Promotion of Bolivian higher education in science and engineering by STEM engagement activities through the participation in NASA HERC

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***Abstract*—STEM engagement goal is to drive a systematic approach to influence students across a spectrum of learning. In a developing country, like Bolivia, the inclusion of STEM education for the educational system can derive in the improvement of its outcomes at different levels. Information acquisition, intrinsic interest as well as further research and technology development could be achieved by the implementation of new approaches focused on stimulating the thirst for knowledge in young people. This paper helps to understand the actual educational system of Bolivia and how the participation into international competencies such as NASA Human Exploration Rover Challenge through engagement activities can bring a positive impact in order to promote higher education related to the fields of space, science and engineering. And how new careers such as Mechatronics Engineering helps to this new educational process showing the activities, challenges and methods made during this path.**

***Index Terms*—Aerospace, Bolivia, Education, HERC, Mechatronics, NASA, STEM, engagement.**

I. Introduction

The development of an integrated system of engineering-focused activities for high school students, coupled with aerospace applications and hands-on experiences, can have a major impact on younger generations in developing countries by generating greater learning satisfaction among students, as well as stimulating their thirst for knowledge. In this study, Mechatronics Engineering department efforts to engage new scholars and NASA's Human Exploration Rover Challenge (HERC) participation consequences and outcomes are evidenced. Data acquired from enrolled Mechatronics students at Universidad Católica Boliviana "San Pablo" (UCB) and participants in STEM events organized by Mechatronics Engineering's scientific student society suggest a possible increase in the country's development and research through these activities.

The NASA Human Exploration Rover Challenge (HERC) is a student competition aimed at the design, development, construction, and testing of human-powered rovers capable of traversing challenging terrains. In addition to the vehicle creation aspect, NASA's HERC encompasses other competition categories. One such category is STEM engagement, which provides an opportunity to share knowledge in science and engineering with high school students. Educational activities offered by the Mechatronics' scientific society where directly linked to HERC and cover various subjects, including mechanical design, vehicle infrastructure, physics, and the engineering design process, among others.

We would like to express our gratitude to the Universidad Católica Boliviana San Pablo Sede La Paz for providing the data of the students entering this institution and for granting access to their facilities for the development of STEM activities.

II. Prior Research

A. Bolivia education system

The education system in Bolivia is governed by Law No. 070 "Avelino Siñani y Elizardo Perez" [1] which establishes the model "Modelo Educativo Socio Comunitario Productivo" (MESCP), which objective is to encourage the acquisition of knowledge based on the demands of the social context. This model purpose is to generate community educational practices, and recover and promote the knowledge and languages of indigenous nations in reciprocal complementary interaction with the knowledge of other cultures around the world. Curivil and Pinto [2], developed an article in which they highlight the following points about MESCP:

- Education is decolonizing. Education in Bolivia core lies on local values and teachings, and tries to break the hegemony of the western colony.
- Education is productive. The purpose of knowledge distribution is to obtain a social-productive benefit, where the development of the person has a service for the person themselves, their region and nature.
- Education is intercultural and multilingual. Education serves as unity for all Bolivians and respect for cultures.
- Education is community. Individuals growth through the dialogue of communities is essential. Interaction between all educational actors benefit people outlook and future.
- Education is scientific, technical, technological and artistic. In order to achieve a full development of society, the rooted indigenous cosmo-vision must be complemented with universal knowledge.

The Bolivian Ministry of Education updates curricular content based on a systematic strategy of continuous training for the country's teachers as established in the Political Constitution of the State (Art. 78 and 96) and in the Plurinational Teacher Training System (DS. 156/2009) [3]. However, there is an alarming educational gap between rural and urban areas, as well as other factors.

B. Disparity in education

Disparity in Bolivian education outcomes can be summarized in technological education accessibility, gender inequality and lack of innovation incentives.

Thanks to the periodic academic curriculum adjustment, Bolivia seeks to include technology as a key element in the integral learning of students. This objective entails several challenges, since increasing the material and availability of technological devices in educational units is not enough [4]. It is necessary to consider new tools for technological inclusion from an early age in order to evidence a change. Digital inclusion in the education system is a topic developed in Bolivia since 2002, however considerable implementations were not carried out until 2005, when the aim was to reduce the digital divide. Thus, in 2015, the Plan of Action for the Information Society in Latin America and the Caribbean (ECLAC) was launched, where data were analyzed in relation to the use of Information and Communications Technologies (ICTs) in students throughout Bolivia, and more specifically in the department of Tarija.

Indicators proposed by the World Summit on the Information Society (WSIS) in 2005 were evaluated. They relate both materials and professional educators in the area and basic services for the inclusion of ICTs in education. Although in 2012, there were 2 million internet connections (30% of the population), it was observed that the internet speed in Bolivia was the lowest in South America. Data was collected from 311 high school students. Among the most relevant data was that 47% of the schools interviewed did not have their own technological equipment, so students had to resort to other spaces to connect, as shown in figure I. In La Paz department

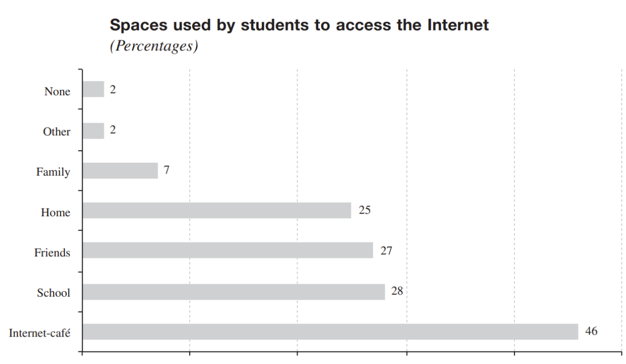

FIGURE I: SPACE FOR INTERNET ACCESS. SOURCE: [5]

alone in 2021, 494509 children were enrolled in the urban area comprising the cities of El Alto and La Paz. These two municipalities represent 66.7% of the city's student population in relation to the other 78 municipalities as a whole. This situation repeats itself in the other 9 departments of Bolivia, where the urban area concentrates most of the student population (69.72%) [6]. This phenomenon suggests the migration of students to sectors with higher educational quality or resources such as computers or good learning environment. A distressing fact in Bolivia is that although teachers consider using ICTs beneficial for learning, the majority is not willing to pay for training in this area. This, among other factors has led to the conclusion [7] that we may even need to wait for a new generation of teachers to adopt ICTs in the educational process and wait a good increase of specialized teacher's formation.

By other hand, gender inequality is expressed in the field of education in a very aggressive way. Women face a more complicated reality when it comes to talking about development, the Journal of Research in Educational Sciences Horizontes [8] exposes data from Latin America on the disadvantages that women face in the social sphere. In the rural area several factors such as the role of domestic work, forced marriages or pregnancies make it impossible for women to attend classes. Nonetheless, data provided by UCB reflects the growing demand for women to occupy executive leadership positions and work specially in the financial management of companies. These data also show a trend towards greater female participation in professional fields traditionally dominated by men. In the case of the Faculty of Exact Sciences and Engineering, among eight careers, 72% are men and 28% are women, out of a total of 1,841 students. A percentage that has increased through the years.

A study by Instituto de Estudios Avanzados en Desarrollo en Bolivia (INESAD) analysed the evolution of the innovation index, using information from the Global Competitiveness Index (GCI), and found that, in Bolivia, the index improved for a few years but fell again, placing us 135th out of 137 countries in technological development in 2017 [9]. For other part, Schimago Journal & Country Rank [10], is an indicator of the scientific influence of academic papers. It shows a big difference between Bolivia and the rest of the world in terms of scientific publications in the area of engineering. However, the data also shows an increase in Bolivian publications, which is consistent with the increase in open access articles and public dissemination.

C. Mechatronics Engineering

In recent years, there has been a evident urge to meet the need to create manufacturing processes, capital goods, increasingly specialized products and mechanical systems for everyday use, which in turn has influenced professionals and scholars to focus in a multidisciplinary approach for the creation of such technologies. The increasing integration of systems designed and created with mechanical, electrical, computer and control systems has lead to the merge of these disciplines forming a new career called Mechatronics. This career has found its purpose in both the automation and control of factories, as well as in the development of products and devices for everyday use.

The growing demand from emerging industries in Bolivia, as well as micro-enterprises, small companies and research institutions has created the need to prepare professionals to join the accelerated progress and changes in technology. The current concept of Mechatronics represents the consolidation of relationships between new ways of working, research, development, operation, maintenance and management of the mentioned technology itself. Thus, this leads the education system and superior studies programs to train modern and multidisciplinary professionals.

Giovanni Gismondi made the decision in 2007 not only to create a new career for the University, but also to bring a career to Bolivia's own academic system. Universidad Católica Boliviana "San Pablo" became a pioneer in having the Mechatronics Engineering Career at national level, starting its first term in 2008. Since then, training engineers capable of designing and developing intelligent electromechanical machines. During the 2017 administration and thanks to the current Career Director (2017-2023), a curricular redesign process took place in order to train professionals to contribute to technological development of the country in even a broader spectrum of areas, which is considered as a priority for the present and future of Bolivia.

The Mechatronics Engineering department has a strong focus on improving the education quality of its students each term and giving them exposure to research and labor opportunities worldwide. Through the scientific society and research center, Mechatronics department tries to inspire the student's participation on STEM events and activities, focused also in decreasing the gap of gender and disparity in education as shown before, knowing that as an engineering that combine different science and engineering fields, become in one of the best careers that can promote and develop STEM engagement through several and diverse activities such as the participation in the NASA Human Exploration Rover Challenge.

D. NASA HERC

An important field of Mechatronics Engineering is aerospace, mechanical and electrical sciences. Therefore, the scientific society of the department is encouraged to be involved in competitions comprised of these areas. One of the most sought-after projects in the department is the Vehicle for the NASA Human Exploration Rover Challenge (HERC).

Every year, NASA's HERC [11] organizes an engineering design challenge to engage people worldwide in the next phase of human space exploration. Apollo and Artemis missions had a major influence in HERC as the competition objective emphasizes the design, construction and testing of technologies, for traversing an unique environmental terrain. Apollo 15's astronauts [12] [13] employed the first automotive vehicle on the moon, the Lunar Roving Vehicle (LRV). This vehicle made possible the collection of more lunar samples than the previous two Moon-landing missions combined, the time spent on the moon was also increased. Similarly, now, NASA aims to further scientific exploration and experiments on the Moon with it's 21st century lunar exploration program is called Artemis, which aims to inspire diverse scientists, engineers, explorers, and other STEM professionals [14].

HERC's main objective is for teams of students in high schools and university to design, develop, build, and test human-powered rovers capable of traversing challenging terrain and a task tool for completion of various mission tasks [11]. Students undergo a series of reviews and testing to design and manufacture by themselves a vehicle able to traverse a course of approximately half-mile that includes a simulated field of asteroid debris, boulders, erosion ruts, crevasses, etc. just as if in an Apollo mission. The competition also invites teams to engage participants in direct educational, science, technology, engineering and mathematics (STEM) activities. STEM activities serve as the framework for NASA to provide not only benefits to students, educators, institutions, but also to help build the next generation of explorers with the technical skills needed to continue pursuing NASA's missions and promote STEM activities for the team's communities and context [15].

E. STEM engagement

Through the NASA HERC, organizers try not only to promote aerospace and science fields for primary and higher education, but also pursuit the increase of STEM education system in the countries that have participation teams. That's why no only America's young people are the only excited people about their space program and more knowledgeable of their nation's work in air and space, in this sense and helped by the STEM Engagement efforts, mobilized to pursue STEM careers and actively engaged in working toward being scientists, engineers, explorers and astronauts, more countries such as Bolivia can benefit of this impact and activities

FIGURE II: STEM ENGAGEMENT ACTIVITY

III. METHODS AND RESULTS

A. Activities description and objectives

The main objective of all events and activities made by the team that participate in the NASA HERC, was to encourage children and young people in STEM fields. Simultaneously, each activity had specific objectives that had to be carried out throughout the integrity of these activities or events.

1) "3D SolidWorks Course" It was a 3D Design course, aimed at children, it was based on guiding them in the creation and 3D modeling of objects, in order to be able

to represent their ideas in something physical and later in something tangible. Achieving the following objectives:

- Development of Ideas
- 3D Modeling fundamentals
- Notions of mechanisms and joints

2) "Up-cycled Rocket Challenge" It was a Rocket competition, aimed at boys and girls from 9 to 15 years old, it was based on the physical explanation and aeronautical history of rockets, for its subsequent creation of a scale model with recycled material, for its subsequent launching in a safe area and determine through a competition, which model developed with better characteristics the physical analysis already explained. The objectives were:
   - Acquire a basic understand of the physical theory of a rocket.
   - Design of scale models of a rocket.
   - Learn to recycle objects with fun interactive ways.
   - Encourage teamwork for healthy competition
3) "School visits" This activity aimed at children from 6 to 9 years old mainly in primary level, oriented to teach from an early age about mechanism and mechanical movement through robots, the main objective is to interact with children and teach them that science can be fun achieving to create robots. The objectives of this activity were:
   - Incentives about science at an early age.
   - Use of materials available at home.
   - Work in teams between boys and girls.
   - Show the science behind each robot
4) "Space experience" It was an activity aimed at children from 9 to 15 years old, in order to show about the NASA Rover Human Challenge competition, the main objective was to show the children what the competition is about and guide them to be part of it, the team focused on developing their ideas to the maximum while showing the progress that the VEMEC Team made for the 2023 competition. The objectives achieved were:
   - Incentives of children and youth about NASA competitions.
   - Development of ideas from children
   - Development of creativity and scientific facts for young people
5) "Women in Engineering" Science fair in commemoration of the "Day of women and girls in science" The Science fair in commemoration of the Day of women and girls in science.I was a specific event to encourage girls in science, whose objective is to encourage and show results of a science fair, this objective more than anything else is to unite and relate students to each other, to share experiences and ideas. The specific objectives were:
   - Union and participation among children in science areas.
   - Innovation and technology by students for students.
   - Encourage the creativity of young minds, especially girls, teenagers, and women.

It was determined that the first scope of the courses imposed in the early stages had a decent amount, but based on more didactic and practical topics rather than courses, the number of members was increasing, reaching more young people. The second didactic point was the theme of competitiveness, by asking a series of questions, the children liked not only to do a scientific work, but also to see it work and compete healthy with other children, learning how to even work as a team. This healthy competition strengthened their competitive spirit, and they were able to see aspects that others did not, even managing to work together to better achieve the goal of winning. Improving all those soft skills related to communication, leadership and team work.

FIGURE III: INCREASE OF CHILDREN IN SCIENCE ACTIVITIES


FIGURE IV: TEAMWORK AND HEALTHY COMPETITION

B. *Curriculum design challenge*

The curriculum design process of the mentioned activities was based on the pillars of the NASA HERC competition guidebook, approaching them from an engineering perspective. One of the challenges was to adapt the knowledge acquired in the competition to make it understandable for secondary school students, considering that many of them did not have robotics or computer laboratories in their educational institutions.

To overcome this challenge, we implemented a strategy that involved searching for tools that would allow teaching technical knowledge without students struggling with the learning curve of the concepts or tools used.

For instance, one of the mentioned course was "3D Design", which provides a practical introduction to Computer-Aided Design (CAD) software for the creation, modification, analysis, and optimization of 3D designs. During university studies, we utilized SolidWorks software with a student license provided by the university. However, due to computational requirements and license restrictions, it is challenging for high school students to access this software. Therefore, in the context of teaching, we found Autodesk's Tinkercad tool. This tool enables students to design in 3D in a more visual and comprehensible manner, particularly for those without prior experience in such tools.

Thus, in all the activities, we sought the most practical and accessible way to adapt the curriculum to provide a better learning experience for the students.

C. Activities structure

The activities developed followed a structure based on the model presented by [16], where the following key points were taken into account:

- Education based on objectives. Since each activity carried out had a theme related to space and the Artemis mission, specific objectives and sub-missions were defined to solve practical problems. Those in charge of the activities prepared the support materials, instructions, and environments for the development of the activities.
- Practical-theoretical. All face-to-face activities began with demonstrations and activities with the participants. In this way, the aim was to obtain their attention from the beginning and then develop a theoretical explanation of the phenomena that could be evidenced during the process. Specifically, activities 1, 3, and 4 of subsection III-A developed theoretical concepts related to liquid and solid sampling by means of creative tools, light filters for taking photographs, and cross-contamination. These concepts are addressed by the "tasks" to be performed in the course of the competition and under the same parameters.
- Multidisciplinary approach. The STEAM approach integrates different disciplines in a single scheme. Therefore, within the activities carried out, we sought to apply areas of study that are learned in the Mechatronics Engineering career, which also has a multidisciplinary approach as shown in table IV.

In addition, three work groups were differentiated in order to correctly orient the activities of each one according their educational degree:

- **4th grade**. Theoretical concepts were developed with images and practical examples. Due to the limited attention span of the children, we opted for activities of low complexity and with materials that did not represent a danger for the children. A particular case was found in activity 3 of the School visit, where after the workshop, the same activities were replicated for other levels and groups, carried out by the same teachers of the educational units.
- **5to to 8th grades**. More advanced theoretical concepts based on mathematics and physics were developed. Since all events were free, low-cost materials were prioritized, but with more complex activities, such as activity 2 Upcycled Rocket Challenge.
- **9th to 12th grades**. They focused on activities with resources provided by the university in terms of software and specialized machines. For example, in activity 1 "3D SolidWorks Course", 3D design skills were acquired in specialized software, which gave students the possibility to deepen their knowledge in the areas of study of Mechatronics Engineering.

D. NASA STEM guidelines

HERC competition has specific goals and guidelines for STEM events aligned with NASA's main objective of inspiring, engaging, educating and eventually employing people. The development of our engineering focused activities are consistent with a reformulation of this approach. The final objective of our STEM education impact is to motivate the interest and embolden young generation in to pursue of higher studies in space science and research for the technological development of the country.

The competition demands the involvement of a minimum of 250 participants in direct educational and hands-on science, technology, engineering, and math (STEM) activities. Additionally, the subject of the activities must be related to mechanical design, vehicle infrastructure, physics, and engineering design process.

The categories that enter for NASA as a STEM incentive evaluation are: Education/Direct Engagement, - Education/Indirect Engagement, - Outreach/Direct Engagement and - Outreach/Indirect Engagement:

- For this, related to Education/Direct Engagement, we had as projects the theme of "School visits" where we focused on showing mechanical design and learning to develop mobile robot mechanisms. We focused on showing, through photos, the learning process and how the children were developing the course, as well as a visual support through slides with which we can explain in a more didactic way to the children.
- With respect to the outreach and direct participation strategy, whose objective is to present the HERC Project to the students, showing progress, development, and ideas of the lunar vehicle we are developing, as well as its operation. For this, we organized the "Space Experience" event, whose main purpose was to show the progress to the students. We tried to showcase each component of the vehicle and how it was manufactured. At the end of each section, we invited the children to participate and

contribute ideas to further develop the topic, so that we could all learn together and share knowledge.

- With respect to Outreach / Indirect Commitment, NASA asks us to interact with the teams in an exhibition environment in an outdoor place or a different space, the goal is to disseminate knowledge, develop the projects to the maximum and encourage more people to know our work, for this we developed “Day of women and girls in science” which was a fair where girls participated more than anything else, and the goal was that students talk to other students, was held in a central square of the city of La Paz, where along with other science spaces, all children could learn and learn more about the event HERC.

E. Data collected

1) Data Information Mechatronics Engineering: The population of students in Mechatronics Engineering ranges between 16 to 30. The most important age group is 16-20, which suggest the majority of students has subjects of the first education curricular cycle.

A clear tendency is shown when comparing the Mechatronics Engineering students background. Approximately 86% of students where previously enrolled in a private school. Only 9% come from a Public School and 5% come from not registered education presumably rural.

There is an evident gap in gender. Only 14% of all Mechatronics students are female. However, considering data from the first term of 2014 it can be seen that the percentage of female students is steadily increasing.

2) Data Information of VEMEC Events: Section III covered the activities carried out by the VEMEC team, covering different areas such as 3D design, mechanisms, rocket development, physical concepts, teamwork, innovation, among other contents. In order to evaluate the results of the quality and degree of satisfaction of our programs, different surveys were conducted among the participants.

3D SolidWorks Course: The goal was to teach students the basics of SolidWorks (computer-aided design and solid modeling software), to enable them to design a basic rover. To evaluate the knowledge they learned, evaluations were made in each class and at the end of the module the 30 students were asked if they would register for the next module using the same learning methodology. The response is shown in Figure V, where 86% of the participants responded that they would participate in our next training.

Up-cycled Rocket Challenge: The goal was to train students in the operation of the Artemis mission rockets and help them understand the physics behind jet propulsion rockets. Our goal was to break down complex concepts into easy-to-understand ones so that students could better understand rocket technology. An evaluation form was made to 45 students in grades 5 - 8, the questions were related to the topics taught, such as parabolic motion, pressure, and aerodynamics. The results are shown in Figure VI, the results show an increase

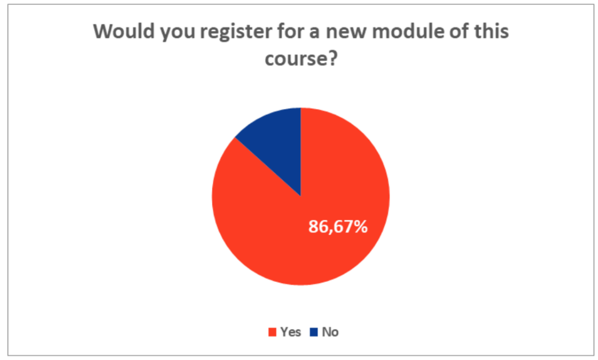

FIGURE V: EVENT EVALUATION RESULTS: 3D SOLIDWORKS COURSE

of 64.4% of students who learned more concepts about rocket construction.

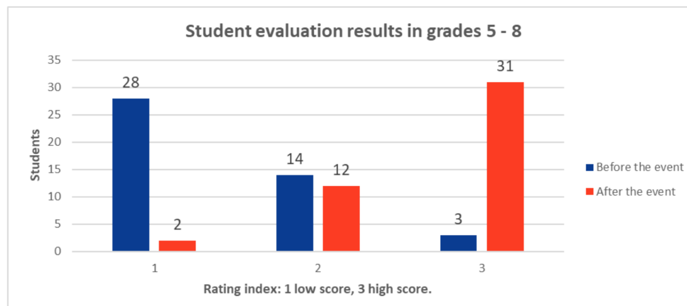

FIGURE VI: EVENT EVALUATION RESULTS: UP-CYCLED ROCKET CHALLENGE

Space experience: The goal was to educate school students on the process of constructing a rover for the NASA HERC competition, including the necessary equipment, basic design principles, and subsystems. We aimed to provide hands-on training and help the students understand how we work, so they could apply these skills to their own projects. Our focus was on teaching the students about the entire process of rover construction, from concept to completion. By doing so, we aimed to inspire the students to pursue careers in science, technology, engineering, and mathematics (STEM) fields, and to contribute to the advancement of space exploration. The participants described the event as a phenomenal and unforgettable experience that provided an immersive look into the world of Mechatronics engineering. The participant highlights the opportunity to observe the labs where Mechatronics students work, as well as the insightful explanation of the rover’s construction process by the team. The participants also appreciated the chance to share ideas and collaborate with peers on improving the rover’s design and constructing new rovers.

Women in Engineering: Was an event to demonstrate to the participants the application of STEM fields through the NASA HERC project, and to visualize the work and role of the

TABLE I: AGE OF THE MECHATRONICS STUDENT POPULATION

Age range	Frequency	Percentage
16 to 20	132	48%
21 to 25	119	43%
26 to 30	23	9%
> 30	0	0%
Total	274	100%

Data source: Student Survey 2019

TABLE II: MECHATRONICS ENGINEERING STUDENTS BACKGROUND

Period	Private School	Public School	Not registered	Total
I-2014	203	24	10	237
II-2014	188	21	10	219
I-2015	208	25	11	244
II-2015	191	21	12	224
I-2016	245	23	11	279
II-2016	228	21	14	263
I-2017	237	27	18	282
II-2017	224	23	14	261
I-2018	266	19	15	300
II-2018	235	23	16	274
I-2019	238	21	19	278
Average	**86%**	**9%**	**5%**	**100%**

Data source: Enrollment database per origin.

TABLE III: GENDER OF MECHATRONICS ENGINEERING STUDENTS

Period	Male	Female	Total	% Male	% Female
I-2014	205	32	237	86%	14%
II-2014	190	29	219	87%	13%
I-2015	212	32	244	87%	13%
II-2015	195	29	224	87%	13%
I-2016	243	36	279	87%	13%
II-2016	224	39	263	85%	15%
I-2017	246	36	282	87%	13%
II-2017	230	31	261	88%	12%
I-2018	255	45	300	85%	15%
II-2018	234	40	274	85%	15%
I-2019	231	47	278	83%	17%
	Average			**86%**	**14%**

Data source: Enrollment database per genre

female members of the VEMEC team to promote more women in STEM careers. The results are reflected in the survey of 208 students who were present in our stand at the fair. The results are shown in Figure VII, where there is an increase of 38.4% of students who increased their knowledge of STEM careers.which shows an increase in knowledge about STEM careers that can be studied in Bolivia. Figure VIII, where there is an increase of 76.4% of students who increased their knowledge of NASA HERC. shows an increase in knowledge about NASA HERC. In both figures blue color shows the results of the survey before the presentation and red color shows the results of the survey after the presentation.

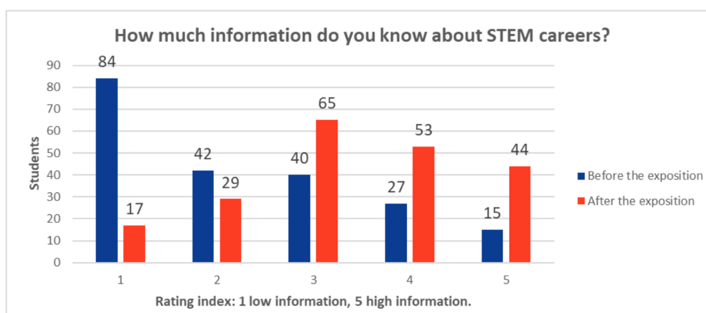

FIGURE VII: KNOWLEDGE OF STEM CAREERS

IV. CONCLUSION AND FUTURE WORK

In conclusion, the integration of STEM education into the Bolivian education system represents a significant opportunity to boost learning at all levels. Currently, not many schools carry out this type of education due to the lack of laboratories and equipment, which is why our provision of university equipment or materials to carry out the activities broke the gap that limits student participation in STEM education.

Due to participation in international competitions, such as

TABLE IV: GRADUATE STUDENTS WORK AREA

What is the highest performance area of your job?		
Answer	Frequency	Percentage
Electronics	6	13.3%
Computer Sc.	3	6.7%
Mechanics	10	22.2%
Control and Automation	12	26.7%
Other	14	31.1%
Total	45	100%

Data source: Professional generation from 2019

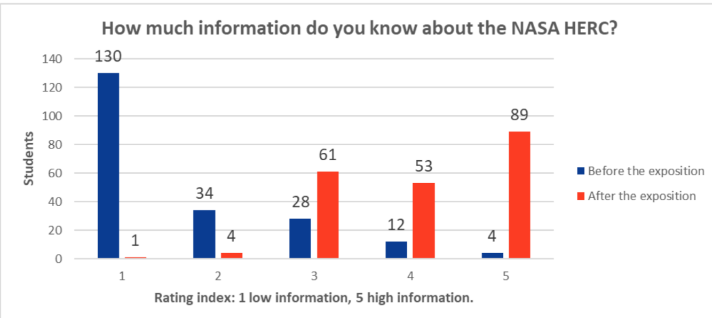

FIGURE VIII: KNOWLEDGE OF NASA HERC

the NASA Human Exploration Rover Challenge, we were able to tailor technical content as an effective strategy to inspire Bolivian youth in the fields of space, science and engineering, fostering the development of research and technology skills.

The introduction of new disciplines helps to better prepare Mechatronics Engineering students and reduce the gender gap of female students that currently exists. By demonstrating activities, challenges, and methods performed during this educational process, it shows how these emerging careers contribute to the formation of professionals and students trained to address the challenges of the future.

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