STRATEGIES FOR THE MATHEMATICS LEARNING IN ENGINEERING CDIO CURRICULA

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ABSTRACT

A marker of success for students in a curriculum of engineering is their performance in the first-year transition. Associated with the CDIO reform in the Faculty of Engineering at the Pontificia Universidad Javeriana (PUJ), strategies focused on supporting students in this transition have been defined. One of these strategies aims to develop mathematical thinking and strengthen students' skills for solving problems through a workshop parallel to the first-year math course. The workshop seeks for students to establish a model of learning mathematics focused on reinforcing basic concepts (numerical, algebraic and variational), building up self-efficacy, developing metacognitive skills, and mathematical abstract thinking. Therefore, this strategy has implied challenges in training and following-up faculty. Results confirm that students recognize the importance of developing mathematical skills for their learning process in engineering. Additionally, the perception of professors supports the hypothesis that students need to reinforce previous concepts from school and develop problem-solving skills to achieve engineering design projects. The workshop has allowed a better adaptation of first-year students to their academic process at university.

KEYWORDS

Engineering, Higher Education, Math Performance, Self-regulated learning, Self-efficacy, Standards 7, 8

INTRODUCTION

In higher education, developing mathematical skills is crucial to succeed in areas as engineering or science. Therefore, self-regulated learning (SRL) and self-efficacy (SE) are essential for mathematics performance. The SRL model is described as a "constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behaviour, guided and constrained by their goals and the contextual features in the environment" (Pintrich, 2000 as cited in Roick & Ringeisen, 2018, p. 148). Bandura (1991) refers that SE influences individual behaviour and determine how students assume challenges and obstacles (as cited in Musso et al., 2019).

In the learning process, students need "a variety of cognitive and behavioural strategies" (Zimmerman, 2000 as cited in Zheng et al., 2020, p. 2). Boerner et al. (2005) and Marsh et al. (2006) mentioned the importance of cognitive strategies to link new information with previous learning and metacognitive strategies to control attitude and motivation as cited in Roick et al. (2018). For the successful application of these strategies, it is necessary to stimulate students' self-efficacy.

In this context, learning strategies might facilitate and build up students' engagement in mathematics. Therefore, it is fundamental to create extracurricular learning spaces for supporting students transition to higher education, particularly, in engineering programs where students require mathematical skills for engineering design.

The Importance of Self-Regulated Learning in Engineering Design

In the field of STEM education, "engineering design requires particular knowledge schema and design processes" (Zheng et al., 2020, p. 2). "An engineering design activity usually involves high-order skills such as observing, modelling, modifying, analyzing, and evaluating a project" (Fan & Yu, 2017 as cited in Zheng et al., 2020, p. 2). The skills above mentioned are based on the self-regulated learning model, where students manage and monitor their learning process using different strategies.

The SRL model proposed by Schmitz and Wiese (2006) consists of three phases: students establish goals for the task in the pre-action phase, recognize and execute cognitive and metacognitive strategies to achieve the previous goals in the action phase, and evaluate outcomes, behaviours and strategies in the post-action phase. In the last phase, as cited by Roick et al. (2018), the feedback influences self-efficacy and determines the plan for the subsequent pre-action phase.

Many researchers affirm that "self-regulation plays an important role in students' efficiency and performance while completing an engineering design project" (Lawanto & Johnson, 2012 as cited in Zheng et al., 2020, p. 2). Based on this, the SRL model is relevant for an engineering learning environment, where students need to gain a variety of skills and learning strategies to cope with their academic performance and educational process.

The Interplay of Motivation and Complexities in Mathematics Learning

For higher education context, mathematics is considered a fundamental subject. In engineering, mathematical skills are needed to build up logical thinking, deal with problem-solving situations and achieve a high performance in other subjects applied to the discipline. Despite its application in engineering, many students experience obstacles and anxiety in their mathematics courses. Low performance in these courses may trigger an academic risk and influence students' motivation.

To overcome those obstacles, motivation is a crucial element in the learning process to engage students and develop autonomy. Motivation has been "classified into intrinsic and extrinsic motivation, with intrinsic motivation referring to doing something because it is inherently interesting or enjoyable and extrinsic motivation referring to doing something because it leads to a reward" (León et al., 2015, p.156).

Engineering students may be motivated to finish their studies for extrinsic reasons such as having a great job or position, but they may understand that mathematics courses are important for their learning and career success (León et al., 2015).

Regarding the effect of motivation in the learning context, engineering programs should be focused on laying out and implementing strategies to enhance students' self-efficacy. Fast et al (2010) have found that students with higher levels of self-efficacy are more likely to achieve a higher math performance (as cited in Musso et al., 2019).

ACADEMIC PERFORMANCE

The academic performance in mathematics has been a concern for the Faculty of Engineering at the PUJ. Some students from advanced courses have experienced difficulties for solving engineering problems. In response, the Faculty of Engineering has focused its efforts on the design and implementation of the basic skills workshop for supporting the students' learning process in mathematics. The workshop is focused on the first-year transition to overcome the obstacles mentioned above since students entered university.

Students' math deficiencies are evident in the State Exam, the entrance test and the math courses performance as described below.

Saber 11 Test

In Colombia, the State Exam for secondary education is the Saber 11 test. This test evaluates five components: mathematics, critical reading, social and civic, science and English. The exam scores each component in different levels, the performance levels for the mathematics component are described in Table 1.

Table 1. Performance levels Saber 11 test

Level	Score	Description
Low	0 – 35	The student reads punctual information but evidences difficulty to integrate different variables and compare data sets.
Intermediate	36 - 50	The student can make comparisons between a variety of data sets in contexts with little information.
High	51 - 70	The student understands information from different types of charts in many contexts, compares data sets with variables and makes algebraic and arithmetic transformations.
Very High	71 – 100	The student solves problems applying probability, trigonometry, functions and algebraic properties concepts.

The results in the mathematics component are presented in Figure 1. According to the classification in Table 3, the 51% of students have a high performance and the remaining 49% of students are classified on average at a very high level of performance.

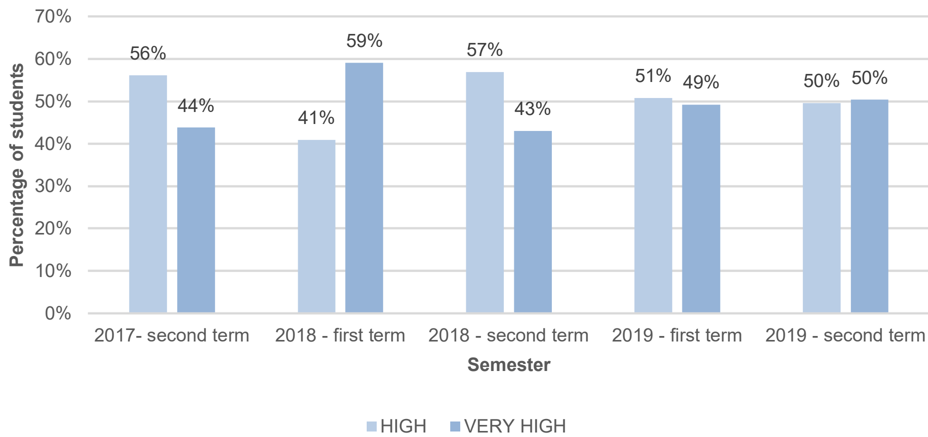

Figure 1. Historical Math Performance of Saber 11 test

Although the results seem to be satisfactory, the students present serious difficulties in addressing mathematical and numerical concepts. As shown in Figure 1, the historical performance in mathematics of first-year students has been similar.

Entrance Test

The entrance test for engineering programs at the PUJ has been applied since the second term of 2017. The test is composed of 30 questions divided into three components: numerical (7 questions), variational (9 questions) and algebraic (14 questions). The historical performance in the entrance test is presented in Figure 2.

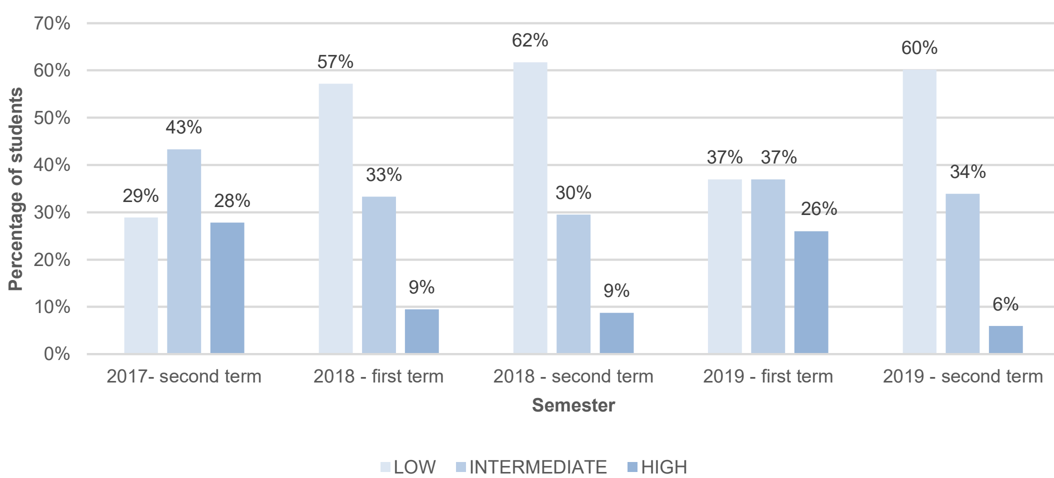

Figure 2. Historical Performance of Entrance test

Most students underperform, and only 16% of students have a high performance on average. These results evidence that students need to strengthen basic concepts and develop skills to enhance mathematical thinking.

Math Course Performance

For many engineering students, calculus is one of the most difficult courses in their academic field. This is evident in the high rate of students that fail mathematics subjects. In engineering programs, the rate for first-semester math course failures is 25% on average, and the early dropout rate (first-year transition) varies between 20% and 30% of the students.

As shown in Figure 3, the highest rates of failure were presented in 2018. For the last two terms, the rate decreased and the behaviour is similar.

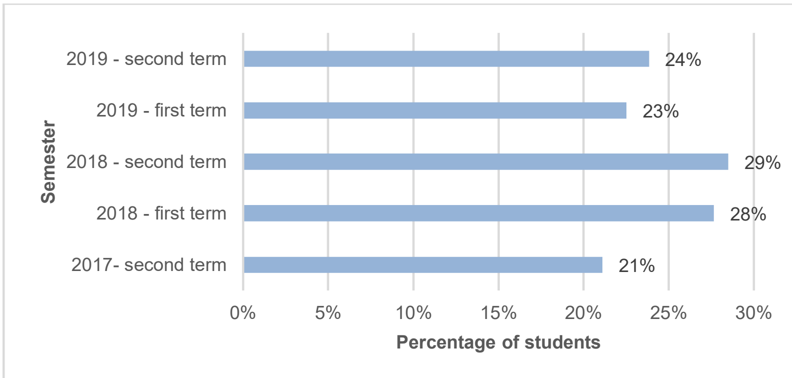

Figure 3. Historical Performance of math courses

These results evidence that students need learning spaces to develop skills and strengthen their previous knowledge from school to succeed in mathematics. Therefore, ensuring student success becomes a priority for the Faculty of Engineering.

STRATEGY FOR DEVELOPING MATHEMATICAL THINKING

The CDIO Initiative

In engineering education context, the CDIO framework provides the guidelines to improve the quality of engineering. Students may build up skills to overcome discipline challenges and program goals through the different transitions.

In response, the Faculty of Engineering has been working in the development and deployment of strategies to support the students' learning process. Furthermore, those strategies aim to reinforce students' self-efficacy and promote autonomy. To facilitate the learning process, the program should make efforts to increase intrinsic motivation in students. Students may recognize the importance of developing skills and applying cognitive and metacognitive strategies for their educational process in an engineering environment. In this context, students articulate knowledge, skills and abilities for developing engineering design projects (CDIO STANDARD 7).

For supporting the learning process in mathematics, the Faculty designed a basic skills workshop. This initiative is based on active learning, where students face problem-solving situations applied to their discipline, and working individually and team working (CDIO

STANDARD 8). Additionally, the workshop activities involve strategies for time management and autonomous learning.

Basic Skills Workshop

The workshop is an extracurricular learning space that accompanies all first semester students for developing mathematical thinking and reinforce previous math concepts learned in high school. The workshop approach is to build up self-efficacy and encourage students to assume new challenges in mathematics.

The learning environment at school is widely different at university, students have to assume new responsibilities, modify their habits, manage the time between academic and non-academic activities, prioritize tasks, build networks with peers and adapt to the exigency and complexity demanded by the university. In the adaptation process, students need tools and strategies to cope with new experiences and situations.

The strategy has been implemented since the second term of 2017 and adjustments have been made to the structure according to students' needs and teachers' perception and feedback. At the beginning, the workshop was focused on levelling out math deficiencies according to the entrance test performance. However, this methodology was not well-founded since students need to develop mathematical thinking skills for engineering design. Nowadays, the workshop is articulated with the first-semester math course, this strategy has increased students' motivation and changed their attitudes towards learning mathematics.

The workshop is divided into two modules; an intensive course and an extensive course. The intensive course aims to level students in fundamental concepts and takes 4 hours per week during the first three weeks. In the extensive course, tools are provided for strengthening the learning process in math involving aspects as management time, teamwork, study habits, autonomous learning and perception of math. The extensive module has an intensity of 2 hours per week after the third week and lasts through the end of the term.

The methodology deployed is based on the key factors of the Singapore math method: concepts, skills, processes, attitudes and metacognition. Integrating these components leads students to become active agents of their learning process, which means that they can develop skills and apply the strategies for solving abstract and real mathematical problems. The key factors are described in Table 2.

Table 2. Key factors of the Singapore math method

Component	Description
Concepts	Mathematical knowledge in different areas: numbers, geometry, algebra, statistics and probability, and data analysis.
Skills	Skills to understand procedures and apply them to problem-solving.
Processes	A variety of abilities that build up students' mathematical thinking.
Attitudes	Attitude towards mathematics learning, influenced by academic and non-academic experiences.
Metacognition	Ability to recognize thinking processes during the learning process.

Furthermore, the implementation process required teacher training and continuous feedback from students and professors to adjust the activities according to their needs.

Strategy Results and Feedback

The evaluation process was conducted by applying a perception questionnaire at the end of the workshop. This instrument evaluated different aspects: metacognition and study habits (Huertas, Vesga, & Galindo, 2014), time management (García & Pérez, 2012), team working (Ku, Tseng, & Akarasriworn, 2013), note-taking (Martínez & Pantevis, 2010), attitude toward mathematics (Aiken, 1974). The aspects above mentioned were assessed with scales proposed and validated by previous authors.

The questionnaire was applied to all the students enrolled in the workshop ($N = 340$) using an online survey tool, achieving a sample of 76 students. The main results of each scale are presented below.

Metacognition

90% of students are conscious about the weaknesses and strengths of their reasoning ability. 84% of the students consider that having prior knowledge about a topic facilitates their learning process. The 10% of students recognize deficiencies in organizing information and they do not question themselves about the different strategies for problem-solving.

Study Habits

24% of students do not use diagrams or outlines to structure information when they are studying. The majority of the students, around the 83%, ask someone when they do not understand a topic, they do not try to search for information or use their resources.

Time Management

50% of students assure that they do not well manage their time. 41% of the students do not define priorities to achieve their academic tasks and 45% of the students do not set deadlines.

Team Working

The majority of the students, more than the 60%, consider that team working is a useful practice for their learning process. Although they believe that working individually is more effective than teamwork, their performance is higher.

Note-Taking

92% of students assure that they usually take notes in class. However, 67% of the students do not often review their notes at home.

Enjoyment and Value of Mathematics

The 84% of students consider that studying mathematics is pleasant, they recognize that strengthen their skills is a priority as well as gaining knowledge in this area. Students value mathematics, they assure that is an essential subject for different disciplines. 72% of the students acknowledge that mathematics is not only memorizing concepts or formulating.

The results evidence that students need to enhance and develop skills focused on mathematics and other aspects as metacognition, time management, study habits, etc. to overcome challenges that their discipline demands.

Students recognize the usefulness of the workshop for reinforcing previous concepts, developing skills and mathematical thinking. They consider that the activities are well-designed. However, adjustments may be implemented in the methodology to enhance students' motivation and commitment.

On the other hand, teachers recognize that most of the students have difficulties to focus and develop activities when they work individually. Additionally, students prefer solving problems without using technological tools such as a scientific calculator because they ignore how to use them. Teachers value activities related to engineering problems to build up students' self-efficacy on mathematics performance.

CONCLUSIONS

The learning process is influenced by different variables in the education context. Enhancing self-regulated learning strategies foster self-efficacy beliefs that impact students' performance. In engineering, it is important to engage students in new learning spaces for developing skills needed to overcome discipline challenges.

The workshop has been a rewarding experience for teachers and students, because both of them have gained skills for a better process of teaching and learning. During this process, it has been identified the need of training continuously teachers in learning strategies and recognize its application in the academic field. Furthermore, the profile and competences of the professor must be defined to ensure the deployment of the strategy.

The strategies to improve students' mathematical learning must be design between the Faculty of Engineering and the Department of Mathematics, to consolidate efforts and enhance the workshops' implementation and following up.

For future research, the evaluation scales must be assessed at the beginning and end of the workshop to evidence improvement in students’ skills.

The CDIO framework is an essential element for continuous improvement in the engineering programs. In this context, articulating the curricula and active learning spaces is a strategic goal.

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