Research Article

Ana Breda, António Neves, José Dos Santos*, Zsolt Lavicza

Utilising a STEAM-based Approach to Support Calculus Students' Positive Attitudes Towards Mathematics and Enhance their Learning Outcomes

https://doi.org/10.1515/edu-2022-0210
received November 30, 2022; accepted November 06, 2023

Abstract: The curricular unit Calculus I – Extraordinary Semester (UCCISE) – was explicitly created to respond to students' difficulties in the curriculum unit Calculus I (UCCI). Only students who fail the UCCI are allowed to attend UCCISE. Considering the enrolled students' familiarity with mathematical software, the potential of group work to stimulate collaboration among students, and the existence of several art pieces on the University Campus, led to the proposal of a groups' project focusing on the calculus of areas based on sections of these pieces. Hence, a STEAM approach emerged to achieve the suggested UCCISE objectives. This study aims to understand how using a STEAM approach in a higher education Calculus course could improve students' perceptions of mathematics, promote their learning, and contribute to lower levels of failure in UCCISE, using teaching experiments as a research methodology. Four researchers were involved in this study, including the Calculus teacher, so this study has action research characteristics. The interpretive paradigm of analysis was used with the triangulation of data. The collected data come from the students' productions, interviews, and final questionnaires. Results show that the work developed by the 35 students was relevant and should be a practice to be used in UCCI. This experience led to a reduction in the levels of failure compared to the UCCI. However, in the first years at a university level, STEAM approaches are still challenging.

Keywords: calculus, higher education, STEAM, teaching experiment

*** Corresponding author: José Dos Santos,** Centre for Research & Innovation in Education, Porto Polytechnic School of Education, and Mathematics Departament, University of Coimbra, Coimbra, Portugal, e-mail: dossantos@uc.pt
Ana Breda: Center for Research and Development in Mathematics, and Mathematics Department, University of Aveiro, Aveiro, Portugal, e-mail: ambreda@ua.pt
António Neves: Mathematics Department, University of Aveiro, Aveiro, Portugal, e-mail: ant.jorge.neves@gmail.com
Zsolt Lavicza: Linz School of Education, Johannes Kepler University, Linz, Austria, e-mail: Zsolt.lavicza@jku.at

1 Introduction

Mathematics is an essential component of any engineering course offered by an institution of higher education, and the reason is simple. The search for solutions to many complex engineering problems involves mathematical modelling. Thus, it is essential that students, future engineers, have high levels of mathematical skill and proficiency to be successful in their professional careers. Transitioning from secondary education to higher education presents significant challenges for engineering students when it comes to solving mathematical tasks that require algorithmic and logical-deductive thinking, as highlighted by Gueudet and Thomas (2020). Besides, as reported in 2002 by the European Society for Engineering Education, the rapid pace of technological development requires frequent updating, which involves mastery of new techniques and understanding new concepts (Barry, 2002). However, these findings are not in line with the fact that, in more and more countries, there is an increasing concern not only with the deterioration of the mathematical ability of the new students in the various engineering programs but also with the difficulty of their retention in these programs being the curricular units of mathematics indicated as one of the contributing factors to this dropout. In addition to the challenges students face in learning and developing mathematical skills, they are also required to have a longer independent study time, which is essential for promoting the autonomy of future professionals. Thus, the self-regulation of student learning is crucial in the university, given what usually happens in school. So, how students self-regulate their learning can significantly influence their academic success (Credé & Phillips, 2011; Schneider & Preckel, 2017).

The acronym STEAM stands for Science, Technology, Engineering, Arts, and Mathematics. The large number of publications on STEAM Education, which have appeared recently, reveals the interest and impact that this topic has aroused in the academic and scientific communities of different areas of knowledge and, in particular, in the area of engineering, which is not surprising, since engineering is one of the core components of the acronym STEAM (Piila, Salmi, & Thuneberg, 2021; Simarro & Couso, 2021). Yakman (2008) proposes the STEAM methodology to develop an educational model to combat the fragmentation of academic knowledge traditionally addressed in different curricular areas. In the teaching experience that we will describe later, we used a STEAM approach to design and implement a pedagogical scenario that maximises students' skills, promotes active learning (Ghavifekr & Rosdy, 2015), contributes to the occurrence of significant learning inside and outside the classroom, and stimulates greater interest in students (Diego-Mantecón, Arcera, Blanco, & Lavicza, 2019). The implemented approach aims to promote knowledge, creativity, and interdisciplinary perspectives (Perignat & Katz-Buonincontro, 2019) while encouraging accountability and peer cooperation to contribute to task commitment and self-regulation of learning (De la Garza & Travis, 2019). It is a pedagogical approach, complementary to traditional pedagogical methods, contributing to meaningful learning in some knowledge domains (Segarra, Natalizio, Falkenberg, Pulford, & Holmes, 2018).

The integration of students from other Portuguese-speaking countries is a pressing challenge for universities in Portugal, as they seek to ensure that these students are welcomed and supported throughout their academic journey. One of the many challenges students from these countries face is communication. Although Portuguese is a common language between them, there are dialectical differences and nuances in oral communication, representing a difficult obstacle for students from these countries to overcome. It is also worth mentioning that academic systems and learning expectations in different Portuguese-speaking countries are highly variable, reflecting the difficulties these students have in adapting to new forms of learning and assessment.

In the absence of preparatory courses offered by some Portuguese universities, the admission of these students into the Portuguese university system is only ruled by the attendance and approval of secondary education, which, despite officially having similar mathematics curricula, in practice, prove to be very different compared to the skills shown by the students. In this situation, the attendance of these students in introductory Calculus or Linear Algebra courses becomes more complex, resulting in the requirement for teachers to adapt their teaching methods and approaches that improve success rates and reduce dropout rates without compromising the development of the mathematical skills necessary for the profiles of students and future engineering professionals.

2 Theoretical Background

Considering the situation of insufficient or practically nonexistent requirements and high rates of failure, some actions were taken, among which are the following: i) reducing syllabus content, replacing some of the more complex material (in students' vision); ii) developing additional units of study; iii) establishing mathematics support teams; iv) doing nothing (Barry, 2002, p. 4).

First, reducing the program of the discipline courses may eventually lead to a higher approval rate. However, eliminating more advanced content is disadvantageous for the most qualified students, who are denied the possibility of adequate preparation for more advanced topics presented in their engineering curricular units. Second, creating additional topics to pre-existing ones is a non-realisable task unless others are withdrawn. One of the most common complaints of teachers teaching math in undergraduate courses is the lack of time to complete the course syllabus. Third, establishing math teams or support centers is expensive, and no studies support cost-effectiveness. For example, at the University of Aveiro, in addition to the usual time, each teacher must clarify doubts to their students, and tutorial hours are distributed (1 h per week and usually per class). However, these additional classes have yet to prove to be of great value, most of them attended by a small number of students. Fourth, doing nothing is not a strategy to be considered; this means leaving the syllabus as it is and feeling the frustration of not seeing or contributing to any positive and realistic change.

Let us now turn our attention to the following questions. *What mathematical competencies would we like to see reflected in a graduate student in engineering?* This question assumes that the meaning of mathematical competence is clear to all of us. Nevertheless, what do we really mean by mathematical competence? Furthermore, how do we measure mathematical competence? Mathematical competence is defined by the ability to understand, judge, do, and use mathematics in various intra and extra-mathematical contexts and situations in which mathematics plays or could play a role. Necessary, but certainly not sufficient, prerequisites for mathematical competence are lots of factual knowledge and technical skills (Niss, 2003). Adopting this definition, the following eight competencies were identified: thinking mathematically; reasoning mathematically; posing and solving mathematical problems; modelling mathematically; representing mathematical entities; handling mathematical symbols and formalism; communicating in, with, and about Mathematics; making use of aids and tools (Niss, 2003). The first four competencies were related to the ability to ask and answer questions in and with mathematics; on the other hand, the last four competencies were related to the ability to handle and manage mathematical language and tools.

Our interest was centred on the use of mathematical modelling and in the use of GeoGebra (if needed) to boost students' work in the curriculum unit of Calculus I Extraordinary Semester (UCESI). By "mathematical modelling competence, we mean being able to autonomously and insightfully carry through all aspects of a mathematical modelling process in a certain context" (Blomhoj & Jensen, 2003). Also, competence in using aids and tools includes knowledge about the aids and tools that are available as well as their potential and limitations. Additionally, it includes the ability to use them thoughtfully and efficiently. We believe that these competencies provide those who own them with what we call mathematical proficiency.

The required strands stated by the National Research Council and Mathematics (National Research Council & Mathematics Learning Study Committee, 2001) for Mathematical proficiency refer that who owns the referred competencies have conceptual understanding; procedural fluency; strategic competence (the ability to formulate and solve mathematical problems); adaptive reasoning (capacity for logical thought, reflections, and justification); and productive disposition (seeing mathematics as worthwhile and being confident in one's abilities).

At the university level, advanced mathematical thinking is also often considered. There is some debate as to whether this term means thinking about advanced mathematics or any mathematics in an advanced way. Tall (1991) claims that the distinguishing features of advanced mathematical thinking are abstraction and the insistence on proof rather than justifications. Advanced mathematical thinking is concerned with introducing formal definitions and logical deduction. The transition from elementary school mathematics (geometry, arithmetic, and algebra) to advanced mathematical thinking (axiomatic proof) at university is particularly interesting. Natural thinkers must reorganise their natural ideas into a proper sequence. In sum, advanced mathematical thinking is the ability to represent abstracting, creative thinking, and mathematical proving. Advanced mathematical thinking is also often considered at a higher education level.

However, what is meant by advanced mathematical thinking? Does it mean thinking, understanding, and using advanced mathematics or thinking about any mathematics in an advanced way? For Dreyfus (2002), advanced mathematical thinking consists of an extensive series of processes that interact with each other, such as representing, visualising, generalising, or even others such as classifying, conjecturing, inducing, analysing, synthesising, abstracting, or formalising. For Tall (1995), advanced mathematical thinking involves using cognitive structures produced by various mathematical activities to build new ideas that continue to build and broaden an ever-growing system of demonstrated theorems.

Assuming this set of competencies previously discussed, a natural question soon arises: What assessment tools can we apply to students' knowledge, perceptions, and abilities in and about mathematics without leading to misleading results? Assessment modes and instruments worldwide produce misleading results, primarily because of insufficient validity, which is often sacrificed for reliability. Besides, we all know that there is often a frequent mismatch between the modes of evaluation we employed and the overall goals and teaching practices. Nevertheless, as proposed by Niss (2003), we can always design assessment instruments considering the following three dimensions: i) the degree of coverage of the competence in analysis, that is, the extent to which the student masters that specific competence; ii) the radius of action that is the spectrum of contexts and situations that such competence can be activated; the technical level indicates how conceptually and technically advanced the entities and tools are with which the person can activate the competence. In agreement with the discussed definitions of mathematical competence and its possible characterisation, another question naturally arises.

2.1 What Questions/Tasks do we Propose to Students During Evaluation Moments?

Sangwin (2003, p. 813) attests that assessment drives what and how mathematics is learned, so "any attempt to elaborate on what is meant by mathematical skills must be based on an analysis of what in reality we ask students to do." Pointon and Sangwin (2003) developed a taxonomy that we should consider in preparing evaluation instruments, in which the following eight characteristics were identified (Table 1).

Successful completion of items in Table 1 is characteristic of adaptive learning in which students engage in an essentially reproductive process requiring applying well-

Table 1: The question classification scheme

1	Factual Recall
2	Carry out a routine calculation or algorithm
3	Classify some mathematical object
4	Interpret the situation or answer
5	Prove, show, justify – (general argument)
6	Extend a concept
7	Construct an instance
8	Criticise a fallacy

(Pointon & Sangwin, 2003, p. 675).

understood knowledge in bounded situations. On the other hand, items 5–8 of Table 1 are also characteristic of the required higher cognitive processes; students need to be involved in higher cognitive processes, i.e., requiring students to behave as experts. Pointon and Sangwin (2003) conducted an analysis of 486 coursework and examination questions used in two first-year undergraduate mathematics courses. Their findings revealed that most of the questions could be completed through routine, without requiring the use of higher-level skills. This suggests that while these courses may provide a strong foundation in mathematical concepts, they may not be challenging students to develop more advanced problem-solving abilities.

In the last decade, the know-how and practices in science education include STEM and STEAM approaches. These interdisciplinary approaches are used to develop students as competent problem solvers and to improve learning activities (Kelley & Knowles, 2016; Pahmi, Juandi, & Sugiarni, 2022; Stohlmann, Moore, & Roehrig, 2012); have been claimed as appropriate ways to develop highly qualified workers and promote economic development (Beach, Henderson, & Finkelstein, 2012; Sharma & Yarlagadda, 2018); create opportunities for students to be more engaged in their learning in the classroom; develops problem-solving skills and creativity, and promotes their higher order thinking skills through exposure to real-world problems (Diego-Mantecon, Prodromou, Lavicza, Blanco, & Ortiz-Laso, 2021; Kelley & Knowles, 2016; Moore, Johnson, Peters-Burton, & Guzey, 2016). Otherwise, the STEM approaches and the related activities increased students' critical thinking and collaboration and their interest and knowledge in pursuing STEM-related careers (Papadakis, 2020; Tzagkaraki, Papadakis, & Kalogiannakis, 2021). Also, a pilot study conducted by Sandoval-Palomares (2022) to evaluate the competencies and attitudes in STEAM education of students and university teachers, was found favourable indicators in understanding, relevance, and satisfaction.

About STEM practices in Europe, it is worth noting the SCIENTIX project, with the objectives of promoting and supporting a Europe-wide collaboration among STEM teachers, education researchers, policymakers, and other STEM education professionals and studying how STEM teachers throughout Europe organise their teaching practices. Through the survey STEM Education Practices in Europe (Nistor, Gras-Velazquez, Billon, & Mihai, 2018), we have a panorama of several critical issues about STEM education. However, this article discusses the first key issue: pedagogical approaches used in STEM teaching. The survey identified a long list of pedagogic practices used in the teaching of sciences and engineering, including traditional Direct Instruction; teaching with experiments; Project/Problem-Based Approach; Inquiry-Based Learning; Collaborative Learning; Peer Teaching; Flipped Classroom; Personalized Learning; Integrated Learning; Differentiated Instruction; Summative Assessment; Formative Assess, including Self-Assessment. However, the report findings regarding the use of these several practices are not surprising: i) traditional direct instruction remains among the most highly reported pedagogical approaches in STEM; ii) Mathematics appears to be taught more often through teacher-focused than any other STEM subject; and iii) ICT teachers are at the other end of the spectrum with the highest use of student-centred pedagogical approaches mainly project/problem-based learning and collaborative learning. For those who are teaching in higher education STEM curricular units, this listing and the characterisation of these practices are quite interesting. First, Portuguese teachers of higher education are not required to undertake any pedagogical-didactic training; second, because it is a quick way of describing various approaches without going into too much detail, which for those who are not from the area is a relief.

Considering the above assertions, the next section will characterise the intervention context developed in our research study.

3 Context of Intervention

Analysing the period between 2012 and 2018, the number of students in engineering courses decreased, the ratio Approved/Enrolled and Approved/Evaluated increased, with the use of diversified teaching methodologies, and prevailing traditional direct instruction.

In the Portuguese University where the teaching experience was carried out, engineering and science students attending the Calculus course are distributed into four *Agrupamentos* (Groupings). Each *Agrupamento* has a Coordinator Teacher responsible for all the teaching dynamics of that Grouping. Looking at the approval rates between 2016 and 2018, two *Agrupamentos* were with the highest approval rates; it was observed that one of them had made a great effort to move to a student-centred methodology while the other used more often teacher-centred approaches; however, as far as we know, we can't find a study linking teaching methods with the assessment tools used in a similar context to this intervention.

Despite the academic's efforts, the number of students failing Calculus I persisted. One of the researchers of this article was challenged to teach Calculus I Special Semester classes exclusively attended by students with at least one repetition in this curricular unit. The idea of using a STEAM methodology, for these students, in this curricular unit gained strength, and it is the report of this teaching experience that we propose to do here. Following this purpose, a teaching experience was conceived, aiming to understand how the use of STEAM approaches can i) help students understand mathematical concepts, ii) promote improvements in student outcomes, and iii) contribute to decreasing unit Calculus I - Extraordinary Semester (UCCISE) dropout rates.

Classes were designed for a maximum of 90 students, but there were over 200 students who met the requirements to participate. As a result, two classes were formed with unequal distribution, as students from different engineering and science courses were included. Despite teaching this curricular unit for several years, the researcher had to face, this time, a new challenge – teaching students with little motivation and commitment. This was the first instance in which the researcher had to teach classes composed entirely of such students.

The research team decided to design a Calculus I teaching approach that would involve and make students co-responsible for their learning – assuming that there would not be a drastic break with the teaching methodologies already known by the students. There were several moments of student-centred learning (Table 2), which were evaluated using various assessment instruments (Table 3) that were deemed appropriate.

In moments of traditional direct instruction, collaborative learning was encouraged with joint intellectual efforts of students with their peers or between students and their teacher.

One of the student-centered approaches adopted and previously mentioned was problem-based learning. Through this method, students work autonomously in groups consisting of five members. By working together in groups, students could share their ideas and perspectives, and develop skills highly valued in problem-solving, communication, and teamwork.

In the next section, the research questions and methods will be stated, in the intervention context.

Table 2: Pedagogical approaches for UCCISE

Pedagogical approaches	Extension		
Traditional direct instruction	***Decreasing***		
	A lot	→	To some extent
Teaching with experiments	***Increasing***		
	Very little	→	To some extent
Problem-based approach	***Increasing***		*Very little ↓*
	Not at all	→	To some extent
Flipped classroom	***Increasing***		
	Not at all	→	To some extent
Collaborative learning	***Increasing***		
	Very little	→	To some extent

4 Research, Questions, and Methods

The purpose of this research study is to examine the impact of the methodological options used in the UCCISE course on student achievement. For this, the study seeks to answer the following research questions:

RQ1: How have these methodological options contributed to improve students' academic outcomes?

RQ2: What are the potential implications of the findings for other intervention programs aiming to improve students' academic achievements?

Table 3: Students evaluation items

Pedagogical approaches	Assessment instruments	Contribution to student's final marks (%)
Traditional Teaching Approach (exercise/problem-solving)	2 Tests	75
Collaborative and Problem-Based Learning (PBL)	Task performed in groups using software, namely GeoGebra	25
Collaborative Learning in the Classroom	—	0

To accomplish this objective, the research team has opted for a qualitative research approach, which involves utilising a theoretical framework and examining research questions by exploring the subjective meanings attributed to them by individuals or groups ascribed to these context problems (Creswell & Poth, 2016). Framing this study as an Action Research study "could be a way of structuring research conducted in real contexts aimed at educational improvements" (Sáez Bondía & Cortés Gracia, 2022, p. 862). This study employs an interpretive paradigm for analysis, combining quantitative and qualitative data collection methods and utilising data triangulation to enhance the validity and reliability of the findings.

4.1 Sampling Selection and Description

The research team consisted of four individuals, all of whom were actively involved in conducting the study. Two of the researchers were affiliated with the Higher Education Institution where the teaching experience took place, with one of them serving as the professor of the UCCISE course. All researchers had expertise in the relevant research areas and contributed to the retrospective analysis of the teaching experiment as well as other essential research tasks. The research study comprises 68 students out of the original 104 enrolled in the UCCISE course. The exclusion of 36 students from the study was due to their lack of participation in any assessments related to the discipline.

4.2 Design and Methods

The Action Research study (Cobb, 2012) began by devising a teaching experience using the STEAM approach, aiming to promote learning, encourage collaboration among students, and foster self-regulated autonomous work.

The study data sources include students' classroom work students' assignments, group problem-based projects, a questionnaire administered to the participants, notes taken by the researcher who taught the course, and semi-structured interviews conducted with each group leader one year after the conclusion of UCCISE.

The research team developed an adaptive problem-based learning (PBL) project, to challenge students to apply mathematical concepts to real-world problems using public art pieces located on the UA campus as a contextual framework. The problem-based learning projects were carefully designed to incorporate mathematical modelling and calculus of areas of planar regions, which were derived from planar sections of public art pieces located at the university campus. By blending theoretical knowledge with practical applications, the students were able to engage in a stimulating learning experience that fostered mathematical thinking and collaboration skills.

The PBL projects were performed in groups of five elements each, using technologies, namely using GeoGebra, and photographs of the referred pieces.

In summary, the pedagogical approaches used, with more significant predominance, were Traditional Teaching, Collaborative Approach in (Classroom), and Problem-Based Learning, developed in the autonomous work time allocated to the UCCISE course.

In the next section, we will provide a more detailed explanation of the PBL projects given to the students.

4.3 Data Collection and Analysis

Before assigning the projects to the groups, a comprehensive guide was developed, presented, and delivered by the students, to illustrate the process of creating planar cuts of a piece of art using sections of conic curves via GeoGebra. This guide included detailed instructions on calculating the area of the sectioned region using a specific procedure, as exemplified in Figure 1.

The work projects aimed to enhance students' communication and mathematical thinking skills using computational tools for mathematical modelling. The focus of each project was on calculating areas of planar regions, and they were carried out in a collaborative learning environment.

Students' productions in the workgroups were presented and discussed in class. The final report of each group should include the corresponding GeoGebra file containing not only the geometric modelling but also all the necessary steps for calculating the intended area. Their performance in modelling, area calculation, and application of acquired knowledge was registered in an observation grid, considering the criteria and weighting indicated in Table 4.

The projects given to the students required solving definite integrals, so an individual questionnaire was also applied to them to understand their difficulties in this subject.

As it is well known, computer algebra systems (CAS) are good integral calculators for solving definite integrals, but this is not always the case. When they fail, there is a need to use mathematical reasoning that transcends memorising and applying formulas. The fact that students had

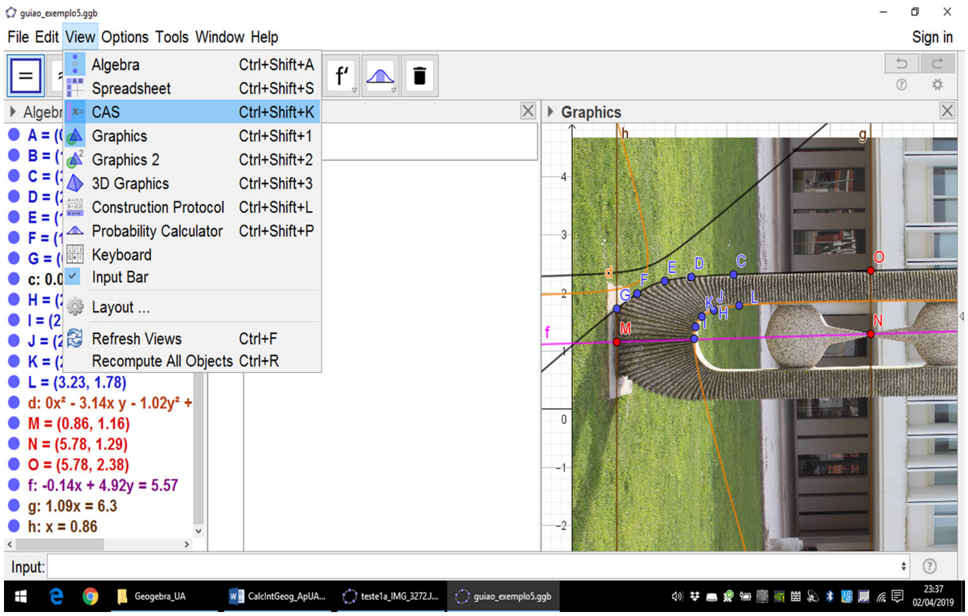

Figure 1: Example of GeoGebra modelling given to students.

to face this situation represented an opportunity to improve their problem-solving skills and cultivate their autonomous learning abilities. As Breen and O'Shea (2011) refer, one way the mathematical community could aid students would be to assign a broader range of tasks to develop their mathematical thinking skills.

As already mentioned, an essential issue for the pedagogical approaches used to be reflected in an added learning value for students is their harmonisation with the corresponding assessment of students.

One of the major challenges we faced in implementing this intervention was to ensure that the evaluation processes were aligned with the instruments and criteria we had adopted. This was especially difficult given that all the participating students were either enrolled in more advanced courses or had overlapping schedules within the same academic year. To address this issue, we developed a compromise solution, which is outlined in detail in Table 3.

The evaluation process gave students a choice between two individual written assignment tests or just a final exam. If they chose to take both assignment tests, a voluntary group project was proposed. For those who declined the project, each test was weighted at 50%, while those who completed the project had weightings as shown in Table 3.

Table 4: Working group assessment criteria, descriptors and scores

Criteria to observe	Descriptors	Scores
Modelling (50%)	Adequate position for the requested modelling	None: 0%
	Identification of symmetries, if applicable	Partial: 25%
	Obtaining the functions that delimit the region	
Area calculation (25%)	Use of CAS commands	Total: 50%
	Other software used, if applicable	
	Obtaining the value of the area	
Report (25%)	Written production (10%)	Insufficient: 0–2%
		Sufficient: 3–5%
	Presentation (10%)	Good: 6–8%
		Very Good: 9–10%
	Oral defence (5%)	Insufficient: 0–1%
		Sufficient: 2–3%
		Good: 4%
		Very Good: 5%

Out of the 104 students enrolled at UCCISE, only 66 attended classes regularly.

Among the 52 students who opted for the evaluation process described in Table 3, we initially formed 11 groups, however, only 36 students (9 groups) completed the project. It should be noted that some students disengaged from their original group and joined another group based on shared interests and extra-classroom commitments.

5 Results

The teaching experience was successfully developed according to plan, from the point of view of the research teacher and the research team. The various components of the teaching experience were implemented, in the classroom and outside the classroom as follows. In the classroom, the professor taught the contents of the discipline, incorporating examples, mathematical proofs of the main theorems, and practical applications, which allowed students a better and deeper understanding of the subjects covered. Through illustrative examples, the students were able to concretise abstract concepts and properties that were being taught. The students' contact with some detailed mathematical proofs deepened their understanding of the subjects taught and promoted the development of their thinking and mathematical reasoning, so useful in problem-solving strategies. Exploring practical applications, students understood the pertinence of what they were learning and how it could be applied in different scientific knowledge areas. To stimulate individual and collaborative learning, the teacher assigned tasks, to be executed individually or in small groups, requiring the application of the newly learned material, being always accompanied by the teacher's continuous formative feedback and monitoring. The projects to be carried out outside the classroom, in groups of a maximum of five elements, and the corresponding guides were also presented. Students were offered the chance to seek additional support beyond the classroom to address any questions or concerns related to the course material and project assignments. However, there was a limited number of requests for this additional assistance.

The assessment in UCCISE was conducted by the internal researchers, considering the information specified in Tables 3 and 4.

The evaluation of participating students was a crucial data source for the research team to assess the experiment's outcomes and students' achievements. The interviews were another source to access the students' perceptions about the experiment's outcomes. According to interviews conducted with group leaders one year after the teaching experience, students highly value the teaching approach, but they also value the moments of traditional instruction. The class dynamics were reported to be engaging, as the teacher encouraged active participation, frequently prompting students to solve problems on the blackboard and explain their resolutions to colleagues, see some students' transcripts below. One interviewer highlighted that the teacher's approach created a positive atmosphere in the classroom, facilitating a good relationship between students and the teacher.

Students' transcriptions regarding the traditional teaching approach:

> *"She is a dynamic teacher; she forced us to participate, well she didn't oblige but often solicited our active participation... In this experience, I immediately felt the difference in the cooperation between the teacher and the students."*

> *"The classes were delivered with energy, so I didn't feel like sleeping, and the concepts were explained in a manner that they are unlikely to be forgotten."*

> *"I don't remember now if she used PowerPoint, but I enjoyed seeing her resolutions, explanations, and detailed proofs written in full on the board."*

Students transcriptions regarding autonomous learning:

> *"What I noticed as the main difference with the standard Calculus course, which is very theoretical, was the practical characteristic of UCCISE, where I could immediately apply what I learned. This was something that I did not feel when I attended Calculus before. I remember that when I got home, I had doubts due to not having been given time to familiarize myself and work with the given concepts. In Calculus I Extraordinary Semester, we had many exercises/problems to deal with, and we were always able to learn and train, so I had just to go home, and do some more exercises/problems. that is what I liked most."*

Students transcriptions concerning students' achievement in UCCISE and the impact of their learning, on the performance in other math-related disciplines.

> *"It helped me a lot; now I do not have any other math course, but physics, and the knowledge I learned in UCCISE, helped me a lot. I have an easy time in solving integrals, in calculating derivatives, that sort of thing, so it was consolidated, so yes, it helped me a lot."*

Student transcriptions regarding the PBL pedagogical approach

> *"I tried to do Calculus I (standard) and failed; I tried a second time and failed again. I developed a phobia. thought about giving up. but not now; it was fun. I could understand. something unattainable for me became easy and fun."*

About UCCISE instruction Improvements, students stated that they were satisfied with the changes that had occurred, with no need for significant changes (the transcription shown down).

> *"I do not think it is necessary to make any changes."*

The participating students attributed their success in UCCISE to the project (extra-class group work) they carried out. Students' creative productions, associated with the geometric modelling of planar sections of art pieces located on the UA campus, are illustrated in Figure 2.

It should be noted that, in the interviews, concerning the collaborative extra-class project, students emphasised the integrating components of art, technology, and mathematics. In other words, they found out that the STEAM approach used in UCCISE was a powerful means to promote their learning in topics covered in the course. By using technology to reduce levels of abstraction, they anchor techniques and skills in math-related disciplines they studied after the teaching experience.

Although the use of GeoGebra was suggested in the initial proposal of the workgroups, the students did not just use GeoGebra but also used other software that allowed them to use CAS capabilities, namely MATLAB. These additional software were mainly used to verify the accuracy of the obtained calculations. It is worth mentioning that all groups used GeoGebra, and it was not clear whether the students' decision to use other software was due to a lack of confidence in their methods or doubts about the accuracy of the GeoGebra results.

All interviewees students agreed that the project work they had developed played a vital role in their understanding of integration calculus, even for those who were not approved. One of them stated that

> *"I think it worked as a formative tool because it helped me better understand the application of the definite integral in calculating areas. I understood because I had to work on it. I could see how things were evolving and what was happening at each step in the search for a solution. The geometric visualization of each performed step was amazing. Yes, it was an experience that helped me to understand and strengthen my knowledge".*

The project work carried out by the 35 students enrolled at UCCSEI was considered relevant, as it provided valuable assistance in overcoming some of the challenges they faced in integral calculus. They also expressed the opinion that this approach should be used in the standard course of Calculus I. In summary, students highlighted the significance of this project work, citing the valuable feedback they received, the collaborative learning environment it fostered, and the importance of using software to combine visualisation and reasoning. They also pointed out it as an effective approach to promoting dynamic learning among them.

Although the research team is aware of the difficulties associated with group work, namely in the involvement of students in autonomous study, it is worth mentioning one of the testimonies made by one of the interviewees:

> *"I do not think the teacher can control, for example, how much each student will study, but working in a group, we have to hand over to work, so it is a form of studying."*

One of the main challenges in maximising the results of this teaching experience was the relatively low number of students who chose to participate in the project work at UCCISE. Out of the 104 students who were initially enrolled, only a minority of 36 students carried out the group work, while the majority of 68 students did not get involved (Table 5).

Figure 2: UA campus art pieces contemplated in students' productions.

Table 5: Assessments results of UCCISE at the end of the teaching experiment

		No. of students
Enrolled		104
Performed		
	1 Assessment test (AT)	66
	2 Assessment test	54
	Workgroup (WG)	36
Approved		27
	WG + 2AT	19
	WG + Final Exam	1
	Remediation Exam	4
	WG + Remediation Exam	3

However, despite this limitation, the results achieved in terms of student success in the discipline were significant, with 64% of the participants who completed the project being approved. This indicates that the design of a STEAM project was effective in enhancing students learning and skills development. Future efforts could be made to increase student engagement and participation in similar activities.

It is worth mentioning that four out of the 68 students were approved without participating in the work project. During an interview with a student who failed the course, he mentioned (transcription shown below) that his failure was not due to the classes themselves, but rather to a lack of discipline and focus when studying at home. The student acknowledged that many first-year students, including himself, often prioritise social events over studying, which can lead to neglecting essential coursework like Calculus. As such, it is important for students to balance their social lives with their academic responsibilities to avoid falling behind in their studies; as a student referred

> *"Not having approved was obviously bad. It was not due to classes for sure; it was more the study at home, the negligence that students have, in the first year, since we have other "social events" and we end up neglecting the study that is essential, this obviously is not only happening in the Calculus classes."*

Our research study has revealed that a significant number of students enrolled at UCCISE elect to skip classes and focus exclusively on preparing for the final exams, missing out on valuable opportunities to deepen their understanding and construct knowledge. Specifically, we observed how a STEAM collaborative approach played a critical role in helping students to achieve good results. Interestingly, the approval rate for UCCISE was higher than that of the standard Calculus I course, which underscores the effectiveness of the STEAM approach in facilitating student success.

6 Discussion

The study's findings align with previous research on the benefits of incorporating STEAM approaches in education, emphasising the significance of integrating arts and creativity into STEM education to foster holistic learning experiences (Ghavifekr & Rosdy, 2015; Perignat & Katz-Buonincontro, 2019; Piila et al., 2021; Pahmi et al., 2022). Arts and creativity in conjunction with STEM subjects enhance student motivation, engagement, and critical thinking skills (Segarra et al., 2018; Yakman, 2008).

The results support the notion that collaborative learning through STEAM projects leads to improved academic outcomes, as indicated in undergraduate STEM education research by Beach et al. (2012). Collaborative learning encourages peer interaction, constructive discussions, and collective problem-solving, positively impacting students' conceptual understanding and skill development (Cobb, 2012).

Consistent with studies emphasising technology's role in mathematics education, the use of CAS and GeoGebra aids students in visualising complex mathematical concepts and exploring real-world applications, observed in this study's STEAM projects. Technology integration in mathematics education has been associated with improved problem-solving abilities and conceptual understanding (Pointon & Sangwin, 2003; Sangwin, 2003).

Students' positive feedback regarding the STEAM projects reflects the effectiveness of STEAM project-based instruction. Students expressed a deeper understanding of integration calculus and its practical applications, supporting the argument that project-based learning enhances knowledge retention and transferability (Diego-Mantecón et al., 2019, 2021).

7 Conclusion

The teaching experience reported here benefited from the initial questionnaire, as it allowed adjustments to the initial design of the teaching activities. In the opinion of those involved in the work project, the STEAM approach proved to be useful in motivating them to study and improve their results, regardless of whether they were or not approved by the UCCISE.

In the questionaries, applied at the end of the teaching experience, and in the interviews, students mentioned that similar experiences should have been used in the first years of their university courses. These results are interesting since the interviews took place one year after their higher education programs began.

The result of this study shows that the STEAM approach used is viable for teaching this mathematical topic, with positive effects on the development of students' learning. However, the results indicate that it cannot be seen only as a remedial learning practice. After the experience, it was found that the work project should have been mandatory and not optional for the students' benefit. New cycles of this teaching experience would be necessary; however, there are several constraints for this challenge to be achieved. Implementing the STEAM approach can be time-consuming, as it often involves project-based learning and interdisciplinary collaboration. This can be difficult to accommodate within existing schedules and curriculum requirements.

Funding information: This research was supported by the Center for Research and Development in Mathematics and Applications (CIDMA) through the Portuguese Foundation for Science and Technology (FCT – Fundação para a Ciência e a Tecnologia), references UIDB/04106/2020 and UIDP/04106/2020; The Centre for Research and Innovation in Education (inED), through the FCT – Fundação para a Ciência e a Tecnologia, I.P., under the scope of the project UIDP/05198/2020; and Organization of Ibero-American States for Education, Science and Culture (OEI).

Conflict of interest: The authors state no conflict of interest.

References

Barry, M. D. J. (2002). Mathematics for the European Engineer-a Curriculum for the Twenty-first Century. *The Brief*, *16*. http://www.kmf.fgg.uni-lj.si/Matematika/Core%20Curriculum.pdf.

Beach, A. L., Henderson, C., & Finkelstein, N. (2012). Facilitating change in under-graduate STEM education. *Change: The Magazine of Higher Learning*, *44*(6), 52–59. doi: 10.1080/00091383.2012.728955.

Blomhoj, M., & Jensen, T. H. (2003). Developing mathematical modelling competence: Conceptual clarification and educational planning. *Teaching Mathematics and its Applications*, *22*(3), 123–139.

Breen, S., & O'Shea, A. (2011). The use of mathematical tasks to develop mathematical thinking skills in undergraduate calculus courses–a pilot study. *Proceedings of the British Society for Research into Learning Mathematics*, *31*(1), 43–48.

Cobb, P. (2012). Conducting teaching experiments in collaboration with teachers. In *Handbook of research design in mathematics and science education* (pp. 307–333). Routledge.

Credé, M., & Phillips, L. A. (2011). A meta-analytic review of the Motivated Strategies for Learning Questionnaire. *Learning and Individual Differences*, *21*(4), 337–346. doi: 10.1016/j.lindif.2011.03.002.

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. Sage Publications.

De la Garza, A., & Travis, C. (2019). *The steam revolution*. London: Springer. doi: 10.1007/978-3-319-89818-6.

Diego-Mantecón, J. M., Arcera, O., Blanco, T. F., & Lavicza, Z. (2019). An engineering technology problem-solving approach for modifying student mathematics-related beliefs: Building a robot to solve a Rubik's cube. *International Journal for Technology in Mathematics Education*, *26*(2), 55–64.

Diego-Mantecon, J. M., Prodromou, T., Lavicza, Z., Blanco, T. F., & Ortiz-Laso, Z. (2021). An attempt to evaluate STEAM project-based instruction from a school mathematics perspective. *ZDM Mathematics Education*, *53*, 1137–1148. doi: 10.1007/s11858-021-01303-9.

Dreyfus, T. (2002). Advanced mathematical thinking processes. In *Advanced mathematical thinking* (pp. 25-41). Dordrecht: Springer.

Ghavifekr, S., & Rosdy, W. A. W. (2015). Teaching and learning with technology: Effectiveness of ICT integration in schools. *International Journal of Research in Education and Science*, *1*(2), 175–191.

Gueudet, G., & Thomas, M. O. (2020). Secondary-tertiary transition in mathematics education. In S. Lerman (Ed.), *Encyclopedia of Mathematics Education* (pp. 762–766). Cham: Springer.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(11), 1–11. doi: 10.1186/s40594-016-0046-z.

Moore, T. J., Johnson, C. C., Peters-Burton, E. E., & Guzey, S. S. (2016). The need for a STEM road map. In C. C. Johnson, E. E. Peters-Burton, & T. J. Moore (Eds.), *STEM road map: A framework for integrated STEM education*. New York: Routledge. doi: 10.4324/9781315753157.

National Research Council & Mathematics Learning Study Committee. (2001). *Adding it up: Helping children learn mathematics*. National Academies Press.

Niss, M. (2003). Mathematical competencies and the learning of mathematics: The Danish KOM project. In *3rd Mediterranean conference on mathematical education* (pp. 115–124).

Nistor, A., Gras-Velazquez, A., Billon, N., & Mihai, G. (2018). Science, technology, engineering and mathematics education practices in Europe. *Scientix Observatory report*. http://www.scientix.eu/documents/10137/782005/STEM-Edu-Practices_DEF_WEB.pdf/b4847c2d-2fa8-438c-b080-3793fe26d0c8.

Pahmi, S., Juandi, D., & Sugiarni, R. (2022). The effect of STEAM in mathematics learning on 21st Century Skills: A systematic literature reviews. *Prisma*, *11*(1), 93–104. https://jurnal.unsur.ac.id/prisma/article/download/2039/1643.

Papadakis, S. (2020). Evaluating a teaching intervention for teaching STEM and programming concepts through the creation of a weather-forecast app for smart mobile devices. In M. Kalogiannakis & S. Papadakis (Eds.), *Handbook of research on tools for teaching computational thinking in P-12 education* (pp. 31–53). United States: IGI Global. doi: 10.4018/978-1-7998-4576-8.ch002.

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity*, *31*, 31–43. doi: 10.1016/j.tsc.2018.10.002.

Piila, E., Salmi, H., & Thuneberg, H. (2021). STEAM-learning to mars: Students' ideas of space research. *Education Sciences*, *11*(3), 122. MDPI AG. doi: 10.3390/educsci11030122.

Pointon, A., & Sangwin, C. J. (2003). An analysis of undergraduate core material in the light of hand-held computer algebra systems. *International Journal of Mathematical Education in Science and Technology*, *34*(5), 671–686. doi: 10.1080/0020739031000148930.

Sáez Bondía M. J., & Cortés Gracia A. L. (2022) Action research in education: A set of case studies?. *Educational Action Research*, *30*(5), 850–864. doi: 10.1080/09650792.2020.1866631.

Sandoval-Palomares, J. (2022). STEAM competencies and attitudes in higher education: The evaluation of experts Competencias y actitudes STEAM en la educación superior: La evaluación de expertos. *Volume 6, Issue 16–July–December–2022*, *6*(16), 19.

Sangwin, C. J. (2003). New opportunities for encouraging higher level mathematical learning by creative use of emerging computer aided assessment. *International Journal of Mathematical Education in Science and Technology*, *34*(6), 813–829. doi: 10.1080/00207390310001595474.

Schneider, M., & Preckel, F. (2017). Variables associated with achievement in higher education: A systematic review of meta-analyses. *Psychological Bulletin*, *143*(6), 565–600. doi: 10.1037/bul0000098.

Segarra, V. A., Natalizio, B., Falkenberg, C. V., Pulford, S., & Holmes, R. M. (2018). STEAM: Using the arts to train well-rounded and creative scientists. *Journal of Microbiology & Biology Education*, *19*(1), 10–128.

Sharma, J., & Yarlagadda, P. K. (2018). Perspectives of "STEM education and policies" for the development of a skilled workforce in Australia and India. *International Journal of Science Education*, *40*(16), 1999–2022. doi: 10.1080/09500693.2018.1517239.

Simarro, C., & Couso, D. (2021). Engineering practices as a framework for STEM education: a proposal based on epistemic nuances. *International Journal of STEM Education*, *8*(1), 1–12. doi: 10.1186/s40594-021-00310-2.

Stohlmann, M., Moore, T., & Roehrig, G. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research*, *2*(1), 28–34. doi: 10.5703/1288284314653

Tall, D. (1991). *Advanced mathematical thinking* (Vol. 11). Dordrecht and Boston: Kluwer Academic Publishers.

Tall, D. (1995, July). Cognitive growth in elementary and advanced mathematical thinking. In *PME Conference* (Vol. 1, pp. 1–61). The Program Committee of the 18Th PME Conference.

Tzagkaraki, E., Papadakis, S., & Kalogiannakis, M. (2021). Exploring the use of educational robotics in primary school and its possible place in the curricula. In M. Malvezzi, D. Alimisis, & M. Moro (Eds.), *Educational Robotics International Conference* (pp. 216–229). Springer. doi: 10.1007/978-3-030-77022-8_19.

Yakman, G. (2008). *STEAM education: An overview of creating a model of integrative education*. STE@M Educational Model.