Engagement in Practice: Co-creation process in higher education contexts to innovate in Pre-calculus curriculum

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Abstract

In Colombia, Engineering Education faces some significant challenges. According to the 'Dropout Prevention and Analysis System' of the Ministry of Education, only 28% of engineering students complete their studies and graduate, and the national dropout rate for first-semester students in engineering programs is around 25%. According to the Ministry of Education, one of the reasons is related to students failing Pre-calculus courses more than once, caused probably by math competences low level upon university admission, low motivation for this subject and disconnection with real context problems. OCDE 2015 report explains this fact since it states that high school students in Colombia score 390 points in mathematics below the OECD, Chile (423 points) and Mexico (408 points) average in the PISA[1] test. To design and implement a possible solution to this challenge, a team of researchers from 'Corporación Universitaria Minuto de Dios-UNIMINUTO, created a robotics curriculum adapted to the pre-calculus mandatory course, through a co-creation process, in which teachers, researchers, and students participated. As result of this process, ten context-oriented and challenge-based didactic guides were created using robotics, mathematics, realistic problems and XXI century skills. Furthermore, teachers and students' perception changed positively, and students using the new curriculum were found to have much better completion rates in their pre-calculus course. This article presents a community engagement model to design and implement engineering education curriculums, where the engagement of multiple parties for problem identification and solution development, that could help students to obtain better math results.

1. Motivations to change educational practices

One of the most significant challenges of education in Colombia is the low scores in standardized tests which measure the competencies of students in Mid School and High School (3rd, 5th, 9thand 11th grades) in science, mathematics, and language. Even that this situation is present in schools from any context, unfortunately, the problem is worst in low-income social sectors, because of the presence of multiple socio-cultural variables that affect learning.

Several efforts have been made at the institutional, local, regional and national levels to change this reality, including curricular reforms, teacher training programs and promotion of innovative strategies, among others. However, the complexity of the educational field limits the possibility to obtain rapidly demonstrable results. Consequently, the situation still is an amount of often uncoordinated actions, wasted efforts and frustrations from the teachers and institutions.

Teachers necessarily question themselves about these results. Although the PISA test performances are just one result indicator of a learning process, it is also a symptom of problems to be solved. A diverse series of concerns regarding students' motivation for learning, the relevance of teaching, the knowledge and the skills demanded by society, and

[1] The Program for International Student Assessment (PISA) is a triennial international survey which aims to evaluate education systems worldwide by testing the skills and knowledge of 15-year-old students. (http://www.oecd.org/pisa/aboutpisa/)

recognition offered to teachers' profession are part of the situation.

The facts explained above shows the need to change described conditions in education and motivates innovation in engineering education. They emerge in the midst of what we might call the crisis of the system, and although favorable, they still result of individual efforts. Even that the educational field is a community-based scenario, it suffers from an essential lack of capacity to build collectively. Students need increase with the accelerated changes of society, teachers' efforts dissipate before the impotence that low results generate. All this adds up to the fact that researchers frequently made contributions from very distant places to where most urgent needs.

'Corporación Universitaria Minuto de Dios-UNIMINUTO is a higher education institution, whose mission is to provide quality education and serve populations of the lowest socio-economic level. This institutional mission implies that an important percentage of students have specific characteristics, including low academic level in mathematics and language skills. That is the case of engineering students, who have several courses in basic sciences as part of their academic curriculum. The course called 'Pre-calculus' is part of the curriculum of all engineering programs, and it registers low performance and high dropout rates (40% in average[2]). The course's teachers express their constant concern for low academic results and high student de-motivation towards the subject, their previous experiences with mathematics in primary and secondary education.

These motivations led a team of researchers from UNIMINUTO's Social Innovation Science Park (PCIS[3]), to design and implement the project described in this document. Inspired in a previous K12 experience based on a STEM[4] Robotics program, which developed mathematics and 21st-century skills in more than 2,000 middle school and high school students, the team conceived a project to create a solution through engaging the community involved in a higher education context.

2. Work related to mathematics education through robotics in higher education contexts

Recent research shows the results of introducing robotics into math curriculum in higher education. For an exhaustive review see the systematic work of Toh, L. P. E., Causo, A., Tzuo, P. W., Chen, I. M., & Yeo, S. H. (2016). The study of Hoying et al., (2017) focused on how to generate enthusiasm for mathematics using robotics, through three elements: (1) assessing preexisting notions of math and robotics, (2) introducing an educational module to highlight the connection between robotics and mathematics, and (3) evaluating the students' new opinions of mathematics and robotics. The study showed that there was a significant improvement in the students' understanding of the concepts of mathematics as well as enjoyment and appreciation, within the field of robotics as a result of the educational module.

[2] Internal reports from UNIMINUTO.
[3] PCIS (acronyms of Social Innovation Science Park in Spanish Parque Científico de Innovación Social)
[4] Science, Technology, Engineering and Mathematics - STEM.

Regarding the use of realistic problems in math education, the work of Shankar, Ploger, Nemeth, and Alan (2013) consisted on the design of a course dedicated to enhancing students interest in engineering and math while providing a social context of competition and cooperation. Results showed that bringing engineering technology into the mathematics classroom can help students understand the subject matter more deeply than in traditional mathematics instruction and when designing curriculum, a need to connect the math instruction and practices to real life content exists. Robots can enable them to visualize the results of varying assumptions, explore consequences, and compare predictions with data while making mathematical models.

In another study, Silk and Schunn (2008) which investigates the use of engineering as a context to learn mathematics through an evaluation of a LEGO-based robotics curriculum. This study is relevant because it presents the curriculum analysis and change made to incorporate robotics, obtaining that engineering design projects are often about satisfying human needs and finding solutions to human problems and that's why they are inherently motivating for students. However, additional supports are required to efficiently enable students' competencies related to the more general mathematical ideas.

Previous studies helped to understand the importance given in engineering and mathematics education to enhance students' motivation. They also showed the need to innovate in the curriculum and to bring into real-life problems to class activities. One of the main challenges was to articulate math contents which students should learn, according to the industry requirements and those indicated by Colombian Government standards.

3. A strategy identified to reduce social gaps and improve learning results

Since 2014, the Social Innovation Science Park of UNIMINUTO, developed a STEM Robotics program partnering with i-Carnegie (now Robomatter Inc., a spin-off of Carnegie Mellon University), through a project carried out in eight rural schools in Colombia, which benefited more than 2,000 middle school and high school students through three years. The project included the training of local teachers, the adaptation to the Colombian context methodology and of a set of guides, and the implementation monitoring during three years. The main results of this process were the increase in motivation for learning of the students and the development of hard and soft skills by both high school students and teachers[5].

The results of this previous experience led to investigate STEM education [1] – [4], [5] around the world. The research showed that among the principal motivations identified for STEM programs are the needs to achieve: i) Development of students' competencies in these areas. ii) Strengthening 21st-century skills; iii) Including a pedagogical perspective of active learning, based on the design and exploration of challenges; iv) teaching teamwork, roles, and responsibilities; v) construction of knowledge centered on the student. [6] – [9]

[5] STEM ROBOTICS is an original program from the Robotics Institute of Carnegie Mellon University developed in Colombia from 2014 to 2016 as part of an inter-agency agreement between this institution and the Social Innovation Science Park of UNIMINUTO.

As a result of that exploration, STEM Robotics model at UNIMINUTO presented an opportunity to address an institutional problem associated with the low academic performance of students at the pre-calculus course, and the possibility of designing a program for higher education that would gather some of the learning up to now.

4. Project design and execution

As described before, low performances in math results are a problem faced by Colombian educational system. UNIMINUTO, a higher education institution of Colombia was the most suitable place for this research because its mission to help low-income students and its high dropout levels. In UNIMINUTO, pre-calculus courses during the four last years have registered an average of 29% dropout rate. Some basic sciences teachers of the institution were invited to work with the STEM Robotics team, to use the results and learning of the programs and projects developed in other contexts previously. And this is how the research project began.

The team of pre-calculus teachers coincided in recognizing in the project an opportunity to address their concerns, interests, and needs facing any innovation process, highlighting the educational level of their students, de-motivation for the subject and the urgent need to do something different.

The project pretended to involve several agents, such as researchers, students, and teachers. Thus, based on UNIMINUTO experience, the project was designed to use the community-engaged methodology [10] shown in Figure 1, in response to the need to co-create knowledge and generate a social and cultural change of a pedagogical nature.

Figure 1: Community – Engaged Scholarship [10]

The project used a community-engaged methodology. This process consisted in knowing community-driven priorities of agents involved in this case, this is, six pre-calculus teachers[6], a group of twenty students taking the course, five students who took the course in

[6] UNIMINUTO has several campuses around the country. In this project, participated teachers from the Main

the past and three researchers of the STEM program (co-authors of this paper). Based on the importance of involving all the agents, research questions were co-constructed, research was designed and developed jointly by all participants, results were analyzed and interpreted in team sessions, involved parties disseminated knowledge obtained and identify future studies. Every step implied the engagement of involved agents, as it is described below:

4.1 Co-constructing the research question

A series of meetings with basic sciences teachers led us to identify the problem of low academic performance in the pre-calculus subject, possibly motivated by low levels of students' math competence resulting from their high school education, lack of educational strategies, knowledge, and skills relevant to the context. On the other hand, students who had already studied the subject were interviewed, identifying lack of motivation due to the absence of innovative elements in the classes, because they do not find utility or meaning in what they are learning and, in general, because it does not seem to be an interesting subject.

The efforts of the research team focused on demonstrating whether a didactic strategy that had been successful with students and teachers at high school level would have positive results in higher education. The team constructed the research question under the principle of shared equitable decision-making resulting in ¿How does the implementation of a co-created educational strategy based on using robotics affect results in a pre-calculus course?

4.2 Constructing Knowledge together: conducting research.

The research team collected data through interviews, videos and observation diaries. They conducted interviews with students taking the course for the first time (one at the beginning, and the second at the end of the course), and the six Basic Science teachers. Students used an engineering journal that stored a set of guides constructed by teachers.

Interviews looked for collecting needs and ideas from involved agents about math contents, real-life problems, possible connections with context. Researchers analyzed the emerging categories from interviews and compared them to pre-calculus curriculum. Based on these findings, the team identified context-based challenges, math contents and skills were selected and distributed in ten guides where used robotics to contextualize the concepts of mathematics with the real world.

The co-construction process was carried out around the design and utilization of these ten guides, starting from a training exercise constituted by the fundamental elements of STEM education registered in the literature and by the results of previous learning and experiences and experiences of researchers and teachers. Guides contained a challenge of the regional context (for example, problems inside the Salt Cathedral of Zipaquirá, a famous tourist spot), the curricular skills required, the contents needed to solve the challenge and some mandatory class exercises to implement with the robot. Robots were used to introduce engineering concepts which help to bring real problems to Pre-calculus class as a tool for challenging students and fostering group work, critical thinking, and problem-solving skills.

Campus, located in Bogota-Colombia.

The team structured guides, each one including four phases: i) presentation of a problem in the Colombian context (challenge); ii) mathematical and robotic concepts taking elements from phase I; iii) solution of the challenge using the mathematical concepts of phase II; iv) evaluation.

Students were again involved in the process in the guides review process done by the team of researchers and implemented in the classes. At the end of each session, teachers interviewed students to know what they liked, what they did not understand and what they had realized. With this feedback, teachers adjusted the guides.

The team supported the construction of the guides, analyzing and applying the factors that favored the students' learning and the teaching processes. The students also participated in discussing with other students who took the pre-calculus course in previous semesters, and also reviewed the guides to contribute from their experience in its improvement.

This experience was carried out with two student groups, which was guided by a teacher; One group used the STEM pre-calculation methodology, and the other was the control group for research purposes. The characteristics of the students of both groups were similar in age, social conditions and engineering programs they were studying.

4.3 Results analysis: an educational innovation created by a community engaged

During the first semester of 2017, the team implemented this research project. In the sample, 46 students participated in the two courses, as a result of the exercise, the team evidenced that the dropout from the pre-calculus course class that participated in this program was 0%, while for the control group was 15%. Dropout rate average during the semester of the research was of 20% in UNIMINUTO. According to the survey applied to the students, it showed that the program generates positive emotions, and motivates them to put into practice the theoretical concepts by implementing the robotics challenges. Students also recognized how mathematical concepts transcend the classroom and contribute to societal challenges. Videos taken during the classes registered higher participation of students in activities and increased communication behaviors compared to the control group.

Regarding teaching, the significant results include the improvement of the attitude of the student. The co-creation process, involving students and researchers, challenged them to guarantee relevance in both the disciplinary and the real sector contents, teamwork, and acceptance of others opinions. The interviews recorded with teachers, registered a change of attitude regarding the development of their class, as a consequence of the dynamic activities of the course. Also, the permanent connection between teachers and students focused on teaching but also in understanding the points needed to build and improve the class guides together.

The results of the project were evidenced, through a diagnostic test performed at the beginning and end of the semester, where it shows that the percentage of students who approve the test increased in six percent (Table 1).

Table 1. Performance results of students taking the implemented pre-calculus course

GROUP	PASSED	FAILED
STEM	36%	64%
CONTROL	42%	58%

Researchers were able to contrast results presented in the literature with their observations of the project implementation. Additionally, they demonstrated the effect of the teachers training when put into practice. They understood the needs in context and contributed directly to the solutions; also, they showed the importance of co-researching, demonstrating the idea that researchers are the one who has the answer and the other participants are merely objects of investigation, is a common mistake. In this case, all participants including researchers were participants in the investigation process.

The educative innovation consisted in a co-construction process in which the community involved participated actively, generating a teaching resource that helps to respond to student, teacher and researcher expectations, and designing a better engineering education course. Literature demonstrated the success of STEM programs and projects in diverse contexts, both in the development of competences of STEM disciplines and in 21st-century competencies. This particular project must continue evolving to demonstrate its capacity to transform math results. However, it has empirically evidenced a critical opportunity to improve engineering education rates, not only in dropout rates and standard tests performance but in generating capacities of engineering students to face real-life challenges and necessities.

5. Knowledge diffusion and future challenges

The team of Social Innovation Science Park currently is working on the publication of the guides and the results produced by this project, so the teachers of UNIMINUTO, which serves more than 120,000 students throughout Colombia,[7] can use them. Additionally, the team is working on teacher training a model, for the development of STEM competencies, and it will be delivered through a short course for higher education teachers, as a result of the research results obtained from this experience.

Future studies will focus on applying the strategy presented in this article, to other science and mathematics courses, to analyze the results obtained regarding skills development and to identify different possible approaches, other than robotics, which can contribute to improve engineering students results in their academic programs and to reduce the dropout rate.

It is also important to highlight the process of co-creation of knowledge developed in this research, which demonstrates the pedagogical potential of establishing collaborative, reciprocal relationships, where all those involved become co-learners, co-educators, and co-generators of knowledge [10]. Therefore, it is necessary to continue the research in the factors that allow obtaining different results and continue gathering evidence that can contribute to an improvement of education's quality in our country and respond to the needs

[7] UNIMINUTO is currently partnering with other institutions and has just opened the IUTEA Higher Education Institute in Ivory Coast.

that motivated this innovation process.

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