Project-based Learning in STEM: Effects of Hands-on PoPBL Activities on Schoolchildren' Scientific Motivation

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Abstract—**This research investigates how Project-Based Learning (PBL) within a Science, Technology, Engineering, Mathematics (STEM) framework influences students' motivation toward science and the development of essential skills. The program was delivered through a series of short, hands-on workshops addressing topics such as astronomy, rocketry, robotics, aeronautics, and computer-aided design. Its primary goal was to connect theory with practice by offering authentic, challenge-driven learning experiences. Based on a Project-Oriented Problem-Based Learning (PoPBL) approach, participants worked through iterative design–build–test cycles that encouraged collaboration, creativity, and reflective thinking. Findings indicate a significant increase in the probability of STEM interest, which rose from a baseline of 0.228 to 0.882 post-intervention, representing a 65.4% gain. Notably, students showed a stronger sense of relevance in their learning and marked progress in key 21st-century competencies, particularly creativity, which exhibited the highest probability of perceived development (0.706), followed by teamwork (0.471) and problem-solving (0.412). Beyond technical knowledge, the initiative helped students engage more deeply with the scientific process, turning abstract ideas into concrete, meaningful projects. Overall, the results suggest that PoPBL-STEM programs can serve as a practical and scalable model for fostering scientific motivation, creativity, and skill development, especially in educational contexts seeking to enhance innovation and technological literacy.**

Keywords—**Science, Technology, Engineering, Mathematics (STEM) education; project-based learning; scientific motivation; creativity; hands-on learning**

I. Introduction

Baran *et al*. [1] mention that in recent decades, Science, Technology, Engineering, Mathematics (STEM) education has taken on a central role in promoting innovation and tackling societal challenges. Yet Samsudin *et al.* [2] mention that many conventional teaching models remain lecture-based and teacher-centered, which can reduce student engagement, intrinsic motivation, and deeper conceptual understanding. As an alternative, Lin *et al*. [3] explain that student-centered approaches such as Project-Based Learning (PBL) have gained ground by encouraging active learning through real-world inquiry-driven projects.

Meta-analytic evidence shows that PBL and related instructional methods produce small to moderate positive effects on students' motivation, beliefs, and attitudes in STEM fields [4]. These results indicate that, when implemented thoughtfully, PBL can help narrow the gap between theory and practice, particularly in resource-constrained settings.

In Bolivia, the adoption of PBL within STEM education is still at an early stage, largely because of limited infrastructure, scarce access to hands-on materials, and gaps in teacher preparation. To address these barriers, this study designed and implemented a series of PBL-based STEM workshops tailored to local schools. The aim was to examine whether these interventions affect students' scientific motivation, engagement, and perceptions of STEM.

II. Background

Technology, Engineering, and Mathematics with Project-Based Learning (PBL) has become increasingly important for developing essential 21st-century competencies. This shift responds to global changes driven by the Fourth Industrial Revolution and the rise of a Super Smart Society, both of which demand people who can address complex, interdisciplinary problems. In this context, PBL is especially effective at promoting engineering-oriented thinking by prioritizing creativity, hands-on production, and experiential learning over instruction alone.

A growing literature base documents the benefits of combining STEM and PBL. Studies report not only cognitive gains but also affective and motivational

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improvements that shape interest, persistence, and eventual career choices in science and technology. For example, Baran *et al*. [1] investigated whether STEM-PBL projects built from waste materials could strengthen 21st-century skills in tenth-grade students. Using a pre-experimental pre-test–post-test design without a control group, they measured outcomes with the 21st Century Skills Usage Scale and follow-up interviews. During the course, students constructed projects such as hydraulic robotic hands, hydraulic bridges, and simple drilling machines. Wilcoxon Signed-Rank tests showed significant increases in autonomy, cooperation, and flexibility, along with greater environmental awareness.

As mentioned by Baran *et al*. [1], qualitative data supported these results: students reported improvements in communication, creativity, and problem-solving skills. The study highlights how tangible, hands-on STEM projects can develop both technical competencies and social dimensions of learning.

Building on motivation, Samsudin *et al.* [2] examined the effect of STEM-PBL activities on students' self-efficacy in physics, a construct grounded in Bandura's social cognitive theory. Their quasi-experimental study included more than one hundred Malaysian tenth-grade students assigned to control and experimental groups. The experimental class, which designed and built a pulley system, reported greater confidence in problem solving than the conventionally taught group. MANCOVA analyses indicated a seven percent increase in self-efficacy, linking hands-on engagement to stronger scientific motivation [2].

Likewise, Lin *et al*. [3] investigated the Engineering Design Process (EDP) within a PBL-STEM framework. Although their participants were preservice technology teachers rather than schoolchildren, the quasi-experimental results are informative: the EDP-STEM-PBL group designed and constructed a mousetrap car across twelve sessions and showed larger gains in design-thinking skills—particularly in problem clarification, idea generation, modeling, and feasibility analysis—compared with the control group. These findings in Ref. [3] suggest that design-centered, project-based approaches bolster higher-order thinking and creativity, both essential for STEM education.

At the tertiary level, Kumar [4] explored whether Educational Chatbots (ECs) could support teamwork and performance in design courses. In a quasi-experimental study with sixty undergraduates, the chatbot-assisted group achieved higher performance and teamwork scores than the control group. However, intrinsic interest and creative self-efficacy did not differ significantly between conditions. This nuance in Ref. [4] implies that technological tools may boost cognitive outcomes while affective variables such as motivation might demand more targeted, human-centered interventions.

Overall, the reviewed literature indicates that PBL-STEM approaches can enhance cognitive and self-regulatory skills through concrete, design-based experiences. Yet the extent to which these practices produce sustained scientific motivation, especially among school-age learners, remains unclear. The present study Kumar [4], addresses this gap by examining how hands-on PBL-STEM activities affect schoolchildren's scientific motivation in a context where experiential learning is still emerging as a core pedagogical practice.

III. Methodology

Baran *et al*. [1] mention that Technology, Engineering, and Mathematics with Project-Based Learning (PBL), a Project-Oriented Problem-Based Learning (PoPBL) approach, an adaptation of the traditional PBL framework, was implemented in short, hands-on STEM workshops to anchor scientific and engineering concepts in authentic, mission-like challenges that produced tangible artifacts. Recent meta-analytic evidence indicates that STEM-integrated PBL yields a large average effect size on learning outcomes, supporting the choice of this methodology. PoPBL emphasizes real-world project work and collaborative problem solving and has been repeatedly linked to gains in 21st-century skills when embedded in STEM programs [2].

The five-step sequence was used in this study [3] and operationalized in the activities mapping shown in Table I, which connects each problem statement to specific design-build-test-iterate actions. As detailed in Table I, every workshop enacted this cycle through a defined challenge, a materials plan, explicit testing metrics, and the production of a public artifact.

A. PBL Adaptation to Workshops (PoPBL)

Each workshop was framed by a driving problem, explicit constraints, and an observable performance metric. Typical prompts included: (i) design a tread pattern in CAD to maximize traction on an inclined rough surface (OrionX Hackathon), (ii) assemble and test a rocker–bogie mechanism (Perseverance Rover kit), and (iii) simulate and program task-oriented behaviours inspired by Artemis IV (Tinkercad/Arduino). Sessions progressed through a lightweight design loop (Think–Make–Improve): concept-prototype-test-iterate, culminating in a public artefact (mechanism, Computer Aided Design (CAD) model, simulation or demo). STEM-PBL module studies report that such structures increase learners' interest, sense-making and effort [4].

B. Problem-Based Structure (5-Step Syntax)

As in Ref. [2], each workshop was mapped onto a five-step PBL sequence adapted from higher-education implementations:

(1) Orient to the problem: Participants received a concise mission brief and a success metric (e.g., obstacle height cleared, incline climbed, path-tracking accuracy).

(2) Organize for study: Teams of three to four students were formed with rotating roles (Designer, Builder, Tester, Presenter). Materials and a test plan were defined collaboratively.

(3) Assist investigations: Facilitators guided inquiry through trigger questions during build-test cycles, avoiding direct solutions

(4) Develop and present: Each team prepared a 60–90 s pitch with a concise demo or defense (CAD, simulation, or results table).

(5) Analyze and evaluate: Teams conducted a brief reflection, proposing at least one improvement supported by test data.

C. Materials and Constraints

To keep attention centered on fundamental scientific and engineering principles, the workshops relied on low-cost, high-leverage materials. These included wooden rocker-bogie kits, marshmallows and toothpicks for constellation modeling, paper and lightweight foams for aerodynamics activities, LEGO Mindstorms sets, basic Arduino components, and accessible school-friendly software such as SolidWorks for 3D modeling and OpenRocket for introductory flight simulations.

Each session incorporated intentionally designed constraints such as mass limits, caps on the number of components, fixed wheelbase dimensions, or time-restricted design iterations to encourage learners to confront authentic engineering trade-offs. Lin *et al.* [3] mention that these structured parameters reflect conditions commonly found in real design environments and align with PoPBL's emphasis on engaging students in meaningful, context-rich problem settings.

D. Teamwork Model

To promote equitable participation and individual accountability, teams adopted rotating roles throughout the activity sequence. Brief stand-up discussions kept to two minutes or less were incorporated to help groups identify failures, plan subsequent tests, and track ongoing progress. Peer evaluation was carried out through an A/B validation process in which each team assessed another group's artifact using the same scoring rubric. Baran *et al*. [1] mention that PoPBL within STEM education consistently associates these collaborative structures with measurable gains in communication skills, teamwork, and self-directed learning.

E. Design Justification

Lin *et al.* [3] and Kumar [4] support the decision to integrate PoPBL with STEM instruction, which was grounded in three key considerations. First, meta-analytic research reports substantial effect sizes for STEM-focused PBL across different educational levels and subject areas. Second, studies conducted within PoPBL environments consistently document pre-to-post gains in essential 21st-century competencies, including collaboration, creativity, and problem-solving. Third, prior work indicates that when iterative testing cycles and clear performance metrics are embedded in the learning process, students show marked improvements in both conceptual understanding and interest in STEM topics. Taken together, these findings support the use of a five-step PoPBL structure originally validated in higher-education settings as a flexible framework that can be adapted to short workshop formats without sacrificing methodological rigor.

F. Measurement and Evidence

To keep attention Consistent with prior STEM–PoPBL research, brief pre/post assessments were conducted, including: 1–3 concept items, 1–2 Likert-type items measuring interest and effort., a 0–3 rubric evaluating key performance dimensions:

(1) Adherence to constraints,
(2) Metric performance,
(3) Conceptual justification using stem principles (e.g., friction, normal force, center of gravity/pressure),
(4) Quality of teamwork contributions.

Artifact documentation, photos, CAD screenshots, and concise data tables were collected to triangulate quantitative evidence and support the validity of observed outcomes.

IV. STEM Activities

A series of hands-on STEM workshops was conducted with participants from primary, secondary, and undergraduate programs. Each session followed a Project-Based Learning (PBL) sequence in which learners were introduced to an authentic challenge, collaborated to design and build a prototype or solution, and later shared their results with peers and facilitators. This iterative cycle structured the learning experience and ensured alignment with core PBL principles. An overview of the implementation flow and instructional pipeline is provided in Table I.

A. Marshmallow Constellations (Astronomy)

The astronomy workshop blended a brief conceptual introduction to star formation and the cultural relevance of constellations with a constructivist, hands-on activity. Primary-level students created physical constellation models using marshmallows and toothpicks as shown in Fig. 1. The session opened with guided observations of well-known constellations and a discussion of their historical importance in navigation and storytelling. Students then selected a constellation of interest, assembled a three-dimensional representation of its pattern, and prepared a short descriptive label explaining its meaning and structural arrangement. Throughout the activity, completion indicators and brief formative questions were used to assess students' immediate understanding of the concepts introduced.

The workshop reached several primary-school groups and yielded high completion levels along with strong performance on quick conceptual checks.

The learning experience was centered on a concrete, meaningful task: representing a constellation and explaining it in a way that others could easily interpret. Students worked in small teams and advanced from defining the problem to producing a physical model, combining basic astronomy concepts with elements of design and communication. The task involved planning, choosing the constellation and its layout, followed by low-fidelity prototyping using the marshmallow-and-toothpick construction method and concluding with a short oral presentation to demonstrate conceptual understanding.

TABLE I. PBL Stages

Activity	Context & Motivation	Define Challenge	Design & Plan	Build & Test	Reflect & Present
Astronomy (Marshmallow Constellations)	Short introductory presentation on stars, constellations and their cultural and navigational uses; guided observation to motivate interest.	Teams selected a constellation to represent physically and prepared an explanatory label.	Students sketched the constellation, selected materials and distributed roles within the team.	Teams constructed the model, checked structural stability, corrected spacing and answered short formative questions.	Each team delivered an oral explanation, answered control questions and participated in a reflective discussion.
Rockets (Bottle rockets/OpenRocket module)	Intro lecture on basic rocketry, safety rules and demonstration launches to motivate participation.	Teams were tasked to produce a stable rocket optimizing altitude, flight time or stability under constraints.	Participants sketched designs, selected geometry and mass distribution; advanced groups ran simulations with OpenRocket.	Teams assembled rockets, conducted launches, recorded performance and iteratively modified design.	Groups analysed flight data, compared with simulations, presented conclusions and proposed next iterations.
CAD (SolidWorks introduction)	Demonstration of CAD examples and explanation of CAD roles in engineering workflows to motivate attendees.	A constrained design brief required a functional mechanical component meeting given dimension.	Students converted requirements into sketches, defined dimensions and planned modeling steps in SolidWorks.	Participants created 3D models, produced technical views and verified geometric constraints; some prepared files for 3D printing.	Participants explained design decisions, received feedback and summarized lessons about modeling strategies.
Robotics (AstroRover, rocker-bogie kits, hackathon)	Motivation through rover examples and mission scenarios; presentation of final challenge tasks.	Teams received a mission brief: design and program a mobile robot that completes assigned tasks.	Groups allocated roles and drafted system sketches.	Teams assembled platforms, implemented control logic, executed trials, logged failures and iteratively tuned hardware/software	Final evaluation included a judged run, a technical presentation and a reflective discussion about trade-offs.
Aerodynamics (Paper airplanes)	Concise overview of the four forces of flight followed with demonstrations to stimulate hypothesis.	Challenge: design a paper aircraft maximizing flight time or distance under fixed sheet and launch constraints.	Students proposed folding patterns, stated hypotheses and measurement procedures.	Teams produced prototypes, performed controlled flights, recorded time/distance and refined designs iteratively	Competitive demonstrations and group discussion compared metrics; participants justified which modifications affected performance

Mapping of PBL stages to concrete actions carried out in each workshop, 2025.

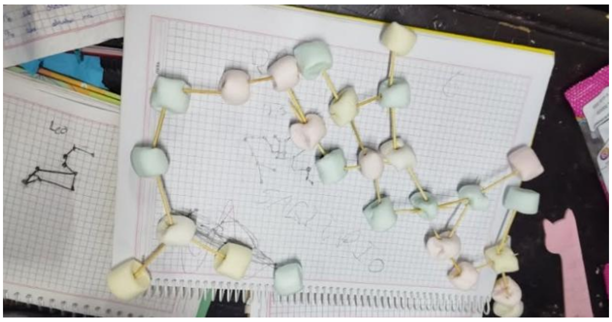

Fig. 1. Low-fidelity prototyping of celestial structures using the PoPBL approach, 2025.

The instructor's role remained primarily facilitative, guiding inquiry rather than directing outcomes. Support took the form of prompting questions, brief checkpoints, and assistance in refining ideas. Evaluation drew on two complementary.

Table I PBL Stages sources: the completeness and coherence of the physical artifact, and the accuracy and clarity of the students' oral explanations.

B. Rocket Workshop (Rocket Design and Simulation)

The rocket workshops combined practical school-level activities with a short technical module, RocketLearn, which introduced participants to fundamental design principles and the use of OpenRocket for basic flight simulation. As shown in Fig. 2 during the classroom sessions, students explored the essential physics of rocketry, assembled simple launch vehicles from wooden or plastic kits, customized their designs, and participated in friendly launch competitions. In the more advanced short course, learners created digital rocket models, ran simulation trials, prepared files for 3D printing, and concluded with team presentations that analyzed their design decisions and results.

Fig. 2. Final evaluation for RocketLearn course, 2025.

C. SolidWorks CAD and AeroCAD (CAD and Aeronautical Design)

The SolidWorks (University Educational Licence) CAD sessions introduced students to 3D modeling with a focus on mechanical components and engineering design intent. Workshops covered basic interface navigation, essential modeling tools, and examples drawn from prior student projects such as a vehicle suspension system before culminating in short, guided design challenges. Each participant produced one or more parts and corresponding technical drawings, resulting in visible engagement and demonstrable skill development.

The CAD activities emphasized constrained design problems that required the application of modeling techniques to satisfy specific functional or geometric requirements. Students justified their modeling decisions and produced virtual prototypes of their artefacts suitable for later simulation or even manufacturing. The process followed a problem decomposition sequence from requirements to sketches to parametric geometry with iterative refinement based on instructor feedback and brief peer review. A short design defense concluded the session. Through this process, participants developed conceptual understanding of design logic alongside transferable technical proficiency relevant to professional engineering practice.

D. AstroRover and Robotics (Mechanics, Programming and Systems Thinking)

The robotics program included multiple instructional formats, ranging from a five-day AstroRover course using LEGO Mindstorms to hands-on rocker–bogie rover builds and multi-category hackathon challenges. The AstroRover course introduced core principles of mechanics, programming, and structural design, culminating in a problem-solving competition. The Perseverance Rover workshops paired a brief theoretical overview of rover engineering with a wooden rocker–bogie construction kit, allowing students to explore the mechanical behavior of mobility systems. The OrionX hackathon extended these concepts further, as shown in Fig. 3, integrating Arduino-based control, formal presentations, and live demonstrations of functioning hardware. During final evaluations, participants showcased programming skills, mechanical reasoning, and inventive approaches to solving the assigned missions.

Fig. 3. OrionX hackathon winners, 2025.

All robotics activities were organized around mission-driven challenges: designing a vehicle capable of completing specific tasks or navigating defined obstacles. Teams distributed responsibilities, built functional prototypes, and iteratively refined both hardware and code through successive testing. The work required coordinated integration of mechanical design, sensing systems, and control logic, reinforced through continuous instructor feedback. The hackathon format added structured presentation and jury evaluation components, strengthening students' communication and argumentation skills, while the multi-day courses provided the time needed for deeper iteration and progressive mastery of key robotics concepts.

E. Aeronautics and Paper Airplanes (Principles of Flight)

The aeronautics workshop introduced the four fundamental forces of flight through a brief theoretical overview, followed by iterative paper-aircraft design and testing as shown in Fig. 4. Sessions were structured around repeated design-test-improve cycles and incorporated friendly competitions to measure flight duration and distance. Implemented across multiple age groups including students from community centers and shelter homes—the activity consistently generated high engagement and visible motivation to refine performance through successive trials.

The learning task was clearly defined: create a paper airplane optimized for a chosen performance metric. Participants proposed hypotheses regarding how specific geometric changes might influence flight behavior, constructed and tested low-fidelity prototypes, and interpreted the results using empirical evidence. Iterative testing prompted evidence-based reasoning and reflective discussion about how structural adjustments affected aerodynamics. Each session concluded with a comparative showcase in which teams presented their designs, shared insights, and articulated the reasoning behind their modifications, an exercise that reinforced both conceptual understanding and scientific communication.

Fig. 4. Aeronautics workshop, 2025.

V. Results

As mentioned in Refs. [5, 6], this section reports the probabilistic and inferential findings obtained from the post-intervention survey. The analysis is presented in terms of estimated probabilities and conditional relationships, allowing us to quantify how the Project-Based Learning (PBL) approach influenced students' interest in STEM, their perceptions of the workshops, and their self-reported learning outcomes. Framing the results in probabilistic terms provides a clearer picture of the magnitude of the observed effects and enables comparison across different participant groups.

A. Probability of Increased Interest in STEM Disciplines

Let Y_i be a binary variable representing student i's interest in STEM, where: $Y_i = 1$ if the student reports interest in STEM, $Y_i = 0$ otherwise.

The estimated probability of STEM interest is defined as shown in Eq. (1):

$$P(Y=1) = \left(\frac{1}{n}\right) \times \sum Y_i \quad (1)$$

where:

- n is the total number of surveyed participants.
- Y_i represents the observed response of student i.

Eq. (1) corresponds to the sample mean of a Bernoulli variable. In this context, it represents the proportion of students expressing interest in STEM.

Using this estimator, the probability of STEM interest before the course was estimated as 0.228. After the PBL intervention, the estimated probability increased to 0.882, as shown in Fig. 5, yielding an absolute probability change of the Eq. (2):

$$\Delta P = P_{after} - P_{before} = 0.882 - 0.228 = 0.654 \quad (2)$$

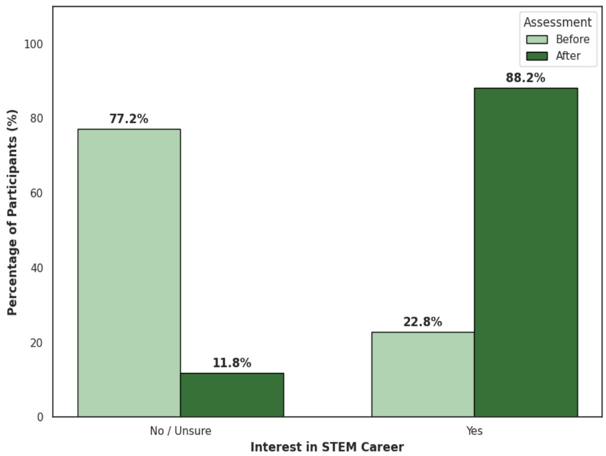

Fig. 5. Probability of interest in STEM disciplines before and after the PBL course.

B. Probabilistic Analysis of STEM Interest Change by Educational Level

Let Y_i be a binary variable representing student i's interest in STEM. To quantify the impact of the PBL course, a change variable was defined as in Eq. (3):

$$\Delta Y_i = Y_{iafter} - Y_{ibefore} \quad (3)$$

where $Y_{ibefore}$ and Y_{iafter} denote the student's reported interest before and after the intervention, respectively.

The variable ΔY_i can take three values:

- $\Delta Y_i = 1$: increase in interest,
- $\Delta Y_i = 0$: no change,
- $\Delta Y_i = -1$: decrease in interest.

Let G denote the educational level of the student. The conditional probability of each outcome was estimated as in the Eq. (4):

$$P(\Delta Y = k \mid G = g),\ k \in \{-1, 0, 1\} \quad (4)$$

This quantity represents the proportion of students within educational level g exhibiting a given type of change.

Across all analyzed grades, the probability of a positive change $P(\Delta Y = 1 \mid G = g)$ was consistently higher than other outcomes.

The expected change in interest for each grade was computed as the Eq. (5):

$$E[\Delta Y \mid G = g] = \sum k \cdot P(\Delta Y = k \mid G = g) \quad (5)$$

As illustrated in Fig. 6, the probabilistic distribution shows a robust inclination toward positive outcomes across all cohorts. Across all analyzed grades, the probability of a positive change $P(\Delta Y = 1 \mid G = g)$ was consistently higher than other outcomes, indicating a net expected gain in STEM interest.

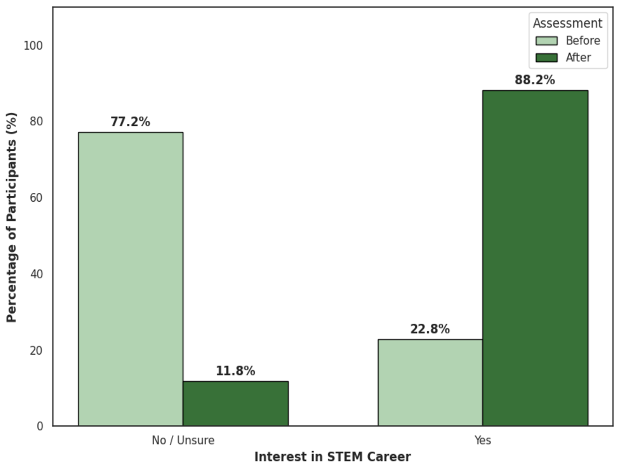

Fig. 6. Expected change in STEM interest by educational level.

The analysis reveals that the intervention consistently fosters interest without regressive effects, as evidenced by the absence of negative expectations even in levels with more balanced distributions, such as 5th Grade (Secondary) with 71% and 3th Grade (Secondary) with 87%.

This high density of positive transitions underscores a generalized receptivity to the PBL methodology, validating the efficacy of the current framework in maintaining an upward trajectory of STEM.

C. Probability of Valuing Key PBL Components

For each PBL component C_j, the probability of selection was computed as in Eq. (6):

$$P(C_j = 1) = \frac{n_j}{n} \quad (6)$$

The highest probabilities corresponded to the use of technological tools (0.382) and learning through real-world challenges (0.353). These results suggest that the "hands-on" nature of the workshops is the primary driver of student engagement, as the Fig. 7.

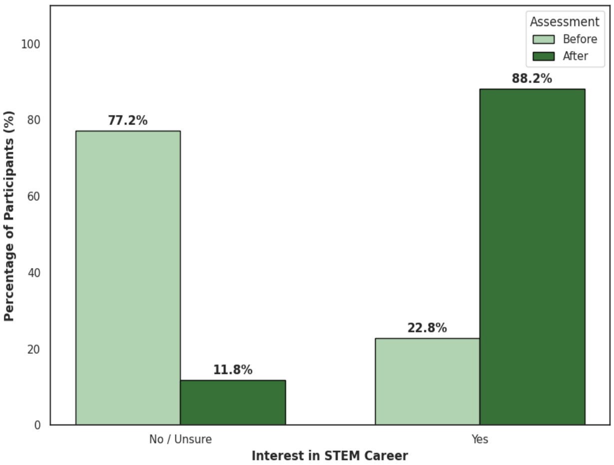

Fig. 7. Probability of selecting key PBL components as most valuable.

D. Probability of Perceived Soft Skills Development

For each soft skill Km, the probability of perceived improvement was estimated as in Eq. (7).

$$P(K_m = 1) = \frac{nm}{n} \quad (7)$$

Consistent with the research's goal of fostering 21st-century competencies, creativity showed the highest probability of development (0.706), followed by teamwork (0.471) and problem-solving (0.412), as shown in Fig. 8. This aligns with the iterative design-build-test cycles inherent in the rocketry and robotics workshops.

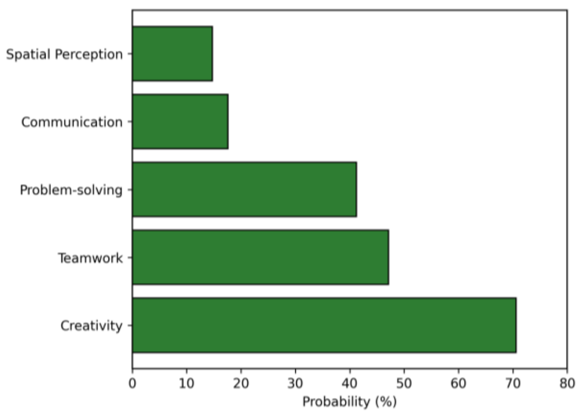

Fig. 8. Probability of perceived development of soft skills.

E. Probability of Transferability of PBL Methodology to School Subjects

For each PB For each subject T_{pbl}, the estimated probability was computed as:

$$P(T_{pbl} = 1) = \frac{n_l}{n} \quad (8)$$

Computer science and technology exhibited the highest probability (0.765), followed by mathematics (0.471) and physics (0.441), indicating that students perceive a natural synergy between PoPBL and quantitative sciences, as shown in Fig. 9.

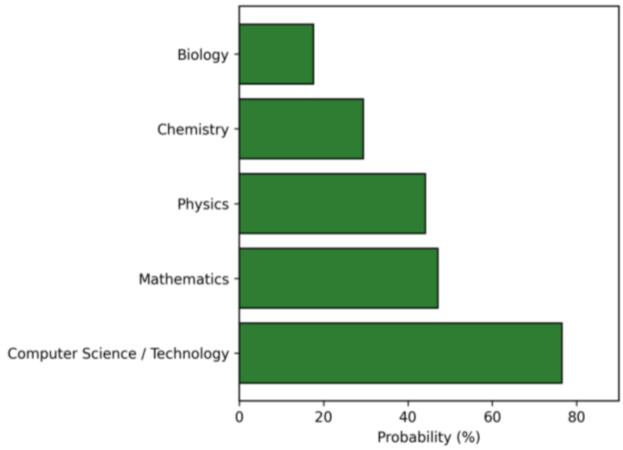

Fig. 9. Probability of preferred subjects for PBL implementation.

VI. Conclusion

The participation of the VEMEC team in NASA's Human Exploration Rover Challenge (HERC) offers a compelling illustration of how Project-Based Learning (PBL) can transform STEM motivation in a developing-country context. The combined quantitative and qualitative evidence shows that this instructional model reshapes student engagement patterns, elevating scientific motivation through exposure to authentic engineering challenges.

One of the most striking outcomes was the pronounced shift in participants' career intentions. The estimated probability of expressing STEM interest, $P(Y = 1)$, increased from an initial baseline of 0.228 to 0.88 after the intervention, representing a 65.4% gain. This change reflects a clear movement from initial uncertainty toward a well-defined vocational inclination. Equally important, the intervention dramatically lowered the probability associated with the "No/Unsure" category, which declined from 0.772 to 0.118.

Taken together, these results indicate that sustained exposure to hands-on scientific problem solving such as rocketry, rover engineering, and robotics helps students reinterpret STEM not as a distant or abstract field, but as a concrete, attainable pathway. The HERC experience thus serves as a strong validation of PBL's capacity to influence career trajectories and strengthen scientific identity, particularly in contexts where access to high-impact STEM opportunities is limited.

The program's impact remained strong and statistically consistent across the different educational levels included in the study. The conditional probability of observing a positive change, we reached an average of 0.654, peaking at 0.870 in key developmental stages such as the third year of secondary school. These values suggest that the PoPBL methodology is broadly adaptable and well-received throughout the Bolivian educational landscape. Likewise, the exceptionally high probability of satisfaction approaching 1.000 for meeting or exceeding expectations speaks to the pedagogical robustness and contextual relevance of the program.

Beyond its influence on individual motivation, the initiative also contributed to the development of essential 21st-century transversal competencies. High perceived growth in creativity (0.706), teamwork (0.471), and problem-solving (0.412) underscores the value of collaborative and open-ended projects as drivers of both cognitive and socio-emotional development. These improvements are closely tied to students' appreciation of core PBL elements, particularly the integration of technological tools and engagement with real-world challenges. Furthermore, the strong transferability probabilities reported for computer science (0.765), mathematics (0.471), and physics (0.441) point to a clear demand among students for curricular innovations that make scientific content more concrete and applicable.

Looking ahead, the findings point to three strategic directions for institutional development: First, formal curriculum integration should build on the high perceived transferability of the approach by systematically incorporating adaptable STEM-PBL modules into the national curriculum. Second, longitudinal impact evaluation is recommended to assess the persistence of the observed probabilistic shifts and to examine their influence on students' long-term academic performance and career pathways in STEM fields. Third, sustainable geographic expansion should focus on developing scalable implementation models capable of reaching diverse urban and rural regions across Bolivia, thereby increasing social inclusion and maximizing the national impact of experiential STEM learning.

In addition, further research and scholarly discussion are encouraged to deepen understanding of these strategic directions and to explore complementary implementation approaches. Academic forums and future studies can provide valuable opportunities to share emerging ideas, compare experiences across contexts, and refine scalable models for experiential STEM education, thereby strengthening both theoretical insights and practical applications.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Fabio Diaz Palacios and Abigail Lopez Tarqui conceptualized the study, conducted and supervised the research, and led the writing and revision of the manuscript. Grace Luna Verdueta conducted the STEM activities. Ariana Reyes Ticona analyzed the data and contributed to the Background section. Ignacio Coriza Rondo wrote the Abstract and Introduction. María Veizaga Galarza drafted the Conclusions, and Valeria Alcázar Gonzales led the Methodology. All authors participated in the implementation of the PBL-STEM activities, contributed to data analysis and interpretation, and approved the final manuscript.

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