and PJ is the final project. The overall final grade (M) combined both parts (Eq. 3):

$$M = (2\ P + + L)/3 \tag{3}$$

In 2024, the assessment formulas were refined to place greater emphasis on summative performance and to fine-tune formative evaluation. The summative component was adjusted to (Eq. 4):

$$P = (3\ P1 + 3\ P2 + PJ) \tag{4}$$

increasing the weight of both theory tests. The formative component (L) incorporated a performance factor (fp) in the laboratory portion (Eq. 5):

$$L = (A + fp\ R) / 2 \tag{5}$$

This allowed for a more nuanced evaluation of lab engagement and contribution.

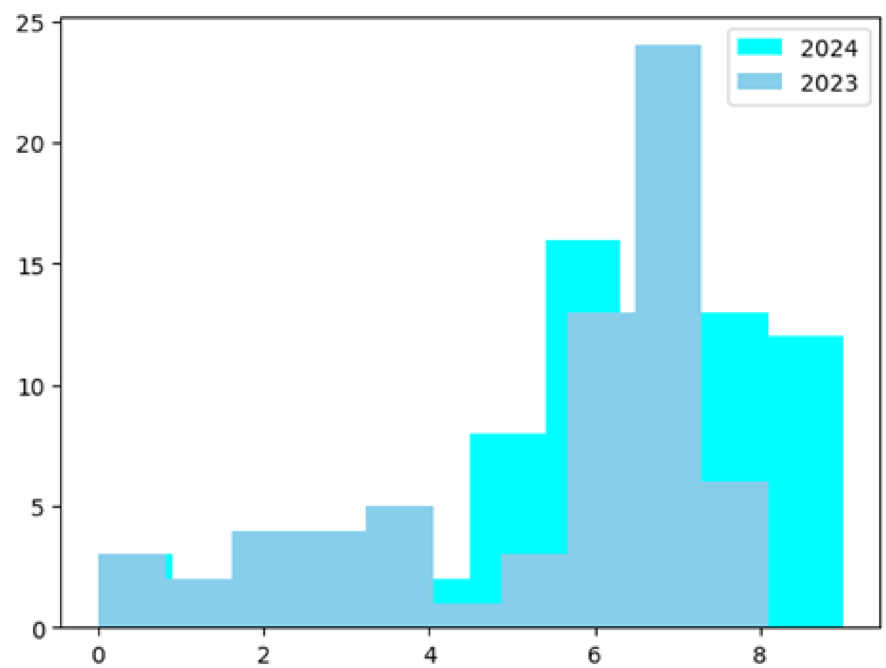


Figure 14. Histograms displaying the final grades for the years 2023 and 2024

Figure 14 displays the histograms showing the distribution of grades for the years 2023 and 2024 in Transport Phenomena I. The grades for 2023 exhibit a wider range, with several high performers but also a notable number of low scores (ranging from 0 to 4). In contrast, the grades for 2024 are closely clustered between 5 and 9, indicating a more consistent performance standard. This suggests an improvement in overall performance.

The Kolmogorov-Smirnov test (Corder and Foreman, 2011) shows that the distributions are significantly different, rejecting the null hypothesis (K-S Statistic: 0.268; P-value: 0.012). Furthermore, the failure rate decreased from 15.6% to just 5.9%. The standard deviation remained stable, indicating that student performance was consistent across both years.

Table 1. Table title (this is an example of table 1)

Parameter / year	2023	2024
Total enrolment	64 students	68 students
Approved	45 students (70.4%)	57 students (83.8%)
Recovery	9 students (14%)	7 students (10.3%)
Failed	10 students (15.6%)	4 students (5.9%)
Average grade (M)	5.4	6.2
mode	7.2	7.5
25%	3.6	5.5
50%	6.4	6.35
75%	6.9	7.5

A comparison of student performance between the two academic years, as shown in Table 1, indicates a significant improvement following the changes in the new approach. The average grade rose from 5.4 to 6.2. Statistical tests indicate a significant difference between the means, as evidenced by the Student's t-test, which produced a T-statistic: -2.424<-1.980, resulting in a P-value: 0.017<0.05 (with n = 124). Additionally, the Kolmogorov-Smirnov test (Corder and Foreman, 2011) shows that the distributions are significantly different, rejecting the null hypothesis (K-S Statistic: 0.268; P-value: 0.012). Furthermore, the failure rate decreased from 15.6% to just 5.9%. The standard deviation remained stable, indicating that student performance was consistent across both years.

These results suggest that placing greater emphasis on tests and refining lab evaluations contributed to improved student learning. The updated assessment model used in 2024 seems to have had a positive effect on student motivation and success, showing that the changes in teaching and evaluation were effective.

6. Discussion

In response to the evolving challenges in education - especially the need to maintain student engagement - various innovative teaching approaches and tools have been proposed to transform traditional learning environments (Vianna Jr. and Vianna, 2023). These methods include active learning, flipped classrooms, hybrid models, and collaborative learning techniques, as well as case-based instruction. Additionally, strategies such as interdisciplinary and transdisciplinary approaches, gamification, and frameworks like CDIO, Problem-Based Learning (PBL), Project-Based Learning, System-Based Learning, and Puzzle-Based Learning have been increasingly adopted to promote deeper engagement and create more meaningful learning experiences.

There are several issues related to innovative teaching strategies in Transport Phenomena, including active learning approaches, technology-enhanced teaching, Problem-Based Learning (PBL), and innovations in assessment and feedback.

Active learning approaches involve collaborative problem-solving within groups, which helps strengthen teamwork skills (Prince, 2004). A related method is peer instruction (Mazur, 1997), where students learn from one another. The concept of the flipped classroom is discussed in depth in section 4.

Technology-enhanced teaching refers to the integration of technology into learning processes. This includes the use of general-purpose simulation software, such as Matlab and COMSOL, to analyze distributions of velocities, pressures, temperatures, and concentrations of species (Zárate-Navarro et al., 2024). It also encompasses the creation of online tutorials and video content, which is linked to flipped learning (Guo et al., 2014). The idea of virtual laboratories falls under technology-enhanced teaching and is part of the broader theme of virtual reality, which is the augmented reality technology is a tool that can support the learning of complex concepts (Rebello et al, 2024).

Problem-Based Learning (PBL) serves as a significant innovation in education, where students work in groups to solve real engineering challenges. Several steps should be considered in this process (Hmelo-Silver, 2004). Other pedagogical approaches like PBL have emerged, including Project-Based Learning, System-Based Learning, and Puzzle-Based Learning.

The teaching of Transport Phenomena is evolving rapidly in response to changes in technology, workplace demands, and educational research. By incorporating active learning, technology-enhanced tools, real-world problem solving, innovative assessments, and inclusive practices, educators can better prepare students for the complex challenges they will face as professional engineers.

In the current educational landscape, the approach outlined in this work—integrating flipped learning, cooperative learning, and hands-on activities—represents a significant pedagogical innovation. Each of these strategies has demonstrated success in various educational contexts, but their combined and structured application in the teaching of Transport Phenomena (TP) is both novel and impactful.

Flipped learning encourages students to engage with theoretical content before class, freeing up in-class time for active engagement and problem-solving. Cooperative learning promotes peer interaction and mutual support, enhancing understanding through dialogue and collaboration. Hands-on activities provide experiential learning opportunities that help students connect theory with practical application.

Although these methods have been used separately in different courses and disciplines, their simultaneous use within a cohesive teaching framework specifically designed for TP is a distinctive feature of this approach. Implementing this strategy has led to measurable improvements in student outcomes, as evidenced by more balanced and higher-grade distributions, along with positive feedback gathered from student surveys. These results suggest that the synergy between these three pedagogical strategies not only enhances conceptual understanding but also boosts student motivation, engagement, and overall performance.

7. Conclusion

Three pedagogical pillars - flipped learning, active-cooperative learning, and hands-on activities - are combined to form a cohesive framework for teaching Transport Phenomena, a course historically perceived as abstract and mathematically demanding.

A key outcome of this work was the noticeable increase in student attention, interest, and participation during class activities under the new instructional approach. The flipped and active learning model successfully shifted the classroom dynamic, engaging students more deeply in the learning process.

The students' opinion reinforces that:

(1) 90% of the students rated the flipped learning approach as adequate or highly adequate.

(2) A strong majority, 93.3%, expressed a preference for the guided study format over traditional lecture-based instruction.

(3) 73.3% found the weekly feedback to be effective in supporting their learning.

(4) ANSYS Fluent was considered an effective learning tool by 73.3% of students.

(5) 79.3% evaluated their overall learning as good or excellent.

Learning objectives were achieved. For example, turbulence models have been identified, understood, applied, and evaluated. Quantitative performance indicators also improved. The final class average increased from 5.4 to 6.2, accompanied by a notable reduction in the number of students who remedied and failed, despite the continued emphasis on written examinations as the primary summative assessment.

Taken together, these three pillars form a comprehensive vision for engineering education reform. By blending flipped learning, active-cooperative learning, and hands-on activities, the approach aims not only to enhance academic outcomes but also to support the development of replicable models for modernizing engineering curricula in diverse contexts.

From a theoretical perspective, the findings clarify how pedagogical models can purposefully integrate cognitive, social, and experiential learning. The results demonstrate that pre-class material engagement, paired with in-class cooperative problem-solving and applied simulations, directly deepens conceptual understanding. This study provides evidence that student-centered pedagogy not only increases engagement but also, importantly, develops higher-order thinking skills in engineering education.

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Appendix A

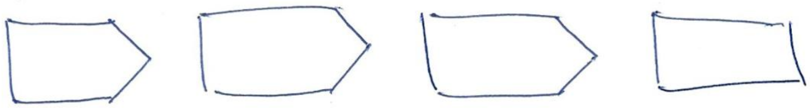
Handwritten Worksheet from the First Synchronous Activity

PQI3202- FT I- Andson

Turbulence Modeling

Group of: names { 1-
3 2-
3-

1- The process for generating the RANS consists of four steps. Based on this, complete the flowchart:



2- What is this relationship?

$\tau_{xy} = -\rho\,\overline{v'_x v'_y}$

Set each variable.

3- What is this equation?

$-\rho\,\overline{v'_x v'_y} = \mu_T\left(\frac{\partial \bar{v}_x}{\partial y} + \frac{\partial \bar{v}_y}{\partial x}\right)$

4- $\mu_T = \rho L_0 vel$

Set each variable.

5- What equation is this?

$$\rho\frac{\partial k}{\partial t} + \rho\bar{v}_x\frac{\partial k}{\partial x} = -\rho\,\overline{v'_x v'_y}\,\frac{\partial \bar{v}_x}{\partial y} - \rho\,\varepsilon + \frac{\partial}{\partial x}\left[\left(\mu + \frac{\mu_T}{\sigma_k}\frac{\partial k}{\partial x}\right)\right]$$

Set k, $\bar{v}_x$, σ_k, $\rho\bar{v}_x\frac{\partial k}{\partial x}$ and $\frac{\partial}{\partial x}\left(\frac{\mu_T}{\sigma_k}\frac{\partial k}{\partial x}\right)$

Appendix B

Second Synchronous Activity: CFD Simulation Using ANSYS Fluent

Escola Politécnica da USP - Departamento de Engenharia Química

PQI-3202 Transport Phenomena I

Turbulence in Fluent - Wednesday 2024

Activity: Turbulence Models for fluid flow through a curve

The starting point is the tutorial in Portuguese carried out in the last class.

https://www.youtube.com/watch?v=R5go5HJIs2c

The following turbulence models should be evaluated:

(1) kw SST

(2) k-e realizable

(3) RSM

Please create a document (in either Word or PDF format) that includes the following information:

(1) The number of iterations performed.

(2) The computational time used.

(3) The pressure and velocity contours.

(4) The velocity field.

Additionally, discuss the results: What do the profiles look like? Is there any recirculation? Is there any stagnation?