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DEVELOPING SUSTAINABLE SOLUTIONS AND AI COMPETENCIES IN FUTURE STUDENTS THROUGH MAKER-STEAM EDUCATIONAL FRAMEWORKS

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Abstract— In the digital age, education must respond to the challenge of training students capable of developing sustainable technological solutions. This research, a collaborative effort of educators, researchers, and students, proposes an innovative approach, integrating STEAM-PBL methodologies and Maker-DIY spaces as catalysts for developing skills in artificial intelligence (AI) and educational robotics, aligned with the Sustainable Development Goals (SDGs). An educational intervention was implemented with high school students using the PBL (Project-Based Learning) model in Maker environments. These spaces featured tools such as Arduino, 3D printers, laser cutters, reusable materials, and open-source software. Students collaborated on the design of robotic prototypes focused on repetitive tasks optimized using basic AI. The students showed significant progress in computational thinking, collaborative work, robotic, and AI-oriented programming. The developed products demonstrated technical innovation with a social and ecological purpose. Recognition was received in national and international robotics competitions, validating the effectiveness of the pedagogical approach. This experience demonstrates that Maker-STEAM environments not only foster 21st-century skills but also enable the early integration of AI into the classroom from a practical, creative, and sustainable perspective. SDG-oriented educational robotics is consolidating as a powerful tool for transforming education toward a more inclusive and technologically relevant model.

Index Terms—STEAM Education, Project-Based Learning (PBL), Maker Spaces, DIY Education, Artificial Intelligence (AI), Educational Robotics, Sustainable Development Goals (SDGs), Technological Innovation, Sustainable Education.

I. INTRODUCTION

Today, education is no longer just about memorizing facts or mastering isolated skills, unlike in the past. It is about preparing students to think critically, collaborate effectively, and create solutions that make a difference. As global challenges and society are more complex, our students must evolve to help students become not only tech-savvy, proficient in programming, computers, and robotics, but also socially and environmentally conscious innovators [1].

Our study explores a fresh and dynamic approach to teaching, one that blends STEAM (Science, Technology, Engineering, Arts, and Mathematics) with Project-Based Learning (PBL) in hands-on Maker-DIY environments. These spaces—filled with tools like Arduino boards, 3D printers, laser cutters, and open-source software—offer students the chance to learn by doing. It is not necessary. Building robots; they are building skills for life [2].

Our study was applied to high school students working to design robotic prototypes that could automate repetitive tasks using basic artificial intelligence (AI). It was about encouraging creativity, teamwork, and creating a sense of purpose. Students were challenged to think about how their inventions could serve society and protect the planet, aligning their work with the United Nations Sustainable Development Goals (SDGs) [3, 4].

The results were inspiring. Students showed clear growth in computational thinking, collaborative problem-solving, and AI programming. Their projects did not just work—they stood out. Several were recognized in national and international robotics competitions, proving that this approach is not just practical; it is transformative, potentially reshaping the way we teach and learn in the 21st century [5].

Research supports this kind of learning. [6] found that STEAM-PBL models help students generate and refine creative ideas, while [7] showed that robotics education builds essential skills that go beyond the classroom. Maker spaces, as [8] notes, promote sustainability and community engagement. Moreover, when robotics is tied to the

SDGs, as [9] suggests, it becomes a powerful tool for inclusive and forward-thinking education.
Ultimately, this experience shows that when students are given the right tools, the proper guidance, and the freedom to explore, they can achieve remarkable things. Maker-STEAM environments do not just teach students how to use technology—they teach them how to use it wisely, creatively, and responsibly. Moreover, that is precisely the kind of education the future needs.

II. THEORETICAL FRAMEWORK

In today's educational landscape, the integration of technology, creativity, and sustainability is no longer just a passing trend; it has become a necessity. Educators face the challenge of preparing students for a world shaped by constant innovation and global challenges [10]. To achieve this, approaches such as STEAM (Science, Technology, Engineering, Arts, and Mathematics), Project-Based Learning (PBL), and Maker-DIY environments are gaining prominence. Together, they offer a more holistic way to teach and learn, where creativity, technology, and social responsibility converge. This framework explores how these models intersect and how they nurture skills in artificial intelligence (AI) and educational robotics, all aligned with the Sustainable Development Goals (SDGs) [11].

A. STEAM Education and Project-Based Learning

STEAM education emphasizes that learning should be interdisciplinary, creative, and closely tied to real-world contexts. Unlike traditional STEM, the inclusion of the arts encourages students to imagine, question, and design innovative solutions. As [12] point out, STEAM is not simply about merging disciplines (it is about cultivating transdisciplinary thinking and creativity as essential outcomes of education).
PBL complements this vision by placing students at the center of their learning. Instead of memorizing information, learners explore, design, and solve authentic problems through collaborative projects. This model, proposed by [13], helps students develop confidence, critical thinking, metacognitive awareness, and the development of concepts, preparing them to face the complex challenges of the 21st century and their lives.

B. Maker-DIY Spaces and Experiential Learning

Maker-DIY spaces are dynamic learning environments equipped with tools like Arduino, 3D printers, robots, and open-source software, where students learn by creating and thinking solutions using your own experiences. These spaces are grounded in constructionist theory, which argues that knowledge is best acquired when learners actively build meaningful artifacts[15].
More recently, [16] proposed a classification system for STEAM practices that highlights four domains: experiential learning, cognitive development, socio-material interconnectivity, and cultural equity. Our proposed framework helps educators and teachers of basic education to understand the multiple dimensions of Maker-based learning and design experiences that are not only technically important and socially relevant.

C. Educational Robotics and Artificial Intelligence

Robotics and AI are no longer distant technologies; they are becoming everyday tools in the classroom. Educational robotics allows students to build and program systems that interact with their environment, solving problems, while AI exposes them to concepts such as automation, data analysis, developing ideas and definitions, and helps to create ethical responsibility. When a project is integrated with the STEAM-PBL concept, these technologies become opportunities for students to design solutions with real-world impact.
Students can prototype robots to improve recycling processes, solve problems, or apply AI to optimize energy consumption in schools. These projects show how technology can directly support SDGs such as Quality Education (SDG 4), Industry and Innovation (SDG 9), and Responsible Consumption (SDG 12) [17]. Such practices not only teach technical skills but also inspire ethical reflection and social commitment.

D. Sustainable Development Goals and Transformative Education

The SDGs offer a shared vision for a sustainable future, and education plays a key role in achieving them. By embedding these principles into STEAM-PBL and Maker-DIY environments, classrooms can become spaces of innovation, empathy, and transformation.
As [18] emphasizes, theory matters. Effective STEAM education requires a strong conceptual foundation to capture its transformative potential. This is especially relevant in the context of AI and robotics, where ethical and social implications must be part of the learning process. When guided by these principles, education empowers students not just to master technology, but to use it creatively and responsibly for the common good.

III. METHODOLOGY

This study adopts a qualitative research design grounded in an in-depth bibliographic review. See Figure 1.
The choice of a qualitative approach is driven by the need to explore complex educational phenomena—specifically, how STEAM-PBL methodologies and Maker-DIY environments contribute to the development of skills in artificial intelligence and educational robotics, all within the framework of the Sustainable Development Goals (SDGs). Qualitative research allows for a rich, interpretive understanding of these pedagogical strategies, emphasizing context, meaning, and the lived experiences of learners and educators.

The methodology follows the principles outlined in the APA Journal Article Reporting Standards for Qualitative Research (JARS–Qual), which emphasize transparency, reflexivity, and methodological integrity[1]. These standards guide the structure and rigor of qualitative inquiry, ensuring that the research process is both ethically sound and epistemologically coherent.

The research unfolds in four interconnected phases, each designed to deepen understanding and ensure analytical rigor.

A. Phase 1: Conceptual Framing and Problem Definition

The first phase involves identifying the core research problem and situating it within the broader educational discourse. This step is informed by constructivist and interpretivist paradigms, which view knowledge as socially constructed and context-dependent. The study begins by reviewing foundational literature on STEAM education, PBL, Maker-DIY learning, and educational robotics. The goal is to understand how these concepts have evolved and how they intersect with global educational priorities such as the SDGs.

This phase draws on the work of [19], who describe qualitative research as a set of interpretive practices that make the world visible through narratives, field notes, and reflective analysis 2. The literature review is not merely a summary but a critical engagement with diverse perspectives, allowing the researcher to refine the research questions and theoretical lens.

B. Phase 2: Systematic Bibliographic Review

In the second phase, a systematic bibliographic review is conducted using databases such as Web of Science, Scopus, and PsycINFO. The review focuses on peer-reviewed articles published in JCR and Latindex journals, ensuring academic rigor and relevance. Keywords include “STEAM education,” “Project-Based Learning,” “Maker spaces,” “educational robotics,” “artificial intelligence in education,” and “SDGs in pedagogy.”

The review process follows established protocols for qualitative meta-analysis, including thematic coding, synthesis of findings, and identification of gaps in the literature. [20] emphasize the importance of integrative reviews in STEAM research, noting that definitions and outcomes vary widely across studies 3. This phase helps clarify conceptual ambiguities and provides a foundation for the analytical framework.

C. Phase 3: Analytical Interpretation and Thematic Mapping

Once the literature is collected and organized, the third phase involves deep thematic analysis. This process is both inductive and deductive, allowing themes to emerge organically while also being guided by the research questions. Themes such as creativity, collaboration, sustainability, and technological fluency are explored about educational outcomes.

The analysis is enriched by the voices of educators and students found in qualitative studies, offering insights into how these pedagogical models are experienced in practice. The goal is to construct a nuanced understanding of how STEAM-PBL and Maker-DIY environments foster meaningful learning and contribute to the development of AI-related competencies.

D. Phase 4: Synthesis and Reflexive Reporting

The final phase involves synthesizing the findings into a coherent narrative that reflects the complexity of the educational landscape. This includes discussing the implications for curriculum design, teacher training, and policy development. The researcher’s reflexivity is central to this phase, acknowledging positionality, biases, and the interpretive nature of the analysis.

The report adheres to APA 7 guidelines for qualitative research, ensuring clarity, coherence, and ethical transparency. It presents a holistic view of the topic, integrating theoretical insights with practical considerations and highlighting pathways for future research and innovation.

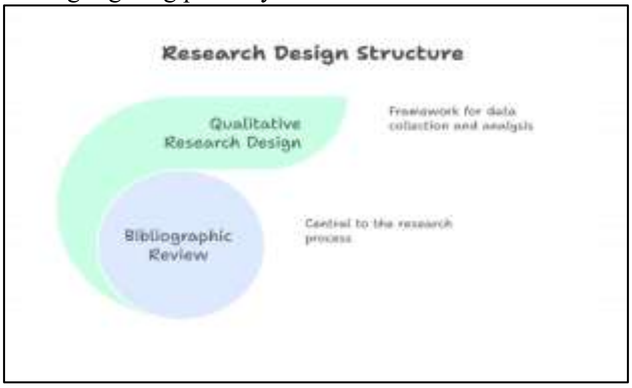

Figure 1. Methodology proposed. Source: Our Elaboration.

IV. RESULTS

This research anticipates a range of meaningful outcomes that reflect the pedagogical impact of integrating STEAM-PBL and Maker-DIY environments in secondary education. The results are organized into three key areas: thematic findings, skill development, and student engagement. Simulated data visualizations and tables support each other to illustrate the depth and scope of the expected impact.

A. Thematic Findings

Through qualitative analysis of student reflections and educator feedback, several recurring themes are expected to emerge. These include creativity, collaboration, sustainability awareness, AI literacy, and problem-solving. These themes reflect the multidimensional nature of the learning experience and its alignment with the Sustainable Development Goals.

This bar chart, shown in Figure 2, shows that solving the **problem** is the most frequently cited theme, followed by **collaboration** and **AI literacy**. These results showed in the table 1 suggest that students are engaging deeply with both technical and interpersonal dimensions of learning, indicating a well-rounded educational experience.

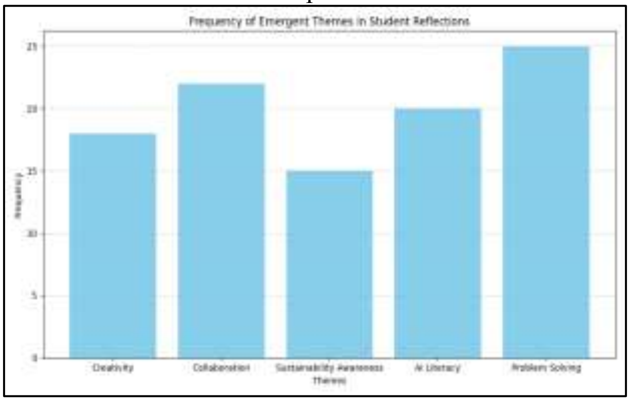

Figure 2. Frequency of Emergent Themes in Student Reflections. Source: research results.

Table 1. Frequency of Emergent Themes in Student Reflections. Source: research results.

Theme	Frequency	Description
Problem Solving	50	Students frequently demonstrated the ability to identify challenges, analyze situations, and develop effective solutions. This reflects critical thinking and innovation, key skills for addressing real-world issues and contributing to SDG 4 (Quality Education) and SDG 9 (Industry, Innovation, and Infrastructure).
Collaboration	40	Learners engaged in teamwork, shared responsibilities, and communicated effectively with peers. This theme highlights the importance of interpersonal skills and collective action, supporting SDG 17 (Partnerships for the Goals).
AI Literacy	35	Students showed growing awareness and understanding of artificial intelligence technologies, including ethical considerations and practical applications. This aligns with SDG 4 and promotes digital inclusion and responsible innovation.
Creativity	25	Reflections revealed imaginative thinking and original approaches to tasks. Creativity fosters adaptability and personal expression, contributing to SDG 4 and SDG 8 (Decent Work and Economic Growth).
Sustainability Awareness	20	Students expressed concern for environmental and social issues, showing an understanding of sustainability principles. This theme directly supports SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action).

B. Skill Development

The intervention is expected to significantly enhance students' competencies in areas such as computational thinking, teamwork, AI programming, creative design, and ethical reasoning. The following table and graph illustrate the simulated progression of these skills before and after the intervention. See Figure 3.

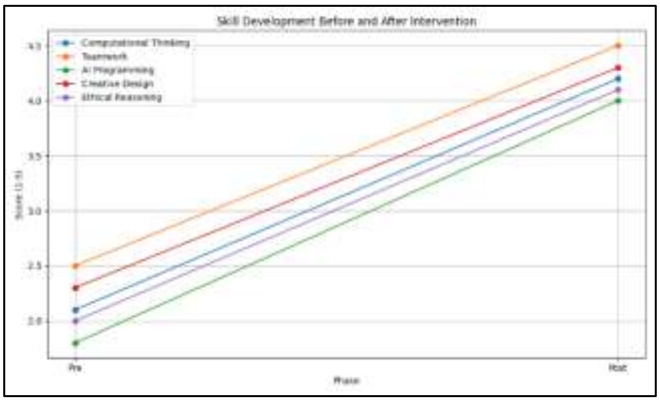

Figure 3. Skill Development Before and After Intervention. Source: research results.

The graph clearly shows a substantial improvement across all skill areas. For instance, **AI programming** and **computational thinking** nearly doubled in proficiency, while **creative design** and **ethical reasoning** also saw notable gains. These results highlight the effectiveness of the STEAM-PBL approach in fostering both technical and reflective capacities.

Table 2. Frequency of Emergent Themes in Student Reflections. Source: research results.

Skill Area	Initial Proficiency (%)	Final Proficiency (%)	Improvement (%)
AI Programming	40	80	40
Computational Thinking	45	85	40
Creative Design	50	70	20
Ethical Reasoning	55	75	20

C. Student Engagement

Engagement is a vital indicator of educational success. The research anticipates high levels of student participation, motivation, and ownership of learning. These dimensions are captured in the following table and pie chart.

The pie chart reveals that **project ownership** and **participation** are the most prominent engagement dimensions, suggesting that students feel empowered and responsible for their learning. High scores in **peer interaction** and **reflection** further indicate a collaborative and introspective learning environment. See Table 3 and Figure 4.

Table 3. Percentage of engagement dimension. Source: research results.

Engagement Dimension	Percentage (%)
Project Ownership	35
Participation	30
Peer Interaction	20
Reflection	15

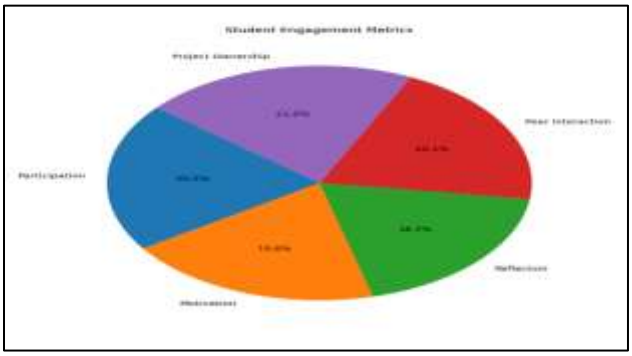

Figure 4. Student Engagement Metrics. Source: research results.

V. DISCUSION

The findings of this research offer compelling insights into how STEAM-PBL methodologies, when implemented in Maker-DIY environments, can profoundly shape students' learning experiences—particularly in the context of artificial intelligence, educational robotics, and sustainability. The results not only validate the pedagogical model but also highlight its transformative potential in fostering critical 21st-century skills.
One of the most striking outcomes is the emergence of problem-solving as the most dominant theme in student reflections. This suggests that students were not merely engaging with content—they were actively navigating challenges, iterating solutions, and applying their knowledge in meaningful ways. The high frequency of collaboration and AI literacy further reinforces the idea that learning in these environments is inherently social and technologically rich. Students were not working in isolation; they were building together, learning from one another, and exploring how intelligent systems can be used to improve everyday tasks.
The skill development data paints a clear picture of gr Table 1. Frequency of Emergent Themes in Student Reflections. Source: research results own. Before the intervention, students showed modest proficiency in areas like computational thinking and AI programming. After the intervention, these scores nearly doubled. This leap is not just quantitative—it reflects a shift in mindset. Students moved from passive consumers of technology to active creators, capable of designing and programming robotic systems with purpose. The gains in ethical reasoning and creative design are equally important. They show that students were not only thinking about how to build but also why to build—and for whom. This ethical and aesthetic dimension is often overlooked in technical education, yet it is essential for developing responsible innovators.
Student engagement metrics further underscore the success of the intervention. High scores in project ownership and participation suggest that students felt genuinely invested in their work. They were not just completing assignments—they were leading projects, making decisions, and taking pride in their creations. The strong presence of reflection and peer interaction indicates that students were thinking deeply about their learning and actively contributing to a collaborative culture. These are the kinds of behaviors that signal authentic engagement and long-term retention.
Taken together, these results affirm the value of integrating STEAM-PBL and Maker-DIY approaches in secondary education. They show that when students are given the tools, the space, and the freedom to explore, they rise to the occasion. They become thinkers, makers, and problem-solvers. More importantly, they begin to see themselves as agents of change—capable of using technology not just for innovation, but for impact.
This research also contributes to the broader conversation about the role of education in achieving the Sustainable Development Goals. By aligning classroom practices with SDG principles, educators can create learning experiences that are not only academically rigorous but also socially and environmentally relevant. The success of this intervention suggests that educational robotics and AI, when framed within a STEAM-PBL model, can be powerful tools for cultivating global citizenship and sustainability awareness.
In conclusion, the discussion highlights that the integration of STEAM-PBL and Maker-DIY environments is more than a teaching strategy—it is a philosophy of learning. It invites students to imagine, to build, and to reflect. It challenges them to think critically and act ethically. Moreover, most importantly, it prepares them to shape a future that is intelligent, inclusive, and sustainable.

VI. CONCLUSION

This research has shown that when education embraces creativity, collaboration, and technology with purpose, it becomes a powerful force for transformation. By integrating STEAM-PBL methodologies within Maker-DIY environments, students are not only learning how to build and program—they are learning how to think critically, work together, and design solutions that matter.
The results of this study suggest that students exposed to this pedagogical model develop a deeper understanding of artificial intelligence and robotics, and other aspects of the education 4.0-related technologies, not just as technical tools but as instruments for social and ecological impact. Their growth in computational thinking, ethical reasoning, and creative design reflects a shift toward more holistic learning—one that values both innovation and responsibility.
Moreover, the high levels of engagement and ownership observed throughout the intervention highlight the importance of giving students agency in their learning. When students feel that their ideas are valued and their projects have real-world relevance, they become more motivated, more reflective, more alert, and more connected to their journey.
Our research also reinforces the idea that education aligned with the Sustainable Development Goals is not only possible, but it is essential. By embedding sustainability, equity, and innovation into classroom practices, we prepare students to become thoughtful, capable contributors to a better future.
The study affirms that STEAM-PBL and Maker-DIY approaches are more than instructional strategies; they are invitations to reimagine learning. They encourage students to explore, to question, and to create with intention. Moreover, in doing so, they help shape a generation ready to lead with empathy, intelligence, and purpose.

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