Slovak University of Technology in Bratislava
Faculty of Mechanical Engineering
17th Conference on Applied Mathematics **APLIMAT 2018**

Proceedings

ACTIVE-LEARNING TECHNIQUES IN MATH COURSES IN ENGINEERING DEGREES: THE PURSUIT FOR A NEW ENGINEER PROFILE

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Abstract. In this work, we present results of application of new teaching methodologies for Math courses in Bachelor Engineering Degrees. The traditional way of teaching mathematics is based on a 'teaching by telling' approach, especially in the early years of the courses. It is characterized by classes with many students, where they are exposed to the contents of a single curricular unit. Recently, there has been an increasing interest by engineering professionals and bodies to accredit engineering degrees in promoting change in this paradigm. The new teaching paradigm proposed here consists on the implementation of eduScrum and Jigsaw in a Differential and Integral Calculus I course in a Bachelor Engineering Degree at the School of Engineering of the Polytechnic of Porto. EduScrum creates an environment where students are masters of their knowledge, increasing their initiative to learn and entrepreneurship. Jigsaw develops more responsibility/autonomy and notion of belonging in students, hardly achieved when working alone. Some results of the implementation of these methods are presented and discussed.

Keywords: eduScrum, Jigsaw, Active-learning, Novel teaching methodologies.

Mathematics subject classification: Primary 65D17; Secondary 53A04, 14Q05.

1 Introduction

The world of education encourages, inspires and helps students to achieve great things in life. Educators are faced with a myriad of individual learners' needs. The traditional classroom encompasses a range of mixed abilities among students, some struggling to meet grade level standards, and some performing above grade level. Educators must, thus, be able to adjust to this immense heterogeneity. Moreover, to engage and develop the new skills of the 3rm industrial revolution, namely, problem solving, critical thinking, communication, collaboration and self-management, educators need to think new pedagogical methods, new ways of teaching, and novel instructional management methods.

In this paper, we introduce results of application of new teaching methodologies, namely eduScrum [9] and Jigsaw Method Teaching Strategy [6], in a Differential an Integral Calculus I course of a Bachelor Engineering degree. This type of methodology engages students in what constitutes real life-learning

experiences, and enhances their knowledge. EduScrum creates an environment where students are the owners of their knowledge, increasing the sense of self-initiative and entrepreneurship. Knowledge's responsibility is thus transferred from teachers to students. Applying the eduScrum framework enhances collaborative learning, emphasizing the students' interactions with each other. With Jigsaw, students learn course's contents cooperatively. It is a strategy in which students become experts in specific topics and teach their topic to their peers. This promotes students' engagement, learning and team group. Students interaction is thus highlighted, developing a sense of belonging to a community and value for each other contributions. *'Some teachers see themselves as the designated expert whose role is to impart their knowledge to students who are empty vessels. That's the wrong metaphor'* - Dr William Rando, Director of Chicago Center for Teaching at the University of Chicago.

In 2007, Shekar [13], underlines manners in which active-learning (AL) can raise up the students learning outcomes in a project based learning methodology. AL has been recognized 'as a means of skills transfer through apprenticeship' and it is a tool to integrate in the student's mind the culture practiced in the entrepreneurial/business world. This author presents a successful case study of a product development applying the PBL approach. Edström *et al* [2] point out the differences and similarities between problem/project-based learning (PBL), and conceive–design–implement–operate (CDIO) teaching methodologies in engineering education. They emphasize that the primordial principle of PBL is that students are responsible for their learning process. CDIO is described as an alternative way to the traditional engineering education, postulating an 'engineering culture' rather than an 'engineering science'. Bottom line, the authors conclude that PBL is a benchmark of student-centered education, paving the way to the implementation of CDIO. Gonçalves *et al* [5], apply a Problem-Based-Learning (PBL) approach to teaching and assessment of a Statistics chapter of the curricular unit of Computational Mathematics in an ISEP Bachelor Engineering degree. The authors implemented the PBL approach at a practical work on 'Simple Regression and Linear Correlation', using MS Excel, for computational support, to 394 students. A questionnaire was elaborated, focusing on the understanding and acquisition of knowledge using PBL. Authors conclude that the new method develops critical spirit, contributes to individual training, namely sense of responsibility, capacity and dis-inhibition in group working, analysis and decision. Pinto Ferreira *et al* [11] describe an eduScrum application, used as a pedagogical approach, on mathematics courses of the ISEP Engineering bachelor program. They provide and discuss results of application.

The goal of the present study is to reply to the following question: how does the implementation of these new pedagogical methodologies, namely Jigsaw and eduScrum, on the Differential and Integral Calculus I Course affect the students' own learning process?

With the aforementioned ideas in mind, the outline of the paper is as follows. In Section 2, we describe the implementation of the new teaching methodologies in the Differential and Integral Calculus I Course in an Engineering Bachelor Course at the School of Engineering of the Polytechnic of Porto (ISEP). In Section 3, we present and discuss the results of a questionnaire posed to students. In the last section we conclude our work and highlight *pros* and *cons* of this pilot-implementation of these novel methodologies.

2 Teaching methodologies

In this section, we describe in more detail the teaching techniques Jigsaw and eduScrum, and their implementation in a Differential and Integral Calculus I of a Bachelor Course at ISEP.

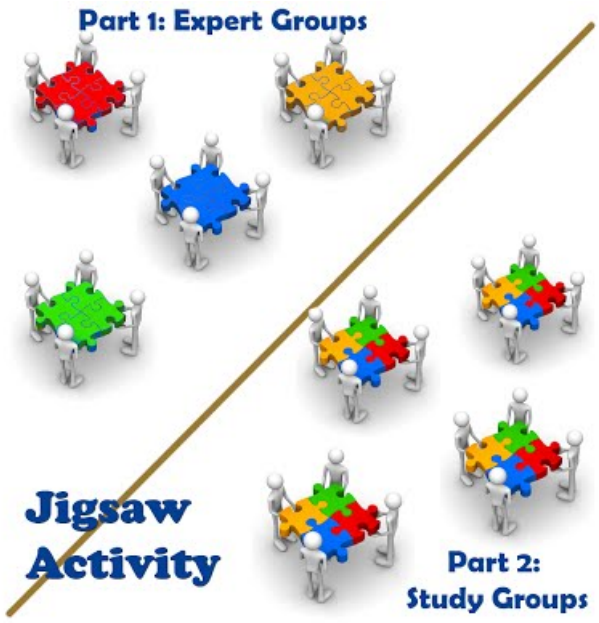

Fig. 1. Flowchart of the Jigsaw methodology [15].

2.1 Jigsaw technique

Jigsaw is a cooperative technique in which the teacher facilitates students' learning. His role is not to teach but to easy students' learning process. Students learn and teach in groups, ie., among their peers. Biggs says that 'Most people learn 95% of what they explain to others' [1]. All students in the groups must learn and teach their subject to others. The later increases responsibility and students' social skills, namely communication and teamwork. In the end, the teacher must check if students have adequately understand the contents of that class. The later may be done with some quiz questions in the end of the class, or any form of evaluation considered valid by the teacher. An implementation of Jigsaw in a class in which 4 concepts must be apprehended by the students is generically designed as follows [10]. The teacher must prepare notes for each of the topics, and these notes are made available to all students. Then students are gathered in groups of 4. These are called the *Home groups*. Each student in these groups learns one of the 4 concepts individually. This task may take 10 minutes. Then, all students who have learned topic i, $i = 1, \cdots, 4$, move to an *Expert group* for that specific topic i. There, they take 10 minutes to discuss between peers the key points of that topic and how they will instruct it to the other members of their *Home groups*, when they return. There, they have 10 minutes to teach their peers. In the end of this activity, the teacher verifies the degree of understanding of the 4 concepts by all students.

2.2 EduScrum methodology

Scrum is a framework for project management in which teamwork, accountability and iterative progress, towards a well-known objective, are highlighted. The main foundations of Scrum are transparency, inspection and adaptation [14]. EduScrum is an adaptation of Scrum to education. Schools are using Scrum to boost students' learning, in an enjoyable team group way. Application of Scrum is associated with a higher quality of education, better grades and higher motivated students [14]. The applicability of eduScrum is done by pre-defining events, the so-called time-boxed events, to generate

Fig. 2. Flowchart of the eduScrum methodology [12].

a sense of regularity and predictability. Each event in Scrum is an opportunity to inspect and adapt something, which enables critical transparency. The core of eduScrum is the Sprint. A Sprint is a logical set of learning material, designed to accomplish a certain learning goal. The time to execute a Sprint is pre-set, something up to two months, so student teams plan well and manage the complexity of the task. The timetable of the Sprint starts with the Sprint Planning Meeting, followed by the Team Formation. The Student Teams plan their actions independently during the Sprint. Stand ups allow teams to discuss assignments and tasks within the Sprint, at the beginning of each class. The Sprint ends with a review and retrospective, students inspect their final work and enumerate possible ameliorations. In our case-study, we implement eduScrum as follows. We (teacher owner) will propose a list of exercises (input tasks) in the practical classes every two weeks (sprints). Students in class are asked to form groups of 4/5 members each (the team). After forming the groups, students will choose a Student Master, who is responsible for distributing the tasks to each member of the group. This procedure ends with a Sprint Review, where it is performed the sprint assessment. The later consists of 3 components: 1) assessment of tasks performed - usually calculating the weighted average of accepted tasks; 2) activities not accepted have a 0; 3) assessing students' individual contribution by analyzing the team's Scrum board. In the Sprint retrospective students discuss key points of the solved tasks and make a brief report of what went well; what went wrong; what should be improved in the next Sprint. Moreover, students' will be evaluated in two written tests, one approximately in the middle of the semester and one in the end of the semester.

3 Discussion of the results

In this section we highlight the results, interpreting the findings and outlining what they mean. A

questionnaire was done to 48 students attending the course of Differential and Integral Calculus I, at a Bachelor Engineering Degree at ISEP, in the first semester of 2017-2018. Were analyzed the following questions about JigSaw (JGi) and eduScrum (EDSi) methodologies in comparison with traditional method(TMi). Also, some benefits (Soft Skills) linked to the different methodologies were analyzed to emphasized the performance of those methods.

Questions:
Q1: JIG1- In your opinion, does working in groups enhances your learning skills?
Q2: JIG2 - Do you consider Jigsaw a useful learning tool?
Q3: JIG3 - Did you feel more motivated to learn with the Jigsaw methodology?
Q4: EDS1 - In your opinion, can the eduScrum methodology help you to develop soft skills for your future professional life?
Q5: EDS2 - Do you agree with the learning by doing method in the practical classes?

Benefits (Soft Skills):

Eduscrum methodology – EDSM

EDSM1- Communication; EDSM2 -Self-motivation; EDSM3 -Leadership ;
EDSM4 -Responsibility; EDSM5 -Teamwork; EDSM6 -Problem solving
EDSM7 -Ability to work under pressure and time management; EDSM8 -Flexibility
EDSM9 -Negotiation and Conflict resolution

Traditional methods of teaching - TM
TM1- Communication; TM2 -Self-motivation;
TM3 -Leadership; TM4 -Responsibility; TM5 -Teamwork
TM6 -Problem solving; TM7 -Ability to work under pressure and time management
TM8 -Flexibility; TM9 -Negotiation and Conflict resolution

We observe that these 9 soft skills are the same for eduScrum and the Traditional Method. The reasoning for the choice of these skills is as follows. Self-motivation improves team and class dynamics, by helping to build trust between peers and with the teacher. Students are motivated to take responsibility for their own and for their peers' learning. Communication helps to build cohorts (i.e., within majors) by enabling students to really get to know each other in class. The later can translate into more interactions outside class, in departmental and campus activities. Teamwork fosters student engagement through peer-learning and more equal participation in the group, by empowering individual students to share their own 'expertise'.

In the following tables are presented the correlation coefficients and chi-square tests for the results of the questionnaire to the questions above. At bold are marked the significant results. In fact, the correlations between JigSaw and EDSM questions show positive coefficients, against negative coefficients when considering the TM.

Table 1 shows the correlation between Jigsaw and the benefits intrinsic to the Edusrum methodology. In both tables 1,2 variables are related to each other. As an example, in table1,is rejected the null hypothesis with no relationship between JIG1 and EDSM1 (p=0.027) and also between JIG1 and EDSM4 (p=0.006) and EDMS5 (p=0.008). The same conclusion between JIG2 and EDMS2 (p=0.021), EDMS4 (p=0.001) and EDMS6 (p=0.04) were observed. The previous results were supported by chisquare test result as presented in table 2. Although JIG3 in table 2 show some association with more benefits.

Table 3 shows the benefits associated with the Jigsaw methodology. These conclusions are also

	EDSM1	EDSM2	EDSM3	EDSM4	EDSM5	EDSM6	EDSM7	EDSM8	EDSM9
JIG1	0,32	0,13	-0,17	0,39	0,38	0,15	0,14	0,16	0,08
	0,027	*0,382*	*0,253*	***0,006***	***0,008***	*0,321*	*0,329*	*0,27*	*0,599*
JIG2	0,15	0,33	0,05	0,45	0,09	0,3	0,28	0,29	0,2
	0,308	***0,021***	*0,727*	***0,001***	*0,533*	***0,04***	*0,052*	*0,048*	*0,164*
JIG3	0,2	0,32	0,25	0,11	-0,1	0,15	-0,05	-0,03	0,06
	0,811	***0,029***	*0,092*	*0,439*	*0,479*	*0,301*	*0,716*	*0,856*	*0,709*

Tab. 1. Correlations JIG vs EDSM

	EDSM1	EDSM2	EDSM3	EDSM4	EDSM5	EDSM6	EDSM7	EDSM8	EDSM9
JIG1	17,233	18,401	14,549	21,446	22,306	11,900	9,197	11,389	8,139
	0,045	*0,104*	*0,267*	*0,011*	*0,008*	*0,454*	*0,686*	*0,496*	*0,774*
JIG2	16,121	17,461	18,386	17,496	9,906	31,735	36,780	20,594	10,807
	0,186	*0,356*	*0,302*	*0,132*	*0,624*	*0,011*	*0,002*	*0,195*	*0,821*
JIG3	21,538	22,856	22,219	22,300	13,167	34,442	43,109	61,868	34,054
	0,043	*0,118*	*0,136*	*0,034*	*0,357*	*0,005*	*0,000*	*0,000*	*0,005*

Tab. 2. Chisquare tests and p-value JIG vs EDSM

	Benefits
JIG1	EDMS1- Communication
	EDMS4- Responsibility
	EDSM5 -Teamwork
JIG2	EDSM2 -Self-motivation
	EDMS4- Responsibility
	EDSM6 -Problem solving
JIG3	EDSM2 -Self-motivation

Tab. 3. Benefits associated to the Jigsaw methodology

confirmed in the literature [7], [8]. According to Murphy [7], the benefits of communication (EDMS1) in Jigsaw technique "develops communication and teamwork skills". The authors [8] argue that students become more responsible (EDMS4) by helping building cohorts "enabling students to really get to know each other in one class, which can translate to more interactions outside of class in departmental and campus activities", [8] . "Fosters student engagement through peer learning and more equal participation by everyone in the group by empowering individual students to share their own expertise [8], improve teamwork (EDMS5) and self-motivation (EDMS2), facilitating interaction between students [7], to achieve a common goal. Self-motivation is a benefit, also mentioned in other works, as linked with jigsaw technique: "Improves team and class dynamics by helping to build trust", [8]; "Students are motivated to take responsibility for their own and each others", [7]. Problem-solving (EDMS6) and critical thinking are other benefits related with Jigsaw "The students were able to answer questions by critically analyzing their papers" [4].

	TM1	TM2	TM3	TM4	TM5	TM6	TM7	TM8	TM9
JIG1	0,04	-0,04	-0,08	0,07	0,08	-0,09	0,06	-0,09	0,14
	0,8	*0,811*	*0,6*	*0,623*	*0,603*	*0,53*	*0,662*	*0,522*	*0,337*
JIG2	-0,12	-0,2	-0,13	-0,06	-0,08	-0,26	0,09	-0,01	0
	0,421	*0,163*	*0,363*	*0,696*	*0,577*	*0,075*	*0,549*	*0,966*	*0,977*
JIG3	0,18	-0,27	0,25	-0,13	0,13	-0,27	-0,1	0,11	0,06
	0,214	*0,063*	*0,086*	*0,378*	*0,381*	*0,061*	*0,511*	*0,475*	*0,701*

Tab. 4. Correlations JIG vs TM

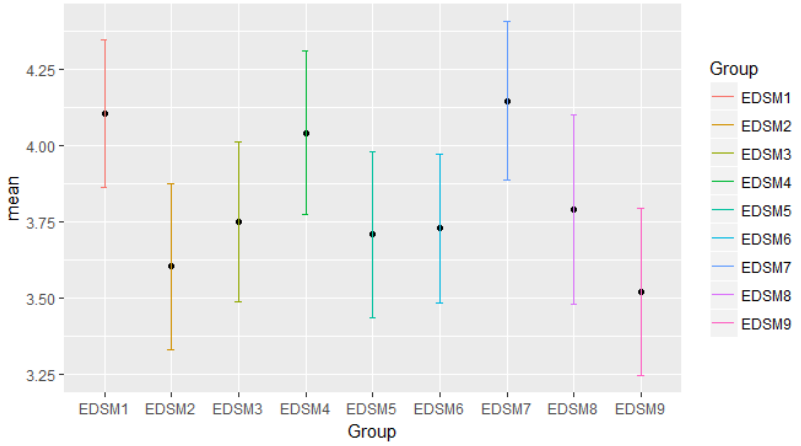

Fig. 3. Eduscrum Methodology

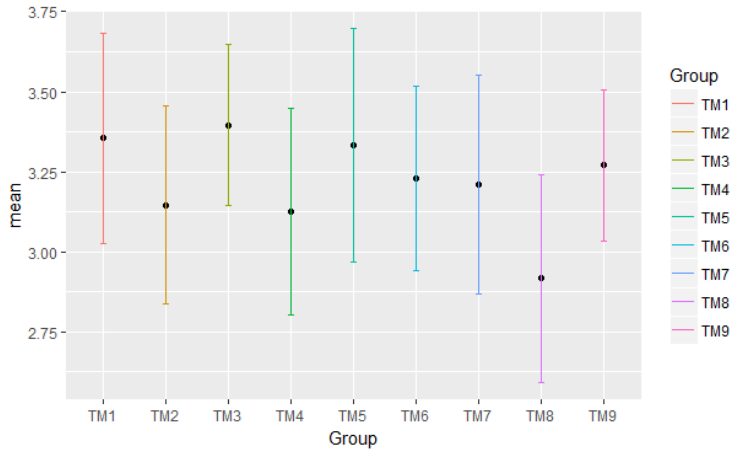

Fig. 4. Traditional Methods

These two figures 3, 4 allow conclude that overall results from traditional methods are below those eduScrum. So, there is a clear that new methodologies promote these skills.

4 Conclusions

In this paper, we focus on some preliminary results of application of Jigsaw and eduScrum in a Bachelor Degree Course at the School of Engineering of the Polytechnic of Porto. The authors presented new teaching-learning methodologies of Mathematics in Engineering Degree courses. We focus on two AL methodologies, namely the eduScrum method [8] and Jigsaw [7]. AL revealed itself useful by helping students to be involved in their knowledge and help them recognize how dynamic a math class could be. Students never felt bored, attending classes till the end, and learning contents happily. According to the results, one could argue, that instead of creating a class of competitive study we contributed to create a cooperative learning math classroom. The students could achieve success by paying attention to their peers (EDMS5 - Teamwork), helping and teaching each other (EDMS5 and EDMS4-Responsibility), they were encouraged to embrace the knowledge from each student around them (EDMS2- Self-Motivation). Also they enjoy a higher sense of ownership themselves (EDMS4-Responsibility) and a greater trust in their peers (EDMS5- Teamwork and EDMS6 - Problem Solving).

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