

Insights from the implementation of active learning approaches in geo-education

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ABSTRACT: Over recent decades, higher education instructors have adopted new pedagogical techniques to boost student engagement and reduce failure rates. This trend became especially evident during the COVID-19 pandemic, which highlighted the shortcomings of traditional lecture-based teaching. Disruptive student behaviour can also impede classroom performance. To combat this, active learning methods like Problem-Based Learning (PBL) and the jigsaw technique are used. This case study from the Polytechnic University of Coimbra details the shift from traditional projects to PBL in the 2022/2023 academic year, and the introduction of the jigsaw method in 2024/2025 to foster collaboration. Typically enrolling about 20 second-year students annually, the course was assessed through surveys and grades, showing these active strategies improve academic results.

KEYWORDS: Active learning, project-based learning, jigsaw classroom, sustainable geotechnics.

1 INTRODUCTION

Since the establishment of Europe's first university, teaching has primarily relied on lecturing (Brockliss, 1996). Traditional lecture-based classes, often seen as passive learning, focus heavily on the instructor, who determines the key topics to be learned (Michael, 2006), and tend to limit students' opportunities to develop critical thinking skills (Fidalgo-Blanco et al., 2017). Contemporary practices and current research indicate that adopting innovative methods, centred on "ask more, instead of telling" principles, can significantly enhance students' performance (Henderson et al., 2011).

Implementing teaching methods that enhance student engagement in the learning process is crucial, emphasising problem-solving over rote memorisation (Michael, 2006). According to this author, this approach fosters more lasting and meaningful learning. Active learning, by definition, involves students reflecting on ideas and applying them in practice (Collins & O'Brien, 2003). During active learning, students also evaluate themselves and their peers, assessing skills as they gather information and work through problems.

Many authors have documented various student-centred learning methods. Among those summarised by Michael & Modell (2003) are problem-based learning (PBL), along with cooperative, collaborative, and group work. This methodology enhances interactions between students and teachers, as well as among students themselves. As stated by Michael (2006) and Freeman et al. (2014), students assume a more proactive role by engaging in activities such as gathering information, solving problems, and reflecting on their current knowledge.

Despite the benefits of PBL, student interaction in the classroom can remain somewhat limited. A common issue is that students tend to collaborate repeatedly with the same peers throughout their studies. To overcome this challenge, the jigsaw classroom technique was introduced. Originally developed in 1971 to reduce social and racial tensions in Austin, Texas schools (Aronson, 2021), the jigsaw method encourages cooperative learning by requiring students to depend on one another to master the day's lesson. Research has shown that this approach not only enhances academic performance but also fosters the development of interpersonal skills (Khine et al., 2019; Kilic, 2008). Furthermore, classrooms that implement the jigsaw technique report lower absenteeism and increased levels of empathy among students.

Following the COVID-19 pandemic, class attendance and academic performance declined. To promote greater student engagement and improve learning outcomes, two pedagogical approaches were introduced as part of the assessment method

in the Study and Behaviour of Soils course within the Sustainable Cities Management degree at the Polytechnic University of Coimbra (Portugal). Students are encouraged to develop geo-environmental solutions, such as green-blue-brown infrastructure, to address urban challenges like rapid flooding or the urban heat island effect caused by climate change. These proposals result from ongoing work throughout the semester.

This study provides a brief overview of how the revised PBL-jigsaw methodology was implemented, with a particular focus on students' final grades and attendance.

2 PEDAGOGICAL FRAMEWORK

2.1 *Geo-challenges*

Since 1950, all EU member states have recorded increased hot extremes, resulting in more ecological droughts in Mediterranean nations and Western and Central Europe (IPCC, 2021). Aside from Mediterranean countries, other parts of Europe have seen changes in heavy rainfall. These extreme events have a significant impact on ecosystems and human communities (IPCC, 2022), leading to increased adverse effects on health and well-being, particularly in cities, settlements, and infrastructure, due to inland flooding.

According to the IPCC (2021), for a global warming of up to 2 °C, hot extreme events occurring every 10-50 years are now expected to happen 5.6 to 13.9 times more frequently. Heavy one-day precipitation events could increase from once every 10 years to 1.7 times more frequent. Climate strategies and adaptation options span multiple fields, with geotechnics crucial for managing ecosystems, urban, and infrastructure systems (IPCC, 2022).

Building on the previous background, students are invited to ideate solutions for urban issues, such as: i) coastal defence; ii) water use efficiency and water resource management; iii) sustainable urban drainage systems; iv) implementation of green and blue infrastructures; v) sustainable urban and land planning; vi) district heating and cooling networks (geothermal energy); vii) waste minimisation and management; viii) transformation of construction methods, materials, and circular economy; ix) carbon capture and storage; x) disaster risk management, including early warning systems..

2.2 *Co-creation methodology*

The problem-based learning methodology implemented in this study is based on the Demola co-creation model (Ribeiro et al., 2024). The model spans eight weeks, with a new task

introduced each week for students to work during class sessions. Students are organised into groups of six, considering factors such as gender, age, high school background, and hometown. This approach ensures high heterogeneity to enhance creativity and group dynamics. The approach aligns with the principles of the Double Diamond model originally introduced by Banathy (1996), which comprises two main stages: the Discovery and the Creation stages.

The “Discovery” stage, as the initial phase, guides students to collect extensive information on the challenge topic. After forming groups, each team proposes a challenge aligned with their bachelor’s degree objectives. This group formation and challenge proposal, conducted during the first week of the co-creation process, marks the first step of the methodology. Over the following weeks, students undertake several tasks divided into two main phases: i) the research phase, and ii) the synthesis phase. In weeks 2 and 3, students list all stakeholders who might influence or be influenced by their challenge, either directly or indirectly. From this comprehensive list, they select three to five key stakeholders for focused research, identifying potential interviewees whose insights will complement the information gathered from literature and other documentary sources. The synthesis phase occurs in weeks 4 and 5. At this stage, students create empathy maps for each target stakeholder, characterising them based on what they say, do, feel, and think. While synthesising this information, students must identify design insights - outcomes that stand out as particularly significant or conjectural. After completing these tasks, students may write a mid-term report based on a PESTLE analysis, providing a macro perspective on the topic.

The “Creation” stage represents the actual design phase, during which students build upon insights gained in the “Discovery” stage to conduct speculative work. In this phase, students explore alternative outcomes to the challenge by transitioning from the current state to a likely future using various thinking tools that focus on identifying “weak signals”. Once these signals are recognised, students develop their speculative designs by asking two key questions: What if...? and How might we...? These questions belong to a creative thinking approach that helps: i) frame complex problems, ii) uncover unmet needs, and iii) develop better solutions (Lahiri et al., 2021) The questions should be provocative and daring, not limited to factual or constrained scenarios such as political, economic, or social factors. The speculative questions and future scenarios form part of the week 7 assignment. Using insights from previous weeks and these questions, students propose three scenarios, pinpointing drivers of change and potential impacts of their envisioned futures. The creative stage concludes with a future report in week 8, combining all earlier findings and speculative work, emphasising the future scenarios which serve as the main outcomes of the co-creation process.

2.3 The jigsaw classroom

The jigsaw classroom approach comprises three main phases, as illustrated in Figure 1: i) students initially work within their home groups; ii) they then join expert groups to exchange and deepen their understanding of specific topics ; iii) finally, they return to their home groups to share the acquired expertise with their peers. This structure promotes mutual interdependence and collaborative learning. Khine et al. (2019) present a jigsaw classroom in six stages, which was adapted to the present situation to fit the specific context and learning objectives.

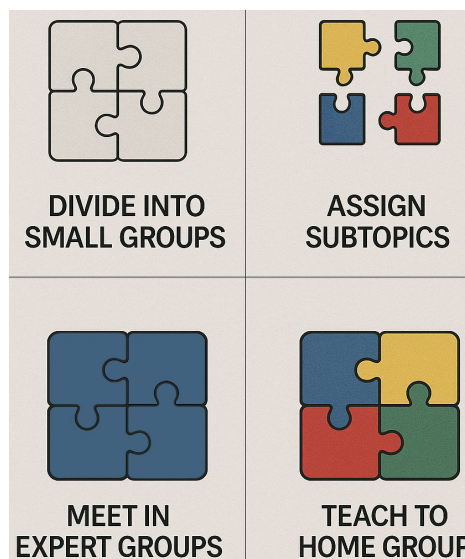


Figure 1. The jigsaw classroom methodology (OpenAI, 2025)

In the first step, students are divided into competency groups (home groups) of six students for research. The second step involves dividing the lesson into six topics (one for each student in each home group). Each student is assigned one topic from the lesson content in their home group and is responsible for explaining it to their group colleagues at a later time. In the third step, the student studies their topic independently.

Once the students are familiarised with the topic, they will join the expert groups. These six groups gather all the students with the same topic. Within each “Expert Group,” students compare their ideas, discuss, and communicate with each other until they have all mastered the material to give the presentation or explain it in their home group. In the fifth step, students return to their original home group. Each student takes the assigned topic to present and explain it clearly to all their colleagues in the home group. The other students listen carefully, take notes, ask plenty of questions, and discuss. The sixth and final step is an assessment period, during which the teachers ensure that all students achieve a minimum level of understanding of the lesson.

3 RESEARCH DESIGN

3.1 Students and course characterisation

This study comprises data collected over the last six academic years, from 2019/2020 to 2024/2025. During this period, a total of 129 students were enrolled in the *Study and Behaviour of Soils* course, part of the undergraduate degree in *Sustainable Management of Cities* at the Polytechnic University of Coimbra. Student distribution over the six academic years was not uniform. The number of students has increased, along with the interest that the first degree of its kind in Portugal has aroused among the student community, rising from 14 in 2019/2020 to 27 in 2024/2025. All students were between 19 and 23 years old, with the majority aged 19. While male students accounted for 76% of the total cohort over the six years, recent data show a rising trend in female participation: 29% in 2023/2024 and 41% in 2024/2025.

The *Study and Behaviour of Soils* course is the second geotechnical-related course in the undergraduate program and is offered in the first semester of the second year. The course includes a weekly workload of 3.5 hours over a 15-week semester. It should be noted that, despite the COVID-19 pandemic, all classes for this course were held in person. The lockdowns that occurred in Portugal in 2020 (March to May)

and 2021 (January to March) did not affect the courses taught in the fall semester, as is the case in the present study.

3.2 Pedagogical and evaluation approaches

Since the 2019/2020 academic year, alongside the final examination, students enrolled in the *Study and Behaviour of Soils* course have been required to complete a project focused on an area of Coimbra (Portugal) affected by urban rapid floods. Drawing on the course content, students are expected to identify a problem and propose a viable solution to mitigate or resolve the issue.

During the first three years of implementation, this project was delivered as a traditional final assignment. Students were expected to work on it throughout the semester and present their results at the end. No intermediate deliverables were planned, nor was any structured thinking strategy suggested. Students worked independently, contacting the professor whenever they needed guidance or assistance. After the COVID-19 pandemic, the decline in students' performance and the rise in failure rates led to the decision to adopt a new pedagogical strategy. Therefore, in 2022/2023, a co-creation methodology was introduced to guide students through the design of a geotechnical solution to address or mitigate urban flood events in Coimbra. Subsequently, in 2023/2024 academic year, the jigsaw classroom approach was implemented to enhance the learning process.

During the 8-week co-creation process, the first 1.5 hours of each class were dedicated to this methodology, introducing the weekly task and enabling student groups to begin their work. The remainder of the class time was devoted to covering the planned syllabus. Teaching methods included expository lectures, complemented by laboratory sessions, problem-solving activities, and jigsaw classes.

3.3 Data collection and limitations

The data presented in this study are based on statistical assessments carried out at the end of each semester by the academic services of the institution. These assessments evaluate key indicators such as student attendance, final grades, and academic failure rates to identify potential issues within the course curriculum. Additionally, the marks awarded for the group project are incorporated into the analysis to provide a more comprehensive evaluation of student performance in the course.

It is known that students' performance is influenced by both internal and external factors (Mulaudzi, 2023). Internal factors include students' characteristics, attitudes, and behaviours, whereas external factors involve elements beyond students' control, such as family background, peer relationships, infrastructure, and teaching quality (Navarro et al., 2007). None of these factors are considered, under the assumption that, if present, their effects are overlapping during the analysed period and do not cause variations in the results.

4 RESULTS AND DISCUSSION

4.1 Attendance and academic failure

Attendance and academic failure are two critical indicators used to evaluate student engagement and overall course effectiveness. Figure 2 shows the evolution of students' attendance and academic failure rates over the six academic years analysed. As can be seen, during the first three years, class attendance decreases significantly - from 81% to 52%, while academic failure rates increase sharply from 7% to 41%. According to the Polytechnic University of Coimbra's internal directives, when the rate of academic failure exceeds 30%, intervention plans must be presented and implemented in the

following academic year. To address this issue, the co-creation methodology was introduced in 2022/2023 and continues to be used today. Since its implementation, student attendance has shown a steady increase, and academic failure rates have declined through to the 2024/2025 academic year.

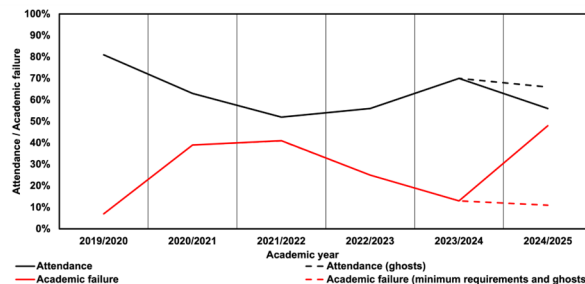


Figure 2. Students' attendance and academic failure.

At first glance, the results may suggest that the benefits of this pedagogical strategy have been fully realised and that it may be time to consider a new active learning approach. However, the 2024/2025 academic year results include two unprecedented situations, which significantly influenced the data. First, four of the twenty-seven students enrolled in the course never attended classes nor were evaluated. These are referred to as ghost students, and they adversely affect the academic performance and attendance data. Second, a group of six students did not meet the course minimum requirements set at the start of the year. Although this did not prevent their evaluation, the penalty for this situation ultimately led to their failure. By incorporating these two situations into the academic failure, the final value drops to 11% instead of 48%, as shown by the dotted line in Figure 2. It is worth noting that a similar conclusion can be drawn regarding students' attendance. Excluding the ghost students, the average attendance rate in class is 66%, which is just 4% lower than the previous academic year (see Figure 2). When these two anomalies are accounted for, the academic failure rate drops substantially—from 48% to 11%—as represented by the dotted line in Figure 2. A similar correction applies to attendance data: when excluding the ghost students, the average class attendance rises to 66%, only 4 percentage points below the previous academic year. These corrections highlight that the apparent decline in performance is not indicative of a methodological shortcoming. On the contrary, the underlying effectiveness of the co-creation approach remains evident.

4.2 Group project and final grades

Students' performance in the course is determined by two components: the group project grade and the individual assessment obtained in the final examination. Thus, it is important to understand how the implementation of co-creation methodology has influenced overall students' grades. Figure 3 illustrates the evolution of average grades across the six academic years as well as their corresponding standard deviation.

The findings give evidence that the co-creation methodology boosted the results of the group project. Since its implementation, the average grade has continuously increased from 66% to 83%. No less significant, the standard deviation has reduced from 27% to 9%. Contrary to the improvement in results from the group project, students' final grades, which comprise projects and written examinations, didn't improve in 2022/2023, when the co-creation methodology was first introduced. This insight indicates that despite the benefits of co-creation, the learning process still needs enhancement to ensure students acquire all the skills and competencies they are expected to develop after completing the course.

To address this issue, the jigsaw classroom was introduced in 2023/2024, replacing some expository lectures. As previously mentioned, students play a central role in their learning process by creating their own knowledge. This new pedagogical approach reversed the usual final grade pattern, resulting in an increase in the average final grade from 10.4 to 12.8 (out of 20 points), with a peak of 13.5 in the first year of implementation. The fluctuating student response to this active learning method may be because it was more widely adopted in other courses last year, reducing the element of surprise present during its initial introduction. The change in standard deviation, rising from 1.1% to nearly 2%, indicates varying levels of student engagement with the lessons using this active learning method. As a facilitator, the professor's primary role is to support all students in achieving a base understanding of the course material. The more actively students participate, the more they learn, which can help them stand out among their peers during assessments.

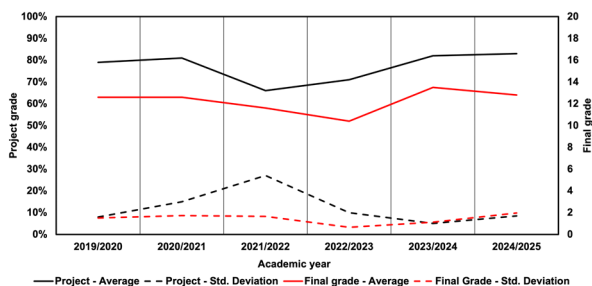


Figure 3. Group project and final grades.

5 FINAL REMARKS

Implementing active learning methodologies is an ongoing process that requires continuous adaptation based on students' engagement and academic performance. The co-creation methodology effectively encourages students to develop more comprehensive conceptual solutions for addressing urban flooding. However, this approach did not yield a significant impact on their final grades. To improve academic performance, the jigsaw classroom technique was subsequently introduced, resulting in a reversal of the previous declining trend. Combining co-creation with the jigsaw classroom approach has proven to be an effective strategy, as it has:

- Increased students' attendance from an average rate of 52% to 66%.
- Reduced academic failure from 41% to 11%.
- Improved the average project grades from 66% to 83%.
- Raised students' average final grades from 10.4 to 12.8 out of 20 points.

The implementation of the active learning approach has revealed an inherent characteristic of student-centred learning methods. While overall grades have improved, the gap between higher and lower performers has increased. This underscores the significant influence of individual student engagement on academic outcomes.

The next challenge is continuously enhancing and adapting the pedagogical approach to engage students more effectively, considering their shorter attention spans, lower tolerance for delayed results, and increasing digital immersion. These factors must be carefully considered to effectively train and educate future professionals in geotechnics. One promising strategy is the implementation of a blended learning approach combined with the flipped classroom, as demonstrated by Araújo Santos et al. (2025).

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