

# Early Research Training in Engineering Education: Systematization of a Project-Based and Prototype-Building Experience

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**Abstract.** *This article systematizes an early research training experience developed through RemiBots at Corporación Universitaria Remington. The strategy combined project-based learning, hands-on exploration, and prototype construction before written project formulation. Institutional records from 2020 to the first semester of 2026 were retrospectively analyzed for 35 unique students. Results show a transition from technical mini-projects to team-based formative research projects and participation of 19 students in academic dissemination activities. The findings describe the strategy's operational feasibility without establishing causal relationships with research competency development.*

**Keywords—** *project-based learning, research training, engineering education, undergraduate research groups*

## 1. Introduction

In higher education, the development of research competencies is often concentrated in the advanced stages of academic programs. This pattern, which is common in engineering curricula, may limit students' opportunities for early engagement in research activities and delay their exposure to processes involving project formulation, experimentation, and academic dissemination. This situation is particularly relevant in contexts characterized by diverse educational backgrounds and unequal conditions of access to educational and technological resources.

In response to this situation, several strategies have emerged to promote students' early participation in research environments. Among them, research training groups have become key spaces for collaborative learning, experimentation, and innovation in the Latin American context [Quintero-Corzo et al. 2008]. These groups not only provide an alternative to research training introduced at later stages, but also enable technological practice to be connected with scientific thinking from the first semesters of undergraduate education.

This article describes and systematizes an early research training experience initiated in 2019 and institutionally formalized in 2020 as the RemiBots research training group, associated with the Systems Engineering program at Corporación Universitaria Remington. The experience integrated hands-on activities, mini-projects, and formative research projects developed with students enrolled in a virtual learning modality. The initiative was grounded in project-based learning (PBL), a pedagogical approach in which students actively participate in developing technological solutions to

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real-world problems. A distinctive feature of this experience was the progressive integration of practical activities, mini-projects, and more structured formative research projects. This sequence made it possible to establish a progression from initial technical exercises to the formulation and dissemination of proposals developed by student teams. Although this pathway is conceptually related to skills such as problem-solving, collaborative work, and critical reasoning, these competencies were not specifically measured in this study.

The experience was implemented in a context characterized by diversity in students' prior educational backgrounds. Participants were students from the Systems Engineering program at Corporación Universitaria Remington, and the strategy was coordinated from a regional campus located in the Colombian Caribbean region. The participants lived in the municipality where the experience was coordinated or in nearby communities and were enrolled in a virtual learning modality. Some of them came from rural areas and had educational trajectories characterized by varying conditions of access to technological and educational resources. These characteristics made it relevant to document the experience as an alternative practical and progressive approach to research engagement. Nevertheless, the study did not include specific instruments to measure educational gaps, academic inclusion, or the development of research competencies. The need to build more inclusive and flexible educational pathways has also been highlighted in international debates on the future of education and the reduction of inequalities in access to learning [UNESCO 2021].

The objective of this study is to describe and systematize an early research training experience that began as an exploratory initiative in 2019 and was institutionally formalized in 2020 as the RemiBots research training group, associated with the Systems Engineering program at Corporación Universitaria Remington. The study also descriptively analyzes students' participation in the experience, their involvement in formative research projects, the evolution of the initiatives developed, and their participation in academic dissemination activities, with the aim of identifying the contributions, limitations, and potential transferability of the strategy to other educational contexts.

Based on this objective, the study is guided by the following research questions:

1. How is an early research training strategy based on projects and the prior construction of prototypes structured and implemented?
2. What patterns of student engagement, project development, and academic dissemination can be observed among the students who participated in this experience?

The remainder of this article is organized as follows. Section 2 presents the theoretical foundations related to project-based learning, constructivism, and early research training. Section 3 describes the context, the participants, and the methodological process implemented within the research training group. Section 4 presents the descriptive results obtained from records concerning student participation, project monitoring, and involvement in academic dissemination activities. Section 5 discusses the findings, presents the limitations of the study, and analyzes the conditions that may influence the transferability of the experience. Finally, Section 6 presents the main conclusions and possible directions for future work.

## 2. Theoretical Framework

Project-based learning has become a relevant pedagogical approach in higher education, particularly in engineering programs, because of its capacity to promote active learning and the development of applied competencies. This approach places students at the center of the educational process and engages them in real-world problems whose resolution requires the integration of knowledge and skills [Thomas 2000]. In this sense, PBL is not limited to content transmission; rather, it makes problem-solving the central axis of learning. Available evidence on active learning methodologies also reports improvements in academic performance and reductions in failure rates in science, technology, engineering, and mathematics disciplines [Freeman et al. 2014].

From a constructivist perspective, learning is understood as an active process of knowledge appropriation in which students construct new understandings through interaction with their environment and the resolution of meaningful situations [Piaget 1970; Vygotsky 1978]. Within this framework, PBL supports meaningful learning by connecting theory and practice in real or simulated contexts. The social dimension of learning is particularly relevant in collaborative environments such as research training groups, where peer interaction constitutes a central mechanism of cognitive development [Vygotsky 1978]. In engineering education, both problem-based learning and project-based learning have been used to integrate disciplinary knowledge, the resolution of real-world situations, and collaborative work [Kolmos and de Graaff 2014].

Several studies have shown that the implementation of PBL in engineering education contributes to strengthening skills such as critical reasoning, problem-solving, teamwork, and student autonomy [Prince and Felder 2006]. Likewise, this approach promotes a greater willingness to learn and stronger engagement in the educational process compared with traditional methodologies centered on content transmission.

In the field of research training, the importance of involving students in research processes from an early stage has been emphasized, as this enables the progressive development of research competencies and supports their understanding of the scientific method [Healey and Jenkins 2009]. Such early involvement strengthens students' capacity to generate knowledge and reduces the gap between academic education and actual research practice.

However, in many educational contexts, research instruction is approached from a theoretical and formal perspective, with the preparation of written documents serving as the starting point. This model may create barriers for students in the early stages of their education or those with diverse educational trajectories because it requires a level of conceptual abstraction that they may not yet have developed. In response to this limitation, there is a need to explore alternative approaches that prioritize experimentation, prototype construction, and hands-on learning as entry points into research.

From this perspective, the strategy described in this study is aligned with the principles of project-based learning and constructivism by integrating the development of technological solutions with research training activities. This articulation provides a conceptual framework for organizing experiences in which practice precedes written formalization. However, because the study did not include specific instruments to

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evaluate accessibility, motivation, or educational inclusion, these dimensions are addressed as interpretive references rather than as empirically demonstrated outcomes of the experience.

As summarized in Table 1, the main differences between conventional research training and the approach described in this study concern the stage at which students become involved, the starting point of the process, the relationship between theory and practice, the treatment of ideas, and the role of academic writing.

**Table 1. Conceptual Comparison between Conventional Research Training and the Approach Described**

| Aspect                                   | Conventional Research Training                                      | Approach Described in the Experience                                                                |
|------------------------------------------|---------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| Stage of student involvement             | Usually concentrated in the advanced stages of the academic program | Promotes engagement from the early stages                                                           |
| Starting point                           | Written project formulation                                         | Hands-on exploration and prototype construction                                                     |
| Relationship between theory and practice | Theory and methodology precede application                          | Initial practical work serves as the basis for subsequent systematization                           |
| Type of initial activities               | Literature review, problem formulation, and academic writing        | Mini-projects, simulations, hardware assembly, and programming                                      |
| Organization of work                     | Frequently individual or centered on course-based activities        | Student teams composed of participants from different academic levels                               |
| Progression of the process               | A previously structured sequence                                    | Gradual progression from technical activities to formative research projects                        |
| Treatment of ideas                       | A relatively stable formulation is expected from the beginning      | Ideas may be reformulated, integrated, or discontinued during the process                           |
| Outputs produced                         | Academic documents and final results                                | Prototypes, diagrams, audiovisual records, and formative research projects                          |
| Dissemination                            | Generally occurs after the project has been consolidated            | May be progressively incorporated through fairs, posters, exhibition stands, and oral presentations |
| Role of writing                          | An initial requirement for structuring the research process         | A subsequent process of systematization and reflection on practice                                  |

The comparison presented in Table 1 is not intended to establish an absolute opposition between the two models, but rather to summarize the conceptual differences that guided the experience described. The proposed approach does not eliminate theoretical formulation or academic writing; instead, it changes their sequence by placing them after an initial stage of exploration, construction, and practical refinement.

### 3. Methodology

The educational experience began in 2019 as a meeting and training initiative aimed at students interested in areas such as robotics and the Internet of Things (IoT). During this initial stage, the activities were conducted on an exploratory basis through hands-on work sessions and the construction of small prototypes. At that time, there was not yet a formally established research training group or an institutional system for registering participants.

In 2020, the initiative was formally recognized as the RemiBots research training group and became affiliated with the Ingeniar Research Group at Corporación Universitaria Remington. From that point onward, institutional forms were implemented to register and monitor members and the activities carried out. Between 2020 and the first semester of 2026, 35 unique students were registered, some of whom remained involved for several academic periods. Therefore, the cumulative figure does not correspond to the sum of the participants registered in each semester, but rather to the total obtained after removing duplicate records across academic periods.

Participation was voluntary and was promoted through periodic calls addressed to students enrolled in the Systems Engineering program in the virtual learning modality who lived in the municipality where the experience was coordinated or in nearby communities. This condition facilitated their participation in face-to-face activities once these resumed. The experience did not involve a fixed cohort: students could join, remain involved for several academic periods, or withdraw for academic, personal, or graduation-related reasons. Consequently, the composition of the research training group and the number of active members varied across the periods analyzed.

To systematize the experience, a descriptive review was conducted of the institutional records available from 2020 through the first semester of 2026. The sources consulted included institutional forms for member registration and monitoring, attendance lists, records of the projects formulated, and information on participation in academic events. Names repeated across different periods were removed to determine the number of unique participants. The information was then organized by academic period and classified into four analytical categories: students' involvement in the experience, participation in formative research projects, the evolution of the initiatives, and participation in academic dissemination settings. The analysis was descriptive and did not include statistical tests or causal estimations.

The working modality varied throughout the period analyzed. In 2020 and 2021, because of the restrictions resulting from the COVID-19 pandemic, the activities were conducted through virtual meetings and remote work on mini-projects proposed by the coordination team. During the sessions, the coordinator demonstrated the use of physical components and materials. However, because most students did not have access to these resources at home, the practical activities were carried out primarily using simulation and electronic design tools. During this period, participants used Tinkercad to simulate circuits, program virtual assemblies, and verify their operation, and Fritzing to create diagrams and representations of the connections. When face-to-face activities resumed, the research training group returned to weekly sessions lasting three to four hours, with a hands-on approach focused on the progressive use of sensors, actuators, and open-hardware electronic modules. Each new component was introduced through short mini-projects, generally completed over one or two sessions.

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Each session followed a sequence that progressed from conceptual understanding to practical implementation. First, the operation of the device was explained, and examples of its application in contexts related to science, technology, engineering, and mathematics were presented. Next, the system design was shown using technical diagrams, the physical assembly was completed, and the required code was developed using open-hardware platforms. Finally, the students reproduced and adapted the assemblies in teams of two to four members, with guidance from the coordination team and opportunities for peer exchange.

Another component of the strategy was the continuous production of visible outputs, such as photographic and audiovisual records of the projects developed, which were subsequently shared in digital environments. These materials were used to document the progress of the activities, disseminate the results, and acknowledge the work carried out by the teams. Although the coordination team regarded them as useful resources for supporting the training process, the study did not include specific instruments to assess their relationship with participants' motivation, engagement, or sense of belonging.

As the students gained experience with different technological components, they were guided in identifying problems and proposing possible solutions. This process led to several formative research initiatives based on the knowledge and experience developed through the mini-projects. The proposals were refined through feedback cycles and, once they reached a sufficient level of development, could be presented at institutional research fairs and other academic events. As shown in Fig. 1, the methodological pathway progressed from the call for participation and mini-projects to prototype construction, the formulation of formative research projects, and their subsequent academic dissemination.

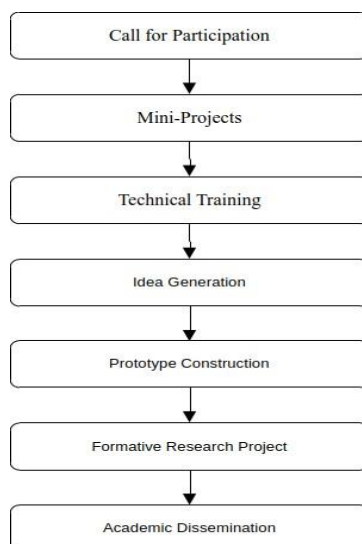


**Figure 1. Methodological Process Implemented in the RemiBots Research Training Group**

From a broader methodological perspective, the strategy was organized around an inverted approach to the research process, in which prototype construction and the practical exploration of ideas preceded the written formalization of the project. In operational terms, students first experimented with, built, and refined their proposals

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and subsequently systematized and documented the process undertaken. This sequence made it possible to structure academic writing on the basis of prior practical experience. However, because no specific instruments were applied to assess perceived difficulty, it is not possible to conclude that this methodological sequence reduced the perceived complexity of research.

### 3.1. Ethical Considerations

This study corresponds to a retrospective systematization of an educational experience and was not derived from an experimental study involving an intervention with participants. The information analyzed came from institutional records generated as part of the academic coordination of the research training group, including registration forms, member-monitoring records, projects developed, and participation in academic activities. For the preparation of this article, the data were analyzed in aggregate form, and names, identification documents, contact information, and any other elements that could enable the individual identification of students were excluded. No surveys, interviews, or additional procedures were conducted exclusively for research purposes.

The study did not undergo prior review by an ethics committee, nor were specific informed consent forms obtained for this publication, because the experience was not originally designed as an intervention-based research study and the analysis was subsequently conducted using aggregated and anonymized institutional information.

## 4. Results

The institutional records show a progressive evolution in students' participation in formative research projects. During the initial implementation periods, particularly between 2020 and 2021, the activities focused on technical training mini-projects proposed and guided by the coordination of the RemiBots research training group. At this stage, the hands-on activities were intended to familiarize participants with technological components, programming, and prototype development, although not all students were involved in formally structured research projects.

Beginning in 2022, a gradual transition took place toward the formulation of student-led projects. This dynamic became more evident from 2023 onward, when a greater number of active members became involved in team-based formative research projects. Consequently, participation in projects was not uniform throughout the period analyzed, but varied according to member retention, the formation of new groups, and the evolution of the initiatives.

The evolution of the strategy from 2020 through the first semester of 2026 is summarized in Table 2, taking into account the working modality, the transition toward formative research projects, and variations in the number and organization of the initiatives.

**Table 2. Evolution of the Experience and Formative Research Projects**

| Period    | Main Characteristics                                                                                                                                                                                       |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2020–2021 | Predominance of coordination-guided technical mini-projects developed through virtual meetings, simulators, and electronic design tools during the period of restrictions caused by the COVID-19 pandemic. |

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|        |                                                                                                                                                                                                                                     |
|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2022   | Beginning of the transition toward formative research projects proposed and developed by students.                                                                                                                                  |
| 2023-1 | Development of four projects involving seven students.                                                                                                                                                                              |
| 2023-2 | No new working group was formed because several members completed their academic programs and there was a temporary absence of students residing in the municipality where the experience was coordinated or in nearby communities. |
| 2024   | Simultaneous development of seven formative research projects.                                                                                                                                                                      |
| 2025   | Reorganization of initiatives and formation of larger teams, with four active projects.                                                                                                                                             |
| 2026-1 | Suspension of some initiatives due to the departure of members and the incorporation of new students; four projects remained under development.                                                                                     |

As summarized in Table 2, the number and organization of the projects varied throughout the period analyzed according to member retention, the incorporation of new students, and the reformulation of the initiatives. The experience evolved from an initial stage focused on technical mini-projects to the development of team-based formative research projects. Variations in the number of projects did not necessarily represent a decline in activity, but rather processes of reorganization, continuity, integration, or suspension of initiatives inherent to the dynamics of the research training group.

Regarding academic dissemination, 19 of the 35 registered students participated at least once in activities aimed at presenting and sharing results, representing approximately 54.3% of the participants. These activities included institutional events, meetings organized by other institutions, and scientific dissemination settings such as those promoted by RedCOLSI. Participation took the form of exhibition stands, poster presentations, and oral presentations. These experiences provided students with opportunities to present their projects to audiences outside the research training group. However, the study did not include specific instruments to assess changes in their academic communication skills.

Another observed aspect was the formation of teams composed of students from different academic levels. Within these groups, more experienced participants supported those in the early stages of their education, particularly during prototype assembly, programming, and the resolution of technical difficulties. From a constructivist perspective, this interaction may be interpreted as a dynamic resembling the zone of proximal development [Vygotsky 1978]. Nevertheless, the study did not include specific instruments to measure knowledge transfer or the collaborative learning that occurred within the teams.

## 5. Discussion

The findings provide a basis for reflecting on alternative approaches to research training in higher education, particularly those that modify the traditional sequence in which written project formulation serves as the starting point. The strategy analyzed proposes an inverted approach in which experimentation, prototype development, and hands-on exploration precede written formalization. In the experience described, this sequence made it possible to organize a progressive pathway from initial technical activities to the formulation of formative research projects. This organization is consistent with the

importance attributed to students' early participation in research practices [Healey and Jenkins 2009]. However, because no instruments were applied to measure perceived difficulty, it is not possible to conclude that the approach reduced this perception among participants.

The experience is particularly relevant when considering its implementation context, which was characterized by the participation of students from rural areas and with heterogeneous educational trajectories. The continuity of the strategy and the involvement of students from different academic levels show that it was possible to sustain spaces for practical training and formative research in this context. Nevertheless, the available records do not support the conclusion that the methodology reduced educational gaps or produced demonstrable processes of academic inclusion. The findings only indicate that the initiative provided opportunities for participation and support to students with diverse access conditions, an aspect that should be examined in greater depth through specific studies on educational inclusion.

The iterative nature observed in the development of several initiatives constitutes a relevant aspect of the experience. The transformation, integration, discontinuation, or reformulation of some ideas shows that project development did not follow a uniform or linear trajectory. Rather than interpreting these changes solely as a lack of continuity, they may be understood as part of a process of exploration and progressive maturation in which students adjusted their proposals on the basis of technical experience, feedback, and the conditions affecting team continuity. This interpretation is consistent with constructivist principles, which view learning as an active and gradual process mediated by interaction with the environment and with other participants [Piaget 1970; Vygotsky 1978]. Nevertheless, because of the descriptive nature of the study, this process was not evaluated using specific instruments designed to measure research competencies.

Another relevant aspect of the strategy was the continuous production of visible outputs, such as functional prototypes and photographic or audiovisual records shared in digital environments. Within the experience, these outputs were used as resources for dissemination, recognition of the work completed, and monitoring of team progress. This practice is consistent with claims regarding the higher levels of participation that active and project-based methodologies may encourage [Prince and Felder 2006]. However, because no specific instruments were applied to assess motivation, engagement, or sense of belonging, it is not possible to conclude that the visibility of these outputs produced measurable changes in these dimensions.

The transfer of the experience to other contexts will depend on specific institutional and territorial conditions, including the availability of technological resources, faculty support, team continuity, the learning modality, and the characteristics of the participating student population. In settings with greater constraints, the strategy would need to be adapted in order to preserve its core components—hands-on exploration, progressive prototype construction, collaborative work, and the subsequent formalization of projects—without assuming that its implementation would produce the same results. Accordingly, future comparative studies could examine which elements of the model are transferable and what adjustments are required in institutions operating under different conditions.

## 5.1. Study Limitations

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This systematization has several limitations that should be considered when interpreting the findings. First, the experience was limited to a single institutional and territorial context and included 35 participants registered between 2020 and the first semester of 2026. Therefore, the findings cannot be directly generalized to other programs or institutions. Second, participation in the research training group was voluntary and depended on the availability of students residing in the municipality where the experience was coordinated or in nearby communities, as well as on factors related to the pandemic, academic persistence, and participants' graduation. Third, the sources analyzed consisted mainly of institutional records concerning student participation, projects, and involvement in academic events, without including interviews, surveys, or specific instruments to measure motivation, educational inclusion, collaborative learning, or the development of research competencies. Finally, the study did not include a comparison group or a longitudinal design aimed at establishing causal relationships. Therefore, the findings should be interpreted as a description of the evolution and operational feasibility of the experience within the context analyzed.

## 6. Conclusions

The experience developed since 2019 shows that, within the context analyzed, it was possible to implement an early research engagement strategy through hands-on activities, mini-projects, and prototype construction. The institutional records available from 2020 through the first semester of 2026 document the participation of 35 students and a gradual transition from coordination-guided technical training activities to the formulation of formative research projects developed by student teams. These findings describe the operational feasibility of the strategy in the context analyzed, but they do not establish its effectiveness or demonstrate a causal relationship between participation in the research training group and the development of research competencies.

One of the main contributions of this systematization is the description of an inverted approach to the research process, in which prototype construction and hands-on exploration precede written formalization. In the experience analyzed, this sequence made it possible to organize a progressive pathway from technical training and mini-projects to the formulation of formative research initiatives. Its application is particularly relevant for reflecting on alternative approaches to early research engagement in contexts involving students with diverse educational trajectories. However, because no specific instruments were used to measure perceived difficulty or the development of research competencies, the findings do not support the conclusion that the approach produced changes in these dimensions.

The findings also show that project development was characterized by processes of reformulation, integration, and discontinuation of ideas, highlighting the iterative nature of the experience. In addition, 19 of the 35 registered students participated at least once in academic dissemination activities. These data describe certain characteristics of the participants' trajectories within the research training group, but they do not establish that the strategy produced changes in the development of research competencies.

From an applied perspective, the experience provides elements that may inform adaptations in other engineering programs interested in promoting early research engagement through hands-on activities, collaborative work, and academic

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dissemination. Nevertheless, transferring the strategy requires consideration of the institutional and territorial conditions of each context, including the availability of technological resources, faculty support, team continuity, and the characteristics of the student population. Therefore, implementation in other settings should be understood as a process of adaptation rather than a direct replication of the model.

Finally, the experience highlights the potential value of practical and project-based strategies for expanding opportunities for early engagement in research in contexts characterized by diverse educational trajectories. Nevertheless, because of the descriptive nature of the study, it is not possible to conclude that the initiative reduced educational gaps or demonstrably strengthened research competencies. Future research should incorporate specific measurement instruments, longitudinal follow-up, and comparison groups to assess more rigorously its possible relationship with student retention, the development of research competencies, and participants' academic and professional trajectories.

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