SOLVING PROBLEMS USING THE ENGINEERING DESIGN PROCESS THROUGH A STEAM PERSPECTIVE

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Abstract

International recommendations emphasize the importance of STEAM education in preparing students to deal with new and complex social, economic and environmental challenges. The approach to STEAM education can involve the use of engineering design, starting from problems of reality that enable the articulated mobilization of concepts from various disciplinary areas, promoting interdisciplinary, where teamwork and context play a fundamental role. We report a study, with future teachers of elementary education, which aims to understand and characterize the learning and reactions underlying the use of engineering design in solving problems of a STEAM nature. The participants worked in small groups to solve problems that involved the application of design/redesign processes, mainly based on knowledge of mathematics and physical sciences. A qualitative methodology was adopted and data were collected through observation, collection of documents, artefacts and photographic records. Preliminary results show that the participants valued the experience, having had the opportunity to solve reality problems collaboratively, mobilizing concepts of mathematics and physical sciences in an integrated way. The participants showed great engagement, persistence and motivation in solving the proposed problem, being able to create a model that fulfilled the requested conditions. From the participants' point of view, this approach constituted an opportunity to favour the establishment of connections between different disciplinary areas. Difficulties were detected in the identification of some concepts from mathematics and physical sciences and in the mobilization of adequate scientific language in explaining the reasoning underlying their decisions.

Keywords: Engineering design, Mathematics, Sciences, STEAM Education; Elementary teacher training.

1 INTRODUCTION

The world is constantly changing, demanding that the next generations have to face new and complex social, economic and environmental challenges. The relevance of routine tasks therefore continues to decline, while problem solving, teamwork and communication deserve increasing attention in today's society. Thus, people are no longer rewarded just for what they know, but for what they can do with what they know [1]. In this sense, there are several international recommendations, [2], [3], [4] that refer that the school should develop in students' skills in line with the previously described guidelines, such as the skills to be creative, think critically, solve problems and make decisions, [1], known as the 4 C's skills. In addition, there should still be a concern for students to work as a team, in order to communicate and collaborate with greater dexterity. In this scenario, effective teaching must involve the student in meaningful learning, through the implementation of individual and collaborative experiences that promote the abovementioned skills [3], [5], [6], [7].

The predominant use of routine tasks is still a common practice in many countries and by many teachers, who devalue the 4 C's skills in today's society. So, the STEAM approach emerging in the context of active learning and the establishment of connections, where the use of challenging problems in authentic contexts are open to multiple approaches and solutions, encourages the 4C's skills which are often lacking in more traditional classes. In particular, engineering-based tasks' solutions provide a rich source of meaningful situations that capitalize on and extend students' learning where the engineering design serves as a rich source of attracting authentic contexts that trace on school mathematics, science, and technology. By integrating these tasks into the curricula, students have the opportunity to see the usefulness of what they learn in school about math and science when solving problems in the world outside of school.

In this context, it is essential to develop practices which are sustainable and produce the desired learning outcomes for students as well as for teacher educators. This paper reports a study carried out with future elementary teachers (6-12 years old) where we were interested to understand and characterize the

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learning and reactions underlying the use of engineering design in solving authentic problems of a STEAM nature. In particular, we are interested in the performance of future elementary school teachers (6-12 years old) along this learning experience, based on solving a STEAM problem, following engineering design processes, identifying the main difficulties and the main contents mobilized to solve this problem.

2 THEORETICAL FRAMEWORK

The next two sections frame our study through a theoretical point of view. We briefly describe the need for an active learning and an interdisciplinary approach through the STEAM perspective, with the focus on the engineering approach.

2.1 An active learning approach

There are significant societal and economic changes and challenges that we are being faced across the world due to the rapid level of technological innovation, a development that is altering the economic and social support of our lives. These changes have had significant impact in the labour market and education. Students no longer can face this new world through instructions focused only on routine skills and routine ideas and procedures. Much of failures in school mathematics has its origin in the affective environment and the degree of challenge created in the classroom, a fact that can seriously compromise students' initial expectations and motivations in relation to school subjects and its role/importance [8], so we have to propose an environment that reverses this situation. We need an exploratory classroom where we use an inquiry-based learning approach, a term that refers to classroom practices in which students understand, pose questions, explore and discuss [9]. This type of classroom is focused on learning; students learn by doing, understanding, analysing, and discussing multiple approaches when solving a task. The role of the teacher is more demanding, where the instructional strategies and the tasks selected are fundamental to attend that initial goal. In this context, active learning arises, generally defined as an instructional method that involves students in the learning process [10], [11]. Active learning has its roots in socio-constructivist learning theory and advocates a classroom practice that engages students in activities such as talking, listening, reading, writing, discussing, reflecting on content through problem solving, in small groups, through simulations or other activities. It requires the engagement of students in meaningful activities that think about what they are doing, being constantly challenged for learning. The focus is entirely on the students and the activity developed, as opposed to the more traditional approach in which they are limited to passively accessing the information transmitted by the teacher. For this, it is necessary that they solve meaningful tasks, the learning of mathematics must include diversified tasks that go beyond routine tasks, focusing particularly on problem solving. It is sought that students internalize a set of strategies that allow them to expand their repertoire and become increasingly competent in mathematics “with” the approach to problem solving [12], [13]. Tasks with multiple resolutions and involving authentic problems in real contexts are privileged.

In the scope of active learning grounded in inquiry-based learning approach, we include an intellectual (cognitive) dimension, as in problem solving tasks, in which students must explain and justify their reasoning. However, in addition to these tasks with an intellectual (cognitive) nature it is also important in this context those that arise from social and physical activities. That is, the intellectual involvement may not be enough, learning needs a social component where students confront ideas, allowing them to work collaboratively is a significant aspect of classrooms where the role of communication and mathematical discussion stands out. This type of collaboration facilitates the sharing and development of mathematical meanings, and it is up to the teacher to foster a sense of community so that students feel safe and confident to take risks and express their ideas, either between peers or with the teacher [10], [13], [14]. The other component to add to this discussion is the movement. Learning requires movement, as an active body incites the brain, making students more engaged, allowing them to be attentive, improve comprehension and memorization which contributes to a better performance [15]. Students, especially the youngest, need to be physically active in the classroom, which can be solved with the use of instructional active strategies as hands-on projects, lab experiments, manipulatives, building models, math trails or gallery walks, that also facilitate interactions.

2.2 An approach to STEAM education - The engineering design

Another aspect that contributes to the failure and lack of motivation from students towards school and certain subjects is related to the approach of isolated themes/contents, without articulation, whether intra or inter-subject. An idea or concept is better comprehended if one understands how it relates or connects with other ideas or concepts that are already known [16], so interdisciplinarity and collaborative practices play a fundamental role in giving meaning to what students learn. Traditional classes have been losing space to a more dynamic model, where the STEAM (Science, Technology, Engineering, Arts and Mathematics) approach emerge in the context of active learning and the establishment of connections. STEAM education should not only involve teaching these core subjects and contents in isolation, but an interdisciplinary approach instead, building on content knowledge developed within and across these disciplines.

STEAM education may be guided by the adoption of different models: the approach of each area in isolation; STEAM as a discipline; STEAM approach through Mathematics; STEAM approach through Science; STEAM through Engineering Design. Knowing the schools' reality and the organization of curricula, it is considered that the approach through a classic subject of the curriculum is easier to implement by teachers, either in primary education of in upper levels. Since Mathematics and Science are traditional subjects of the school curriculum, it is natural that teachers find it easier to use STEAM education having one of these subjects as a starting point rather than embarking on a STEAM program per se, since in many countries STEAM does not exist in the curricular matrix. Students' poor achievement in math and sciences, particularly in problem solving and inquiry tasks is an issue of great concern for many countries across Europe, which may prevent them from making certain career choices, directly related to those subjects (for example engineering professions). These results can be, in many cases, related to the use of routine tasks, frequently deprived of meaning. In particular, Mathematics Education argues that it is necessary to work on mathematics in an integrated and interdisciplinary way. We endorse the ideas of Martín-Páez et al, [17], that defend for STE(A)M learning the integration of conceptual, procedural and attitudinal contents through a group of STEM skills for the application of ideas or the solving of interdisciplinary problems in real contexts. In this perspective we advocate STEAM education as a teaching approach in which students build and demonstrate understanding and/or knowledge through involvement in an engineering design process in which Science, Technology, Engineering, Arts and Mathematics work together.

We consider that engineering design is an approach that promotes a bridge between math and science concepts, as well as arts, starting from problems from the real word that foster creativity, collaboration, decision-making, critical thinking, communication and reasoning, promoting a natural STEAM integration. There are several frameworks for engineering design, but it is consensual that it is a cyclic process, composed of steps, leading to the achievement of a certain objective. The most know is the Cunningham e Hester [18]. that is composed by seven-steps: ask (define the problem/identify the constraints); imagine (brainstorm ideas/choose the best one); plan (draw a sketch); create (follow the plan and test it); test and evaluate; improve/redesign; and share solutions. Based is some authors, [19], [20], we adapted the design process of Cunningham and Hester [18], (Fig. 1) changing some of the names of the steps proposed, in order to make the cyclical process clearer, after testing and evaluating the prototype, we may need to improve it or, in the worst case, retake the redesign process.

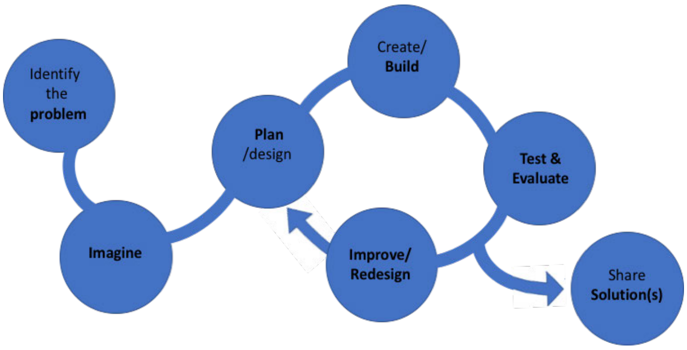

Figure 1. Engineering Design Process steps (adapted from Cunningham and Hester [18])

Engineering design activities may be an opportunity for interdisciplinary learning [18], giving new meaning to math and science concepts, facilitating the integration of Arts and Technology; it also opens a pathway to engineering, for boys and girls, particularly if it is used in the early years of schooling, and also contributes for engage students in mathematics mostly because we are math educators. Teachers are the driven force for this change to occur, so we believe that teachers need to develop their abilities, through training, to make in the future a difference with their own students' development.

3 METHODOLOGY AND RESULTS

In this manuscript we describe a particular study that aims to understand and characterize the learning and reactions of future elementary school teachers (6-12 years old), in a learning experience based on solving a STEAM problem, following the engineering design cycle (ED), identifying the main difficulties and the main contents mobilized. To conduct this research, we followed an exploratory qualitative methodology [21]. The participants were forty-five future teachers enrolled in an Undergraduate Course in Primary Education (6-12 years old) that attended a curricular unit of Integrated Mathematics, in the scope of the didactics of mathematics, during a module about problem solving, where we proposed an authentic problem, the Paper Table Problem (Fig. 2).

The problem:
The paper table
Build a table strong enough to support a heavy book. The table top should be about 21x28 cm (A4) and the table legs will be made of paper and should be approximately 20 cm long.

Figure 2. The Paper Table Problem

The students worked in groups of 3/4 elements during two classes in a total of four hours. To solve the problem, they had some materials: one sheet of cardboard (for the table top); eight publicity leaflets; one masking tape; a heavy book; and a white sheet of paper (A3). They did not have access to more materials, even if they needed. Data was collected in a holistic, descriptive and interpretative way and included: classroom observations; all the written documents, that included individual records and the poster with the synthesis of the ED; artefacts (prototype of the table); and photos.

To achieve the solution of the problem they had to follow the ED model (Fig. 1) and they could only construct the prototype, after making a sketch of the table they decided to do within the group. After the table construction, they had to create a poster explaining all the work developed to reach the solution, characterizing each phase of the ED cycle, including their difficulties, and identifying the main concepts, ideas, procedures of mathematics and physical sciences. We analysed all the data through three main categories of analysis- mathematics and physical sciences knowledge, main difficulties related to the table construction and related to the use of the ED cycle, and reactions to the experience.

We present some photos (Fig. 3) of the work developed by the students during the implementation of the ED cycle. All the students accepted the challenge with some doubts in the beginning of the process, because they had never solved a task of this nature and had some resistance to use the ED cycle. After overcoming some of the initial difficulties, they began to identify the type of table they could construct. These steps took some time to decide what to do (Fig. 3).

Figure 3. Students' work through the steps 1-2-3 of ED

Students began to look for the paper that would be used in the construction of the table's legs. They made many attempts - some rolled the paper to make tubes (cylinders) and others chose to do wider tubes; other groups opted to construct solids, mainly prisms; they used the tape to tie the paper and confirmed the length of the legs. Then after getting these elements ready, the groups began to use them as isolated legs or joined some of them to get some structures to support the top of the table. Sometimes, during this step, they tested the resistance of the table using the book's weight (Fig. 4).

Figure 4. Students' work through the steps 4-5-6 of ED

In some cases, at the first try, the table stood for some seconds, but fell down when they put on the book. These students had to revise the chosen model or revise the way to roll the paper to get the tubes or the way they connected the elements; others, got a solid prototype table at the first attempt. The Fig. 5 shows some the students' prototypes of the table.

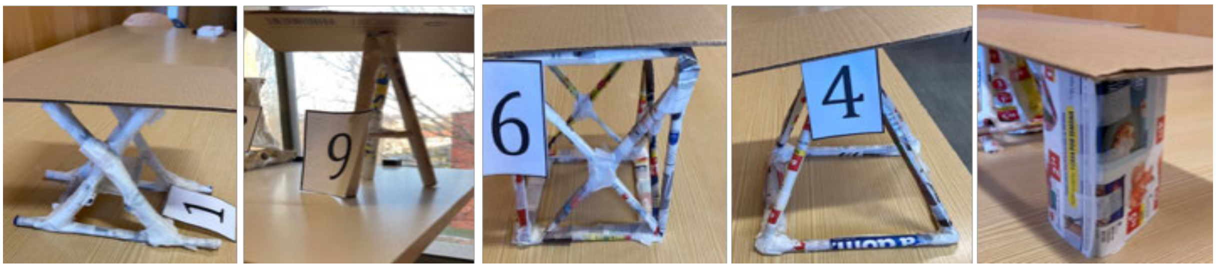

Figure 5. Table prototypes through step 7 of ED

After all, the students were able to be successful and construct a table. They began to create their poster following the given previous instructions. In this step they discussed: how to organize the information through the poster; then had to revisit the ED cycle, thinking back on the work developed to describe their thoughts and processed in each of the ED steps. With the prototype in front of them, they began to look for the ideas, concepts, procedures they used in the scope of mathematics and physics sciences. They had some aesthetic concerns with the poster constructions. To finalize, they had to describe their reaction to this experience (Fig. 6).

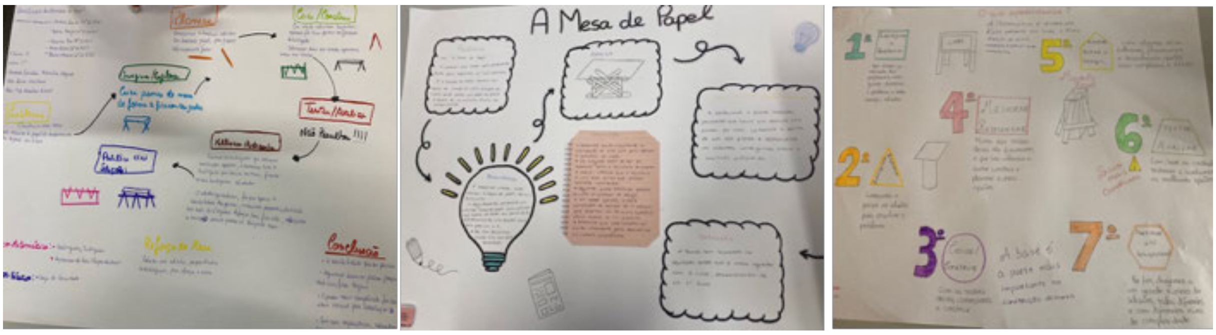

Figure 6. Some of the posters

We can synthetize our main preliminary results in the following ideas. These students, future teachers: a) valued the experience, having the opportunity to solve an authentic problem, in a collaborative way, mobilizing mathematical concepts (geometry and measurement) and physical sciences contents (centers of mass and forces) in an integrated way; b) had a great engagement, showing persistence and motivation in solving the problem, through many discussions, trials and errors, but all were able to create a model according to the requested conditions; and c) manifested attention to aesthetic features, not only in the preparation of the poster, but in the construction of the prototype of the table.

However, some difficulties were detected, namely: in drawing the sketch (3D); in the identification of some mathematical concepts and in the identification of some concepts of physical sciences (one of the aspects observed was that, despite not verbalizing the physical and mathematical concepts, during the manipulation of the materials it was concluded that these concepts were present in the way they built and in the way they positioned the book to test the table's stability to support the book); in the mobilization of adequate scientific language in the reasoning underlying their decisions; in precisely justifying the need to improve the design/execution plan of the model; in the use/interpretation of the ED model, most students did not follow the cycle in the presented order, starting with the manipulation of materials and then going back to contextualize the problem.

4 CONCLUSIONS

This approach constituted an opportunity to favour the integration of some disciplinary areas [17], [18], (mathematics, science, art), as well as the fundamentals of engineering, occasionally resorting to technology. Science, and in particular physics, contributed to justify the balance and resistance of the table and the materials used. The technology was used spontaneously in the exploration phase, during brainstorming. Engineering contributed through its design model to address the problem. The art contributed to the aesthetics/design of the prototype and the elaboration of the poster Mathematics contributes to solving the task, allowing, for example, to use problem solving strategies and to understand the effect of using some geometric concepts (shapes; and the idea of symmetry; measurements; weight).

Given the collaborative engagement and motivation that the students expressed we will follow up on this approach. However, there are some aspects to improve, like: review the engineering design model, simplifying it; refine the materials used; propose tasks where technology has more expression. Also, we need to have more studies, that give us insights about the interdisciplinarity and discover the role of mathematics in these tasks/projects. We can see potential in this type of tasks and in their resolution using ED, but we also recognise that it will be challenging for educators to look for tasks that are suitable for the elementary school level, since we had some difficulty in finding adequate problems/projects for these school levels.

Teacher education programs should include experiences that stimulate preservice teachers' knowledge, particularly solving the same tasks and using the same teaching and learning principles that they are expected to use with their own future students [7], [14], [22], [23].

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