Research and development of a creative instrument to allure students towards Engineering

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***Abstract*— Nowadays, with fast technological progression and an increasing complexity of problems, society needs more efficient and more sustainable solutions. This entire dynamic must be based on sustainable development goals (SDGs) as they present themselves as a common global vision of humanity's goals and targets. Within this premise, education is a key factor in producing responsible, competent, multidisciplinary, and highly trained Engineers who can respond to society's needs. However, there is a global opposite trend where there is a decreasing number of students enrolled in higher education in courses in this scientific area. With the objectives of awakening a sense of ingenuity and promoting vocations in Engineering in elementary and high school students, the *Há Engenharia em Mim®* (There is Engineering in me) program was developed by the national professional association of Engineers in Portugal, the Ordem dos Engineers. Through this creative tool, curiosity, sagacity, astuteness and attractiveness towards Engineering are stimulated in a simplified and captivating way, meaning that the widespread implementation of this program can mitigate or reverse the trend of students moving away from choosing careers in Engineering.**

Keywords—Education, Engineering, innovation, creativity

I. Introduction (*Heading 1*)

The 21st Century brings many challenges to society, forcing professionals to adapt to the demands of the labor market, providing themselves with technical and practical knowledge and multidisciplinary vocations. Marked by rapid development in technology, this century requires companies to follow the evolution of technology in order to guarantee a response to current challenges. "*No factor is more critical in underpinning the continuing health and vitality of any national economy than a strong supply of graduate engineers equipped with the understanding, attitudes and abilities necessary to apply their skills in business and other environments"*. This quotation [1] from UK Royal Academy of Engineering provides the adequate context to the perspective of what we are going to report in this paper.

There is a general understanding among the scientific community that STEM education is a current educational phenomenon that promotes the improvement of the quality of students' understanding of disciplines related to science, technology, engineering and mathematics, resulting in learning that is very rich in content that prepares students to solve problems in your future professional activity [2]. However, the question arises of the reasons that may lead students to withdraw from these subjects. One of the reasons that has gained some consensus as to why most students do not enter careers in these fields is that they do not experience relevant topics in STEM, especially engineering, throughout their K12 studies [3]. Consequently, it remains to clarify what are the most efficient and effective methods to teach engineering at the K-12 level and how they relate to other STEM disciplines [4]. Another factor is that most educators are not prepared for multidisciplinary, that is, the need to mix knowledge from STEM education or even pedagogical content knowledge so that they can pass this content on to their students [5].

According to the results of the OECD's Program for International Student Assessment (PISA), it is possible to verify a very significant drop in student performance worldwide. The average performance in OECD countries fell by 15 points in mathematics and by 10 score points in reading. In the PISA report, it is compared that this decrease is the same as half a year's worth of learning in reading and three quarters of a school year in mathematics. In contrast, average performance in science did not change significantly [6].

Among other challenges in Portuguese education today we can identify innovation teaching methodologies, the ability to attract and motivate students towards exact scientific areas and the guarantee of a quality education system. Yet at this time when society's need for engineering talent is huge, and when society is increasingly interested in how they can help to save the planet and create innovative solutions, we are failing to persuade them for exciting engineering careers, having the lowest number of students enrolled for the first time in Higher Education in courses related to Engineering, as shown in figure 1 [7].

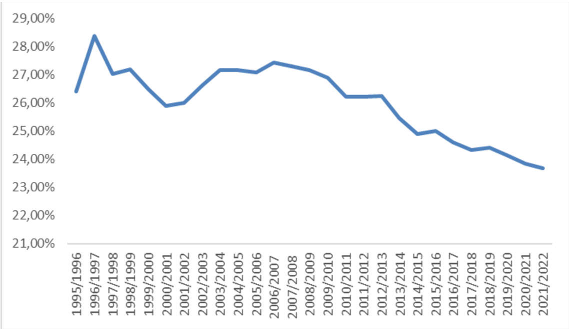

Fig. 1. Ratio between total available places and enrollment in Engineering-related courses per academic year in Portugal between 1995 and 2022.

This issue has a deep impact on the society, particularly on the national strategy outlined by the government and on commitments with formal partners. The fact that secondary school students demonstrate resistance to studying and not getting good grades in elementary subjects in STEM learning, highlights the lack of interest in professional careers in these scientific areas, which can cause a deficit in the labor market of capable specialized labor to meet the needs of society. This phenomenon is already a reality in Portugal and, by analyzing information from the Census, from 1981 to 2011, it is possible to identify the upsurge of foreign employers and the increase of their relative importance in the total employers of the country to compensate for gaps denoted in the law of demand/need in the labor market. If these gaps are not filled, there is a risk that the government will not be able to fulfill commitments, such as the execution of funds from programs such as the Recovery and Resilience Facility (RRF), whose impact on Portuguese society has been clear, at same time that the failure to take advantage of it would mean a loss of a crucial national opportunity.

One structural problem that is possible to verify in modern school is lack of strong inter-disciplinary connections, since it cannot use received knowledge neither in current situations and day-to-day practices, nor in other curricular units[8]. It appears that it is insufficient to enroll students in problem-based learning exercises that only add knowledge in 'science' without its practical application in real situations, making the expressed need of evidence through experimentation. Experience in the 'practice of engineering' should be obtained through judicious, rigorous, challenging, and complex experiential learning processes that apply engineering theory to scenarios requiring design resolution [9]. It is important to mention that experiencing Engineering in a practical sense also means that the student will experience science, mathematics and, depending on the model and platform, technology. Therefore, a combination of these previously mentioned scientific areas could be an effective and quite efficient solution to mitigate or even reverse the problem highlighted.

II. The Relevance of Developing Tools in Education Innovation

The need for digital transition, new technologies and the demand for increasingly multidisciplinary professionals shape the needs of the labor market, resulting in an adaptation of the educational system without compromising the quality of education. STEM learning combined with new approaches demonstrates the effectiveness in developing students' creative thinking abilities, as they experience practical activities combined with repetitive solving steps such as preparation, exploration and verification [10]. In this point, it is essential that the educational system becoming changed to meet student's needs. The organization of STEM programs and school education initiatives plays an important role, improving students' overall performance in the sciences areas, such as science and mathematics, boosting students' opportunities for STEM-related careers [11]. An undeniable fact is that technology is constantly evolving, and that society demands more practical, more efficient, and more sustainable solutions, which is why it is imperative that future engineers are prepared with concepts and knowledge adapted to these premises. In order to be more appealing to young students, catching their interest and energy, the development of creative tools becomes a strategically high value not counting for the ability to be adaptable at different groups and contexts, considering the complexity of the developed theme.

III. Sustainable Development Goals and Education

The sustainable development goals (SDGs) cover a wide range of challenges, namely in the social, environmental, and economic domains. Addressing them will require adaptations to how economies and societies function in interaction with environmental and sustainability issues [12]. In each objective, there are several indicators that allow measuring progress towards achieving the outlined goals, and there are several entities that annually reflect the approach to these values through reports. Education is a science reproduced in these objectives, which includes some aspects such as inclusive and equitable quality education, arguing that learning opportunities must be lasting and not discriminatory in access to them[13]. When applying SGDs, there are trade-offs and synergies between sustainable development goals and targets since there are intrinsic interconnections. For mere academic reasoning, an action in SDG 3 (ensure healthy lives and promote wellbeing for all at all ages) also relies on ending poverty (SDG1), providing access to education (SDG 4), achieving gender equity (SDG 5), reducing inequality (SDG 10), and promoting peace (SDG16)[14]. On the other hand, it is very important to be aware of the negative synergies. Continuing with mere academic reasoning and consulting the UN's annual reports on the development of sustainable development goals, Zero Hunger (SDG2) can be accelerated by sacrificing Life Below Water (SDG14), through social aspects such as overfishing. This means that promoting and investing in SDG 4 will make it possible to impact other SDGs, directly and indirectly, resulting in synergies that can be positive and negative. Highlighting this factor, it becomes crucial to understand the importance of Education in sustainable development goals, carrying out studies that measure the positive impact that each action can have on the outlined goals and targets, creating strategies that can mitigate negative synergies [15].

IV. Methodology

In the earlier school years, it is possible to verify that throughout their academic career, reluctance and compassionate distance from exact curricular subjects, such as mathematics, physics and chemistry are clearly evident. The question becomes more pressing when it comes to their motivation and propensity to pursue this academic path as their own choice, over a longer period, later mirrored in a professional life. It is equally evident that the future of education involves a revolution in teaching methodology, focusing on technologies, digitalization and sustainability.

Therefore, schools must adopt highly adequate teaching strategies based on sustainable development objectives, training today's students to be highly trained professionals, especially in STEM learning domains.

In order to understand and change this paradigm, the *Ordem dos Engenheiros* created an Engineering Discovery activity that aims to (re)discover in teenagers the stimulus and practical sense for the exact sciences, namely engineering, in a playful-pedagogical 'hands on' approach, based on a STEAM (Science, Technology, Engineering, Arts and Math) learning tool. With this new creative tool, based on Scratch software, it is proposed practicing critical thinking, analyzing data and developing prototypes that solve complex problems relevant to the real world.

Through careful experimentation, the purpose is to make teenagers aware of all the specialties that make up engineering and how they are reproduced in society and in our daily lives, allowing them to study mathematics, physics, computer science, electronics, and robotics, not forgetting social and organizational skills. The belief is that learning is compatible and exciting while playing as shown in figure 2.

Fig. 2. Example of an activity from the *Há Engenharia em Mim*® program.

Stimulating creativity and curiosity through simple but fundamental engineering processes, gaining not only students' interest and motivation for the exact sciences, but also developing and broadening their knowledge, with a view to observing, participating, and contributing in a proactive way to the issues of everyday life and coexistence. At the end, we'll be able to declare: *Há Engenharia em Mim* (there is engineering in me). And in you?

The implementation of this activity aims to build self-confidence, motivation and improve school success, as well preparing students for an increasingly challenging and complex future, requiring investment in hands-on teaching-learning models. It should be noted that it is important to recognize the role of science, technology and engineering for the SDGs, since these are the bases that support progress, anticipate the future consequences, and which pave the way for crucial aspects such as the digital transition, sustainability transformations and responses to important agreements such as the green deal [16].

At the same time, this project becomes an opportunity to obtain data and statistics to measure the interest that students have in STEM learning. In addition, this project provides an opportunity to find the effect that a creative tool can have on students who experience science, technology, engineering and mathematics. To measure the previous parameters, a systematic review of the literature was carried out in order to choose a high-value instrument that has been duly proven and accepted within scientific research, also checking other systematic reviews of the literature carried out in this context. This measurement tool must assess students' attitudes towards STEM learning, and develop relevance in its usefulness and appropriateness based on reported psychometric properties[17]. For this purpose, the STEM Career Interest Survey (STEM-CIS) was chosen due to its applicability, adaptation demonstrated and validated characteristics[18].

The moments chosen to apply this measurement tool were at the beginning of the activity, when students arrive in the room where it will take place, and immediately after the end of the activity. This results in obtaining reliable data since at the beginning the students have not yet experienced any activity related to the STEM theme, and immediately after the activity the feelings and perceptions about what they developed are quite fresh. Figure 3 represents the activity sensing operating diagram.

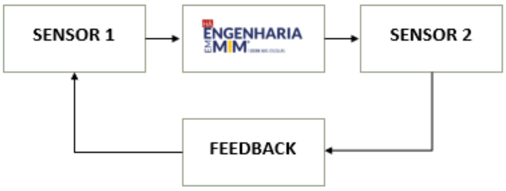

Fig. 3. Program sensing working diagram.

The respective survey is made available to students with a QR code, allowing the process of completing the questionnaire to be more agile and interactive, using technology. Furthermore, the environmental aspect is highlighted as the use of paper is avoided. In terms of data processing, the platform on which the survey is run allows real-time visualization of student responses, data processing in quantitative and statistical terms and the reproduction of graphs with all the data obtained, which is makes it an advantage in the speed and interpretation of the results obtained.

V. Pratical Case Study

The implementation of the proposed activity aims to build confidence, motivation and improve school results, as well as preparing students for an increasingly challenging, complex and multidisciplinary future, requiring investment in hands-on teaching-learning models. It should be noted that digital and technological platforms are equally valuable in terms of their attractive power over students, as they are easily accessible, fun and interactive. However, we prioritize the hands-on aspect of this activity so that they can awaken emotions and feelings while creating their own model.

Through a well-known platform like building blocks, students are challenged to develop a solution that combines creativity, efficiency and effectiveness in a final result. The project's chosen platform is the SPIKE™ Prime tool, as shown in figure 4, and also BricQ Motion Prime with the purpose for preparing children for school and life with creative intuitive solutions.

Fig. 4. Example of the the SPIKE™ Prime tool platform, with an instruction book from the *Há Engenharia em Mim®* program, which helps students assemble the prototype.

From the execution point of view and under the guidance of the Intervention Squad, students work together as a team and bring to this activity intrinsic engineering skills for each stage of the creative process, defining a problem and its solution, making different prototypes , establishing systematic testing procedures, analyzing data to improve answers/solutions and descriptively justifying which is the adequate solution for that problem and what is the advantage of having several possibilities for the same problem, it is essential to understand that there is no right or wrong answer; only the development of improvement processes, clarifying that the primary objective is to explore the entire process of building a prototype from the idea through materializing, experimenting and testing, evaluating and improving until solving the problem. This process results in several groups of students producing several prototypes, in order to find the most efficient solution to move a robot without using wheels, since animals do not move on wheels, culminating in the so-called "gadget flea" race, name assigned to the project under study. Within this activity, in simple words, students experienced the foundations of mathematics, electronics, robotics, programming, creative arts, language and literature.

Focusing on the science aspect of mathematics, 'the Achilles heel' of many students, we introduce the following themes into this activity as an example:

• Calculate the flea's speed (cm/s);

• Determine the equation for a flea contraption distance traveled = speed * time;

• Calculate the distance it would move after 8, 16 and 24 seconds.

This tool also applies to the development of vocational guidance, since there are underlying characteristics that, being evident in the implementation of the activity, can be explored, particularly in terms of correlation with construction and engineering, arts and communication and mechanics. At the same time, before the start of the activity and with the aim of demystifying the area of Engineering and what a professional trained in the science of Engineering does, a promotional and motivational video is used where the most diverse areas of Engineering are listed, subsequently opening the discussion and involvement of students so that they can ask questions about their doubts and reservations about possibly considering pursuing a career linked to Engineering.

As mentioned previously, the case study project is called Gadget Flea, since the final prototype should resemble a mechanized flea, as can be seen in figure 5.

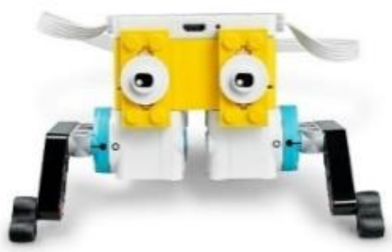

Fig. 5. Example of a mechanized flea.

As can be seen in figure 6, the dispersion and division of the room is exemplified so that students are grouped together. This division aims to promote teamwork, division of tasks and diplomacy between students, with a maximum number of four students so that both are actively involved in the project. An excess of participants per group would result in the inertia of some elements, which is something this project does not aim for.

Fig. 6. Division of the room into groups, along with the modules and instruction book.

Inside the box that is given to each group of students are several accessories, which can be seen in figure 7, which can be used by them, and through a trial-error process they choose which methodology in their opinion works best. the project in terms of effectiveness and efficiency. Each student is free to apply their creativity and ingenuity to the test, so the diversity of prototypes that are observed in each activity is notable.

Fig. 7. Detail of various accessories that can be used by students in designing their prototype.

These accessories can be simple bars, axes, decorative ones or even accessories that stimulate your operating curiosity, such as LED lights, which can be attached to the prototype as shown in figure 8.

Fig. 8. Prototype example with an attached LED spotlight.

In the case of the gadget flea competition, to be as close to the desired prototype and to implement rules, we encourage you to create new leg prototypes to move the flea's body forward faster, thus avoiding the use of wheels for movement. We begin discussion mediation by asking them to describe the methods they used to improve the movement of their fleas. As the activity progresses, feedback is given on each group's performance, but participation in constructive feedback from each group is also requested in order to stimulate each group's performance during the project. Five minutes are given to test and improve their models before the final competition, encouraging students to give their fleas different characteristics, adding pieces and other materials, being able to position pieces on the test track or create uneven surfaces that are more difficult to walk on. This differentiation stimulates creativity and allows for public discussion about which prototype is the most original, and in figure 9 it is possible to observe a different prototype.

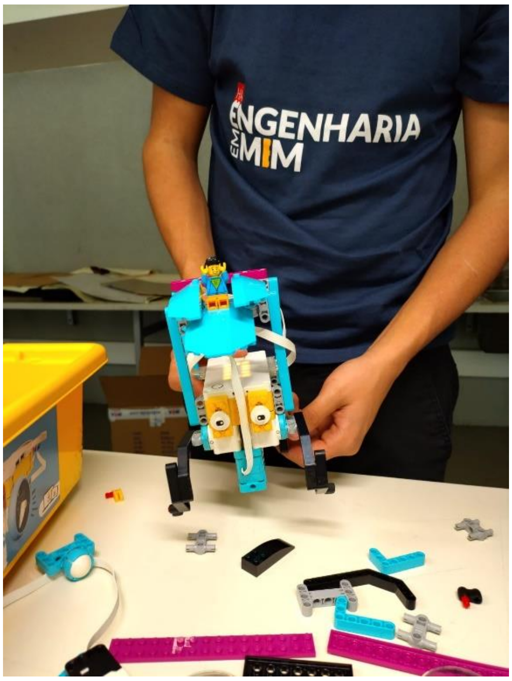

Fig. 9. Example of an original prototype made by a student involved in the project.

During the execution of the project, students in each group are encouraged to develop at least two new ideas to make the flea moving faster. To implement some mathematical dynamics, it is suggested positioning four pieces of two different colors approximately 50 cm apart to create a start line and a finish line, as demonstrated in figure 10.

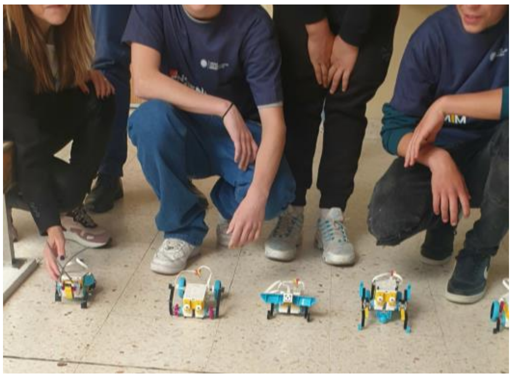

Fig. 10. Example of starting line and aligned prototypes.

It is noticed that at the beginning of this activity, most students were not very receptive to the activity, since the activity starts by covering topics such as mathematics and physics, or engineering. By watching a short film about the different engineering specialties and the unfolding of the activity, interest increases considerably, making the room small for so much hustle and bustle and energy. The animation sets in and despite the timed times, the teenagers intend to improve and improve their prototypes more and more, stating that time is short, as they explain the need for constant evolution that their prototype requires and that as an Engineering project (as they call it), deserved more time to evolve.

The signal of wanting to know more about the project, including how it is programmed, what new additions can be made, how the module has energy and what prototypes can be made with the platform tool, transports them to a new vision of these curricular subjects and exact sciences, which initially seem so distant and unappealing to them, and after experiencing their practice, they become part of them and want to experience more and more. As the saying goes, practice makes perfect!

VI. PRELIMINARY ASSESSMENT

This chapter presents some conclusions drawn from the data and statistics obtained, so as the program is still in the testing and improvement phase, the universe of available data is still small (26 students tested). Nevertheless, we consider the provisional data to be quite relevant and encouraging. Regarding the measuring instrument, the chosen survey is based on questions constructed from the Likert scale, presenting a self-descriptive statement, offering as a response option a point scale with verbal descriptions that include extremes - such as “totally agree” and “totally disagree”, allowing measurement of different levels of intensity of perception. In order to quantify each response, a 5-point system was chosen. To do this, simply add up the numbers associated with each value feeling to produce an overall score, namely, 1 = strongly disagree, 3 = neutral, 5 = strongly agree.

Figure 11 reflects the quantification of the survey carried out with provisional data, verifying a variation in each domain of STEM learning between the first sensor and the second sensor in accordance with what is proposed in the methodology.

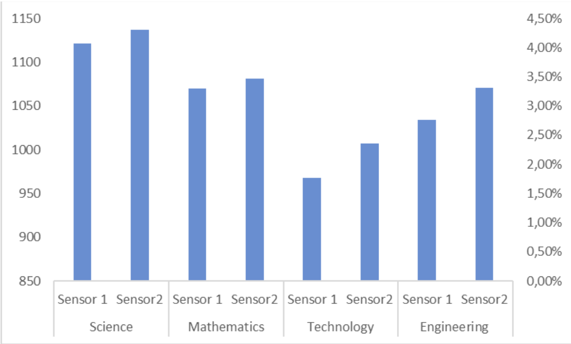

Fig. 11. Variation of data obtained, before and after the activity carried out.

Carrying out a preliminary assessment, we verified a positive variation in favor of STEM learning, with an increase in student interest of 1.43% in science, 1.03% in mathematics, 4.03% in technology and 3 .58% in Engineering.

From a qualitative point of view, and with regard to national and international projection, this program has aroused the interest of several national and international entities, so the development of partnerships is a strategy for strengthening the program and validating the results obtained. This research work, together with the *Ordem dos Engenheiros – Região Norte* and its program *Há Engenharia em Mim*®, was presented to the Presidency of the Portuguese Republic, with an attribution being considered for the high patronage of the Honorable President of the Portuguese Republic.

The creative tool was also proposed to the UN as an accelerating action in the implementation of SGD 4, which should be included in the SDG Actions Platform. Following the same philosophy, the professional association Ordem dos Engenheiros - Northern Region made a pledge to join the European Alliance for Apprenticeships, European Commission entity, with the aim of strengthening the quality, supply and overall image of apprenticeship demonstrated in this program as a promoter.

VII. Expected Results

After implementing and using the creative tool "*Há Engenharia em Mim*®", and despite the time set for executing the challenge having ended, it is possible to verify that students are motivated, curious, and challenged to improve their prototype, achieving better and more efficient results. It is expected and believable that these activities will awaken within students the perception of continuous improvement in results, the importance of ingenuity in solving tasks and the development of vocations in Engineering. The implementation and use of an assessment tool will be important to verify the effect this program has on students in the short, medium, and long term[17].

For mere academic reasoning, and analyzing the data obtained in the previous chapter, if these results were represented by the increase in their respective discipline in access to higher education, it would mean a considerable increase in the professionals available in the labor market that would result in the mitigation or even the reversal of the problem by this research work highlighted.

VIII. Conclusions

The development and implementation of creative programs and tools are highly efficient in enticing, captivating and promoting skills and qualities in adolescent students, as it motivates them to continually improve solutions, the sense of facing challenges and not being afraid of failure. Stimulating vocations in certain scientific areas promotes rapprochement and willingness to pursue professional careers within these scientific areas, which could solve current labor market problems and improve the sustainability of the current system. The data obtained in the preliminary assessment are very encouraging and promising very positive results, demonstrating enormous potential in this creative tool that has aroused interest from several national and international entities.

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Com o Alto Patrocínio de Sua Excelência

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O Presidente da República

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Erasmus+ Enriching lives, opening minds.

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