Evaluation of STEAM Methodologies in Undergraduate Applied Mathematics Courses

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Abstract

In recent years, STEAM practices have become very popular, especially in higher education. The shift from STEM (Sciences, Technology, Engineering and Mathematics) to STEAM, which includes Arts, added a new paradigm to education, with the goal to emphasize students' creativity and intellectual curiosity. In this paper, the case study within the ERASMUS+ project FUTUREMATH is presented. This case study includes analysis of implemented STEAM methods in four undergraduate courses. The paper focuses on analyzing both students' satisfaction in the adoption of STEAM methodologies, and the role of this approach for their better understanding of complex mathematical topics. The findings of this research lead to the conclusions that students accepted the new approaches very well, and that STEAM approach helped them in relating calculus topics with the topics in their academic majors. This work outlines good STEAM practices in working with students, as well as it addresses future needed improvements.

Keywords

Higher education, STEAM approaches, STEAM methodologies evaluation

1. Introduction

STEAM is an educational model which acronym stands for science, technology, engineering, arts and mathematics, and as such it serves as access points for guiding student inquiry, dialogue, and critical thinking [1]. With the expansion of science, technology, engineering and mathematics (STEM) job market, there is a hope that with STEAM initiatives students will gain more than high-tech skills and that with integration of the arts part into STEM, STEAM will provide pathways for personal-meaning making and self-motivation [3].

In STEM fields, it has been a challenge for many years to reduce attrition rates, typically caused by dropping out of the academic programs or university [4]. Traditional methods of teaching, in the modern educational environment, have become methods that do not produce sufficiently good learning results. One of the considered approaches to mitigating this effect is by introducing technology along with innovative teaching practices.

Implementation of STEAM methodologies in the classroom has its benefits, but also its challenges. In order to have an effective integration of STEAM methodologies in the curriculum, teachers have to have detailed knowledge about STEAM concepts and to participate in continuing education [5]. In other words, teachers have to be very familiar with the content, but they often have to teach outside their "comfort area" of speciality [6].

Advanced mathematical topics such as calculus for undergraduate studies received significant attention, especially when technologies with innovative teaching and learning approaches are applied

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[7]. Calculus is often regarded as one of the foundational courses for most STEM majors; therefore, noteworthy efforts have been investigated in order to introduce technologies for innovative teaching practices. Although the majority of students do recognize topics in mathematics as an important subject, in practice, very few students properly recognize the value of mathematics [8, 9]. In order to improve student engagement and overall learning outcomes, it can often be beneficial to apply those mathematical concepts to real-world examples and situations, which in turn aids the students to find math problems easier and less abstract to identify with [10]. It is fortunate that a significant crossover potential with science, technology, engineering, and the arts exists, making the goal of student engagement an achievable one [11]. Current, emerging and disruptive technologies can drive the necessary and hence inevitable change throughout the educational landscape, especially in higher education, leading to the redefinition and reshaping of both teaching and learning, in accordance with the principles underlying the interdisciplinary STEAM approach, particularly by designing interactive, collaborative, and inquiry-based learning environments [12].

This paper presents part of the Erasmus+ FUTUREMATH project, dealing with implementation of STEAM methodologies in teaching calculus topics in the curriculum of courses taught in three undergraduate academic majors: software engineering, information technologies and game development. Calculus topics were presented through the application in the “real world” problems that are related to the topics and future courses needed for these groups of students. STEAM methodologies and their teaching/learning content was developed for four different courses and relating to the following lesson topics:

1. Big O notation,
2. Recurrence relations,
3. Elliptic curve cryptography,
4. Classification in machine learning, and
5. Implementation of numerical integration methods using the Java programming language.

For the purpose of this study, a student survey was designed and distributed, with the aim of determining student level of satisfaction with the new way of teaching.

The paper is organized as follows. Section 2 describes implemented STEAM models and principles. Section 3 represents research methodology used for data collection and analysis in four different pilot courses. Section 4 presents results and discussion. Section 5 concludes the paper.

2. Implemented lesson format

The STEAM model implemented in the case studies analyzed in this paper, was inspired by the active learning strategies used both in online and in-class settings. In the pilot lessons, similar principles were implemented. Online content of the lesson follows designed lesson plans and typically contains: learning objectives, previous knowledge assumed, description of the practical problem (“real world” problem/application), student project or problem assignment, theoretical/instructional content, lesson video, activating exercises, discussion, self-evaluation with feedback, assessment, and student homework assignment. The lesson starts with clearly stating the learning outcomes and objectives of the lessons, which highlights the expectations that students should have from learning the lesson. This is followed by the “interest catcher” used to introduce students where students will be able to apply calculus topics in “real world” problems. In our case, all the students that participated in the pilot lessons, were students from the academic majors relating to the computing disciplines, and most of the “real world” applications relate to that. Table 1 gives examples of interest catcher for pilot lessons.

Table 1
Examples of interest catchers for pilot lessons.

Lesson title	Interest catcher with "real world" problems/applications
Recurrence relations	Examples of recursion in programming, A mathematical example of recursion is the definition of factorials, The tower of Hanoi
Big O	How are programs analyzed and how they behave during scaling?
Classification in machine learning	Classification of Iris dataset using Bayesian classifier.
Definite integrals solving in Java	Software implementation of integration methods
Elliptic curve cryptography	How can blockchain use less processing (and therefore electrical) power?

Once the student's interest has been caught and clear expectations in learning outcomes and lesson objectives have been set, students can approach the instructional part of the lesson. Given that STEAM methodology relies on active learning strategies, lessons represent a combination of instructional material, along with assigned projects, problems, videos, assessments, etc. Each lesson contains assessments, which are designed to assess learning outcomes. These assessments are used in different formats and with different purposes. While some are self-assessment tests designed for students to receive instant feedback on their understanding, the others are used to assess and grade student knowledge. The used assessments were in different formats: quizzes, tests, discussion, self-reflection.

Two types of videos (clips) were used:

1. Introduction to the lesson – short 3–5-minute videos used for teachers to introduce learning outcomes, objectives and expectations. This video can be used to introduce an interest catcher.
2. Lecture video – video that is no longer than 10 minutes with the goal to introduce students with main concepts through instructions and explanations.

The lessons were built on the practical problems and projects assigned to students (based on problem-based or project-based learning methods), closely related to calculus topics. The online content was made to engage students to be more motivated in their learning. The developed lessons were then published on a learning management system so that students can either access content, either interactively or download it in PDF format. By making the lesson available online to students, their progress and activity could be followed.

3. Methodology

This paper investigates the student satisfaction with the lessons developed and implemented using STEAM methodologies and principles. Pilot lessons were implemented in four different undergraduate courses by applying different calculus topics for undergraduate students in three different academic majors: Software engineering, Information technology and Video game development. The lessons were implemented both in the classroom and in online learning environments.

The purpose of this analysis is to show the impact of STEAM approaches in understanding calculus topics in students' mathematics and non-mathematics classes. In each class, student motivation and problems were related to one or more calculus topics with the "real world problem". In non-mathematics courses, these problems were relating to the main topics and goals of the course itself. The underlying assumption was that relation to the “real world problems” would help not only improve their motivation, but also tune their interest and keep their attention to the calculus topic, by trying to solve the defined problem.

The pilot course lessons were attended by a total of 108 undergraduate students. A total of four courses with five lessons covering calculus topics were taught:

(i) Discrete structures (with lessons Big O notation and Recurrence relations),
(ii) Introduction to object-oriented programming (with lesson Definite integrals in Java),
(iii) Blockchain technology in data protection (with lesson Elliptic Curve Cryptography), and
(iv) Artificial intelligence (with lesson Classification in Machine Learning). Discrete structures and Introduction to object-oriented programming were taught to first- and second-year students, while courses Blockchain technology in data protection and Artificial intelligence were taught to third-year and fourth-year students.

After the lesson piloting, the students were asked to fill out the survey with the goal to analyze students’ satisfaction with introduced mathematics topics and methodologies used. There are nine single-answer multiple-choice questions in the survey. For the questions one to eight, 5-point Likert scale was used with five offered answers: I agree, I partially agree, I neither agree nor disagree, I partially disagree, and I disagree. The Likert scale was chosen as it is very efficient for classroom lectures evaluation [13]. The ninth question was the question with only two offered answers. Although 108 students attended pilot lectures, totally 79 students completed the survey. The survey addressed the following issues:

- How satisfied are students with new methodologies?
- What can be improved so that students could easier understand complex mathematical problems and their application in real world problems?
- How important is inclusion of various additional materials in different formats to keep students interested in the given topics and motivated to be active during and after classes?

Given the exploratory nature of this study, as this study was part of the larger sample within the FUTUREMATH project, responses from individual course surveys were combined. The intent of this analysis is not only to investigate satisfaction of students with new STEAM methodologies in their classes, but also to use the results for the improvement of lesson content from the perspective of the teaching and learning. The results were analyzed using descriptive statistics (frequency, mean, standard deviation and median). In order to be able to address future improvements and better increase student motivation to study calculus related topics, dependence between all parameters was analyzed using correlation matrix with Pearson’s coefficients that included statistical significance [14]. This approach gave a good understanding of significant relationships between collected answers and helped in analysis of implemented STEAM technologies in students’ understanding of calculus topics in pilot lectures.

In order to perform defined analysis, student answers were scaled according to Likert scale, where the answers were transformed as follows: 5 - I agree, 4 - I partially agree, 3 - I neither agree nor disagree, 2 - I partially disagree and 1 - I disagree. The last question (Teaching material is available in the form: printed or electronic) with two possible answers were transformed as follows: 1 – Electronic and 0 – Printed. Obtained results and discussion follows in the next section.

4. Results and Discussion

The results' analysis is divided into two parts: (i) the analysis of student satisfaction with newly implemented STEAM methodologies, and (ii) the analysis of correlation between the questions about students’ satisfaction in order to address the future improvements of teaching and learning design for the teaching of calculus topics for STEM student majors.

4.1. Analysis of Student Satisfaction

Table 2 shows the survey answers for all five pilot lessons, filled out by 79 of the 108 students in the pilot courses, while Table 3 shows the mean, standard deviation and median of the survey answers.

Based on the analyzed students' answers, the students were most positive about the organization of the lesson 4.86±0.38. 87.34% of students agreed, 11.39% of students partially agreed, while only 1 student (1.27%) neither agreed nor disagreed. When it comes to perception whether the computer environment helped them with visualization of mathematics concepts (4.57±0.73) in total 69.62% of students agreed, while 18.99% partially agreed, 10.13% neither agreed nor disagreed, and only 1 student (1.27%) partially disagreed. It should be noted that in all courses, computer environments were used in different ways. While all lessons were presented to students using university's LMS, the assigned tasks and problems required using different software tools. The least additional software tools were used in the course Discrete structures, and this is where all the "I neither agree nor disagree" answers came from.

Four out of five lessons were taught live at the University's campuses, while the fifth lesson was taught via Zoom platform. In each lesson the presenter had a visual aid, such as power projector, screen, speakers, etc. All lessons were accompanied by a presentation, assigned tasks and problems, assigned tests and other learning materials relevant to the lesson. In total, 75.95% of students agreed that visualization helped them to acquire knowledge more easily, a total of 22.78% partially agreed, and only 1.27% neither agreed nor disagreed. Based on the averages on the survey results students were positive regarding the perceived help from the visualization in their learning, 4.75±0.47.

All planned lessons were presented with a reflection on contemporary "real world" problems, mainly relating to computing disciplines. Some of the students did not actively participate in the reflection; however, most of the students were excited to join in the conversation and work on assigned tasks. In total, 62.03% found teaching contents to be interesting, 25.32% partially agreed, 7.59% neither agreed nor disagreed, and only 5.06% partially disagreed, with the averages being 4.44±0.84.

While some of the topics were too abstract for some students, the presenters gave multiple real-world scenarios in which the solutions deriving from the topics presented could be applied. After presenting "real world" applications, students were more eager to follow the lesson. In total, 59.49% of students agreed that the lessons topics are applicable in everyday life, 24.05% partially agreed, 13.92% neither agreed nor disagreed, 1.27% partially disagreed, and only 1.27% disagreed. With the averages of 4.39±0.87, this question has the smallest grade and we can conclude the following: when teaching to first year students, when fundamentals are necessary to be covered for more advanced topics, it is challenging to relate mathematics to the full extent, other than mentioning how these principles will be later applied in their courses and field of study.

In addition to the full lesson content published on university's LMS, students were given additional useful literature that can be used to further expand their knowledge. In total, 68.35% of students agreed, 24.05% partially agreed, 5.06% neither agreed nor disagreed, 2.53% partially disagreed, while 0% disagreed, with the averages 4.58±0.71. Similar to the previous question, first-year students can have difficulties learning from undergraduate-level textbooks, especially if they are accustomed to high-school curricula.

An improvement that we propose is the addition of so-called "hand-on" textbooks or "cookbooks" for first-year students, which focus more on examples and real-world applications. Furthermore, STEAM methodologies should be incorporated from the beginning of studies whenever possible, with the goal of getting students accustomed to these principles and practices. Certainly, the approach of implementing STEAM methodologies would require additional effort and a level of creativity from the teachers themselves.

Table 2
Survey answers for the five taught lessons.

Questions	I agree	I partially agree	I neither agree nor disagree	I partially disagree	I disagree
Q1: The lesson was well organized	69	9	1	0	0
Q2: Computer environment helped me to get visual approach of mathematics contents	55	15	8	1	0
Q3: Visualization helped me to acquire knowledge more easily	60	18	1	0	0
Q4: Teaching contents are interesting	49	20	6	4	0
Q5: Teaching contents are applicable in everyday life	47	19	11	1	1
Q6: Teaching contents are applicable in sciences	48	18	7	4	1
Q7: Literature is adequate for understanding the teaching contents	54	19	4	2	0
Q8: The communication with the teacher helped me to acquire knowledge more easily	67	7	2	0	3
Q9: Teaching material is available in the form: printed or electronic	77 (Electronic)	-	-	-	2 (Printed)

Table 3
Survey questions for implementing STEAM methodologies.

Questions	Mean±	Standard deviation	Median
Q1: The lesson was well organized	4.86	0.38	5.00
Q2: Computer environment helped me to get visual approach of mathematics contents	4.57	0.73	5.00
Q3: Visualization helped me to acquire knowledge more easily	4.75	0.47	5.00
Q4: Teaching contents are interesting	4.44	0.84	5.00
Q5: Teaching contents are applicable in everyday life	4.39	0.87	5.00
Q6: Teaching contents are applicable in sciences	4.39	0.94	5.00
Q7: Literature is adequate for understanding the teaching contents	4.58	0.71	5.00
Q8: The communication with the teacher helped me to acquire knowledge more easily	4.71	0.85	5.00
Q9: Teaching material is available in the form: printed or electronic	0.97	0.16	1.00

4.2. Analysis of correlation between the questions

Table 4 shows a correlation matrix between the answers, which emphasizes a strong positive correlation between most questions. The degree of correlation was classified as small (0.10 - 0.29), moderate (0.30 - 0.49), and high (0.50 - 1). We have found that the strongest correlation exists between the applications of teaching contents. Namely, students strongly agreed that the teaching contents are applicable both in everyday life and in sciences (Q5 and Q6, $p < 0.001$), Furthermore, in both applications students found the teaching contents to be interesting, with a moderate positive correlation (Q4 and Q5, $p < 0.001$; Q4 and Q6, $p < 0.001$).

In addition, good course organization, as well as teacher communication is reflected with teacher's literature recommendations (Q1 and Q8, $p < 0.001$; Q7 and Q8, $p < 0.001$). Students who thought the lesson was well organized strongly agreed that visual aids and communication with the teacher helped them to acquire knowledge more easily (Q1 and Q3, $p < 0.001$; Q1 and Q7, $p < 0.001$), and also thought that the teaching contents were interesting (Q1 and Q4, $p < 0.001$).

Students who agreed that computer environment helped them to get a visual approach to mathematics had a moderate positive correlation with finding the lessons more interesting (Q3 and Q4, $p < 0.001$), adequate literature (Q3 and Q7, $p < 0.001$) and communicating with the teacher (Q3 and Q8, $p < 0.001$).

However, the strong correlation between communication with the teacher and application to sciences (Q6 and Q8, $p < 0.001$) suggest that teachers may have a more scholarly approach to teaching in their classes. These results are backed up by the small correlation between Q1 and Q5, showing that, although lessons are well planned, they still lack more examples from everyday life compared to those in sciences. Similarly, a moderate correlation between application in sciences and adequate literature exists (Q6 and Q7, $p < 0.001$), which agreed with our previous conclusions that textbooks are not always aimed at practical, real-world examples.

Table 4

Correlation coefficient matrix of the survey answers

Questions	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Q1	1.0***	0.24*	0.52***	0.51***	0.17	0.22*	0.4***	0.54***
Q2		1.0***	0.17	0.27*	0.41***	0.21	0.37***	0.38***
Q3			1.0***	0.42***	0.12	0.11	0.22	0.3**
Q4				1.0***	0.42***	0.44***	0.27*	0.43***
Q5					1.0***	0.74***	0.27*	0.38***
Q6						1.0***	0.46***	0.55***
Q7							1.0***	0.54***
Q8								1.0***

*** - $p < 0.001$, ** - $p < 0.01$, * - $p < 0.05$

5. Conclusions

This paper presented the implementation of STEAM methodologies in the undergraduate curriculum of academic majors relating to the computing disciplines. The intent of this work was to do an exploratory study on the sample of students from one university, in order to identify through the student satisfaction analysis how satisfied the students with new implemented STEAM methodologies were, and their perception of contribution of STEAM methodologies in their learning. In addition, this study was used to address future improvements that can be used in teaching and learning design using STEAM methods in teaching calculus topics in mathematics and non-mathematics courses.

Based on this study, it can be concluded that integrating STEAM principles into STEM studies can be very beneficial for keeping the interest and motivation among students, to better understand mathematics fundamentals that they need and will need in their profession. This approach does acquire additional effort from teachers and a level of creativity when introducing active learning methodologies and STEAM principles. When appropriate, students should be taught with STEAM principles from their beginning of studies, to get them acquainted with the principles as well, so that later they would be accustomed to this type of learning.

The major strengths of this teaching methodology can be summarized as follows. Firstly, “real world” problems can be easily implemented as examples during classes, making the topics easier for students to understand. Secondly, the inclusion of various additional materials in different formats allows students to be interested in the given topics. Finally, more abstract and complex mathematical problems can be presented in a manner that keeps students active during and after classes.

For future work, we intend to extend the pilot lessons to complete courses at all years of undergraduate studies, which would be taught during the whole semester. We also plan to improve the surveys by increasing the number and type of questions. After completing the pilot courses, a detailed course evaluation analysis will be performed, with the goal of examining students’ adoption of STEAM methodologies.

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