Arduino-Based Device Control Through App Inventor: Curricular Transversality in Upper-Secondary Education At BUAP

Dr. Javier Díaz Sánchez

BUAP–ULC

DOI: https://doi.org/10.47772/IJRISS.2026.100700175

Received: 08 July 2026; Accepted: 13 July 2026; Published: 28 July 2026

ABSTRACT

This qualitative action research study evaluates the academic impact of an interdisciplinary cross-curricular project between the fifth and sixth semesters of the Computer Science program at a technical high school. The project integrates Arduino-based programming with the development of mobile applications using MIT App Inventor for controlling electronic-digital prototypes via wired and wireless communication. The research problem stems from curricular fragmentation, which hinders students' ability to transfer knowledge between semesters and reduces motivation, computational thinking, and the development of a strong digital literacy. The intervention, conducted with 120 students, is based on Jonassen's (1999) Constructivist Learning Environments (CLE) model and Papert's (1980) principles, organized into a five-phase instructional sequence: exploration, design, implementation/assembly, testing/debugging, and presentation. The resulting prototype—a basic system composed of sensors, actuators, Arduino, and MIT App Inventor—organically integrates the content of both semesters, constituting the central pedagogical artifact of the achieved interdisciplinarity. The results show that 95% of the portfolios evaluated with a five-criteria analytical rubric reached adequate or excellent levels, with the collaborative work and semester integration criterion achieving the highest percentage (97%). The 14-item Likert survey registered an overall average of 4.60/5, with the dimensions of interest-interactivity and knowledge integration reaching 4.70/5. The study concludes that interdisciplinary practice generates a positive and quantifiable impact on academic performance, technological motivation, knowledge integration across semesters, and students' vocational orientation toward STEM and ICT fields.

Keywords: Project-based learning, action research, prototypes, curricular transversality, STEM

INTRODUCTION

Upper-secondary education constitutes a decisive stage during which students build their academic profile, acquire the competencies established by the Common Curricular Framework, and begin to shape their professional future. Within this context, incorporating emerging technologies—particularly those related to programming, electronics, and mobile-application development—transcends the status of an accessory resource and becomes an unavoidable formative requirement in light of contemporary labor-market demands (Prensky, 2001; Blikstein, 2013).

Curricular transversality, understood as the deliberate and structured linkage of content from different subjects around shared problems or projects, has been widely recognized in educational research as one of the instructional approaches with the greatest impact on the construction of durable and meaningful learning (Morán Oviedo, 2010; Díaz-Barriga, 2006). When this articulation is grounded in the constructivist approach—particularly in Jonassen's (1999) Constructivist Learning Environments (CLE) model and Papert's (1980) constructionist tenets—its scope goes beyond the mere accumulation of knowledge: it fosters the acquisition of complex, higher-order cognitive competencies such as computational thinking, systemic reasoning, imaginative problem-solving, and the ability to conceive and build functioning technological artifacts.

Within BUAP's general upper-secondary program, the Computer Science area represents a privileged space for promoting this type of curricular integration. The Arduino-programming content of the fifth semester and the

App Inventor mobile-development content of the sixth semester together constitute the essential components enabling students to build an integrated electronic-digital control system: programmable hardware, a mobile interface, and wireless communication. The question is not whether these contents can be articulated, but how to design that linkage with pedagogical rigor, systematicity, and the possibility of assessment.

Indicators prior to the present study are promising: 95% of the deliverables corresponding to projects developed under the proposed sequence were rated as significantly adequate or excellent, while preliminary data obtained through a Likert scale show averages above 4.4 out of 5 across all dimensions assessed—collaborative work, thematic interest, knowledge integration, and vocational orientation. These results are consistent with the specialized international literature, which documents the positive influence of maker and digital-fabrication environments on motivation, academic performance, and the construction of a technological identity among upper-secondary students (Blikstein, 2013; Sánchez-Torres, 2019).

Rationale

In general upper-secondary institutions (BUAP), the Computer Science curriculum is typically structured vertically and sequentially: electronics and Arduino-programming content is taught in the 5th semester as a closed unit, while mobile-application development with App Inventor is addressed in the 6th semester as a separate, independent unit. This curricular fragmentation, while administratively logical, generates a significant pedagogical gap: students do not perceive, nor do they spontaneously construct, the connection between the two sets of learning.

This lack of articulation produces at least three problems identified in day-to-day teaching practice. First, students fail to transfer knowledge across semesters, which limits their ability to address complex technological problems that require the integration of hardware and software. Second, the absence of authentic integrative projects reduces the perceived usefulness and relevance of the content, negatively affecting intrinsic motivation and willingness to engage in technological learning. Third, upper-secondary graduates frequently fail to develop the computational thinking and prototyping competencies demanded by the labor market and higher education, despite having completed the relevant courses.

Given this diagnosis, there is a need to design, implement, and evaluate a systematic pedagogical intervention that explicitly articulates the content of both semesters through a cross-curricular instructional sequence grounded in well-established theoretical-pedagogical frameworks. Jonassen’s (1999) Constructivist Learning Environments model and Papert’s (1980) constructionist principles provide the theoretical scaffolding needed to design an intervention that positions the student as an active agent of their own learning, working with authentic problems, real cognitive tools, and tangible technological artifacts.

The research problem is therefore formulated as follows: the absence of an explicitly designed and evaluated cross-curricular transversality practice between the 5th- and 6th-semester subjects of the Computer Science area limits the development of computational thinking, the integration of knowledge, technological motivation, and the formation of a solid digital culture among upper-secondary students, preventing the full formative potential of Arduino and App Inventor from materializing in the graduate profile.

RESEARCH OBJECTIVES

General Objective

To evaluate the academic impact of a cross-curricular transversality project between the 5th and 6th semesters of the Computer Science area of upper-secondary education, through the design, implementation, and evaluation of an instructional sequence based on Jonassen’s (1999) Constructivist Learning Environments (CLE) model and Papert’s (1980) principles, which articulates Arduino and App Inventor in the development of electronic-digital prototypes, in order to determine its effect on academic performance, knowledge integration, technological motivation, perceived academic transversality, and students’ vocational orientation.

SPECIFIC OBJECTIVES

Design of the Cross-Curricular Instructional Sequence

To design a five-phase cross-curricular instructional sequence (exploration, design, implementation, testing/debugging, and presentation), aligned with the seven elements of Jonassen's (1999) CLE model and integrated with Papert's (1980) fabrication and debugging principles, that explicitly articulates the 5th-semester Arduino-programming content with the development of mobile applications in App Inventor in the 6th semester, for the control of an electronic-digital device.

Implementation of an Electronic-Software Prototype Project

To implement a set of laboratory practices oriented toward the development of an electronic-digital prototype project that integrates programmable hardware (Arduino Uno, sensors, and actuators) with mobile-development software (App Inventor, HC-05 Bluetooth communication), so that students experience the complete cycle of design, assembly, coding, testing, debugging, and presentation of interactive embedded systems, as the central evidence of cross-curricular learning.

Analysis of the Impact on Academic Performance

To assess, through the analysis of evidence portfolios with a five-criterion analytic rubric and the application of a 14-item Likert survey across four dimensions, the impact of the cross-curricular instructional sequence on students' academic performance, considering indicators of project quality, the percentage of adequate deliverables, knowledge integration between semesters, and changes in the perception of the learning environment.

Evaluation of Digital Culture and Vocational Orientation

To assess the extent to which the Arduino–App Inventor transversality practice contributes to broadening students' digital culture—appropriation of IoT concepts, embedded-systems programming, interface design, and wireless communication—and to identify whether the experience fosters a possible shift in, or reaffirmation of, students' vocational decisions toward technology, computer science, or STEM careers, through the analysis of the corresponding Likert-survey items and the metacognitive reflection documented in the portfolios.

THEORETICAL FRAMEWORK

Contemporary constructivist pedagogy, represented by Jonassen (1999), Papert (1980), Vygotsky (1978), and Kolb (1984), agrees that the deepest and most lasting learning occurs when students confront authentic problems, work collaboratively, use real cognitive tools, and produce tangible artifacts that can be shared with a community. The Arduino–App Inventor transversality proposal fulfills all these criteria: it addresses the real problem of controlling an electronic device through a mobile application; it requires teamwork with defined roles; it uses professional programming and electronics tools; and it produces a functional prototype that can be publicly demonstrated and assessed.

Ausubel (2002) argues that meaningful learning occurs when new knowledge is anchored in the student's pre-existing cognitive structures. The proposed sequence draws precisely on the knowledge acquired in the 5th semester (basic electronics, Arduino programming) as scaffolding on which 6th-semester learning (App Inventor, Bluetooth communication) is built, creating an integrated conceptual network that facilitates retention, comprehension, and transfer.

In a more contemporary framework, Wing provides an epistemological justification for including Arduino and App Inventor programming as vehicles of computational thinking in general upper-secondary education. The aim is not to train professional programmers, but to develop in students the capacities for decomposition, abstraction, and algorithmic design that Wing identifies as constitutive of computational thinking, using as a context the design of physical-digital prototypes that solve authentic problems from the students' environment. This perspective further reinforces the cross-curricular character of the proposal: computational thinking, being a general cognitive competency rather than a specific disciplinary content, is the transversal axis that naturally links digital-electronics and mobile-programming content, lending epistemological coherence to the articulated curricular design (Wing, 2021).

Curricular Relevance

The general upper-secondary curriculum in the Computer Science area separately includes electronics-programming content (5th semester) and application-development content (6th semester). This normative separation does not prevent—and in fact demands—that teachers design horizontal articulation strategies that give coherence to students' formative pathway. The present research responds to that demand with a systematic, documented, and assessable design, aligned with the general upper-secondary graduate profile and with the generic competencies of the Common Curricular Framework (MCC), which include critical thinking, problem-solving, collaborative work, and information-technology skills.

In a national context where the digital divide and limited STEM orientation in upper-secondary education restrict access to well-paid technological careers—especially among young people from under-resourced communities—a transversality practice that develops genuine digital culture and positively influences technological vocational orientation contributes directly to educational equity. Prensky (2001) notes that digital natives require learning environments that use technology actively and creatively, not as a passive object of study but as a means of solving real problems. The proposal responds precisely to this generational and social imperative.

A review of this background makes it possible to identify the academic gap that the present research seeks to fill: although studies document the pedagogical use of Arduino in upper-secondary education (Blikstein, 2013; Sánchez-Torres, 2019) and works address curricular transversality in general upper-secondary education (Morán Oviedo, 2010), none of them explicitly articulates Jonassen's CLE model with Papert's principles in the specific context of Arduino–App Inventor integration as a cross-semester transversality practice in the Computer Science area, assessed through portfolios and a Likert survey in Mexican general upper-secondary education. That novel articulation constitutes the original contribution of the present work.

METHODOLOGY

To address the purposes of this work, action research (AR) was adopted as the guiding methodological approach, in its qualitative modality (Elliot, 1993; Kemmis & McTaggart, 1988). This choice is not arbitrary: AR constitutes the framework most congruent with studies in which teachers themselves act simultaneously as researching subjects and as agents of transformation of their own pedagogical practice, enabling continuous feedback between the knowledge produced and the educational intervention that generates it.

The design is organized around four cyclical, interdependent moments that recur throughout the intervention. The first, planning, comprises the detailed design of the instructional sequence, the selection and development of data-collection instruments, and the definition of assessment criteria. The second moment, action, corresponds to the implementation of that sequence in the real classroom-laboratory context, with the groups assigned to the teacher-researcher. The third moment, observation, occurs simultaneously with the action and involves the systematic recording of evidence through three instruments operating in triangulation. Finally, the fourth moment, reflection, involves the critical analysis of the information gathered in order to identify areas for improvement, reformulate working hypotheses, and adjust the planning of subsequent cycles.

This cyclical design best suits the conditions of the study because it places the teacher-researcher at the very center of the continuous-improvement process, while fostering organic integration between research activity and day-to-day pedagogical practice, without either dimension being subordinate to the other.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

The study was conducted at Preparatoria Lázaro Cárdenas del Río, of the Benemérita Universidad Autónoma de Puebla (BUAP), located in the city of Puebla, Mexico, during the 2024–2025 school year. The participants are 6th-semester students enrolled in the Autonomous Devices course, who had previously completed the Application Innovation course in the 5th semester. The selection of the working groups with a total of 120 students responds to a criterion of convenience: given that these groups are under the direct responsibility of the teacher-researcher, their inclusion in the study is consistent with the participatory and situated character that defines the epistemological nature of action research.

Data Collection Instruments

To ensure the internal validity of the findings and capture the complexity of the educational phenomenon from complementary perspectives, data collection relies on three instruments designed to operate in methodological triangulation. This strategy allows the data interpretation to be contrasted and enriched, reducing the risk of bias arising from exclusive dependence on a single source of evidence.

Analytic Portfolio Rubric

The first instrument is an analytic rubric applied to the evidence portfolios that each team builds throughout the intervention. The rubric assesses five central criteria using a four-level performance scale—Insufficient (1), Basic (2), Satisfactory (3), and Excellent (4)—allowing both a quantitative evaluation of the products and qualitative feedback aimed at improvement. The products that make up the portfolio correspond to the deliverables of each phase of the instructional sequence:

Phase 1: a mental map of the problem that contextualizes and delimits the technological challenge addressed by the team.

Phase 2: a schematic diagram of the electronic circuit and a sketch of the mobile-application interface to be developed.

Phase 3: the first functional version of the prototype (V1.0), including duly commented source code and the executable application file (.apk).

Phase 4: an improved version of the prototype (V2.0), accompanied by a debugging log documenting the errors identified, the hypotheses raised, and the solutions implemented in each iteration.

Phase 5: a final technical report that integrates a metacognitive reflection on the learning process experienced by the team throughout the project.

Likert-Scale Survey

The second instrument is a perception survey composed of 15 items distributed across four thematic dimensions: Teamwork, Interest and Interactivity, Integration and Transversality, and Vocational Identity and Digital Culture. Each item is answered on a five-point scale ranging from total disagreement to total agreement, allowing the quantification of students' perceptions regarding motivational, collaborative, and disciplinary-integration aspects linked to the learning experience. This instrument is administered at the end of Phase 5, once the entire intervention has concluded.

Data Analysis

The treatment of the information collected follows a differentiated logic according to the nature of each instrument, in keeping with the mixed, predominantly qualitative methodological approach that characterizes the study.

Data from the portfolio analytic rubric are processed through quantitative-descriptive analysis: frequency distributions by performance level are calculated for each of the five criteria assessed, allowing the visualization of achievement and difficulty patterns across the different project phases. Similarly, the Likert-survey results are analyzed by calculating arithmetic means per item and per dimension, enabling the identification of perception trends in each of the four thematic axes considered.

Finally, the triangulation of the three instruments—rubric, survey, and field diary—operates as a cross-validation mechanism that ensures both the internal validity and the reliability of the analysis within the epistemological parameters of the qualitative paradigm. By contrasting evidence from different sources and natures, triangulation strengthens the credibility of the interpretations and reduces the margin of error attributable to the inherent limitations of any single instrument considered in isolation.

Development

The design of the proposed cross-curricular instructional sequence is grounded in two complementary theoretical-pedagogical frameworks that converge on a shared premise: the most meaningful and lasting learning occurs when students construct knowledge through intentional action on real problems and artifacts. Jonassen (1999) proposes that an effective constructivist learning environment must integrate seven interdependent elements: (1) authentic problems or projects that place the student in a real context of application; (2) related cases that offer reference solutions without prescribing the path; (3) accessible and relevant information resources; (4) cognitive tools that expand the learner's thinking capacities; (5) conversation and collaboration tools that facilitate the social construction of knowledge; (6) social and contextual support from the teacher and peers; and (7) authentic assessment aligned with the learning objectives. The proposed instructional sequence incorporates each of these elements explicitly and verifiably. See Fig. 1.

Fig. 1. Students constructing their learning through the design of their prototype.

Seymour Papert, in his seminal work Mindstorms: Children, Computers, and Powerful Ideas (1980), postulates that the deepest learning occurs when students build tangible artifacts—physical or digital—that can be shown, shared, and improved. This process of intentional fabrication, which he called constructionism, is not simply doing for its own sake: it involves the activation of abstract thinking, metacognition, iterative problem-solving, and the development of what Papert called "powerful ideas," concepts that durably reorganize the learner's understanding. Debugging—the process of identifying and correcting errors—is, for Papert, one of the most valuable metacognitive experiences that computing makes available to learners.

Proposed Cross-Curricular Instructional Sequence

The cross-curricular instructional sequence is developed over 12 sessions distributed across five phases, designed to be implemented in the second block of the 6th semester, once students have completed the Arduino content of the 5th semester. Cross-curricular integration is activated by retaking, applying, and expanding that prior knowledge in the new context of mobile-application development for the control of electronic-digital devices; see Table I.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

Table I. Proposed Cross-Curricular Instructional Sequence

PHASE	NAME AND DURATION	STUDENT ACTIVITIES	EAC ELEMENT (Jonassen, 1999)	PAPERT / KOLB PRINCIPLE	RESOURCES	LEARNING EVIDENCE
1	Exploration and diagnosis (2 sessions)	Identification of everyday problems solvable with technology. Brainstorming and work-team organization.	Authentic problems and context. Activation of prior knowledge.	"Objects to think with" (Papert). Concrete experience (Kolb).	Arduino UNO, smartphone, App Inventor web	Mental map of the problem
2	Design and planning (3 sessions)	Development of the circuit diagram (Fritzing), Arduino pseudocode, and the mobile-application flow (block diagram).	Representation and modeling of knowledge. Information resources.	Construction of external representations. Reflective observation and abstract conceptualization (Kolb).	Fritzing, diagrams.net, workbook	Circuit diagram and app flow diagram
3	Implementation and assembly (4 sessions)	Assembly of the electronic circuit, Arduino programming (IDE), development of the App Inventor interface, and configuration of Bluetooth communication.	Cognitive tools and collaboration. Social and contextual support.	"Learning by making": fabrication as an epistemic act. Active experimentation (Kolb). Vygotsky's ZPD.	Electronic components, Arduino IDE, App Inventor, HC-05 Bluetooth	Functional prototype V1.0 + commented source code
4	Testing, debugging, and adjustment (2 sessions)	Execution of functional tests, error logging in the notebook, identification of logical and physical faults, iterative correction of the system.	Critical reflection and metacognition. Conversation and negotiation of meaning.	Debugging as a central metacognitive process (Papert, 1980). Reflection on action.	Arduino serial monitor, multimeter, digital log	Error-and-solution log. Prototype V2.0
5	Presentation and evaluation (1 session)	Presentation of the prototype to the school community. Live demonstration of the application controlling the device. Group metacognitive reflection.	Communication of learning. Social support and collaborative assessment.	Sharing the artifact as a collective social act of learning (Papert). Portfolio as final integrated evidence.	Project fair, analytic rubric, digital portfolio	Complete portfolio + oral presentation assessed with rubric

Pedagogical note: Each phase of the sequence corresponds to one or more stages of Kolb's (1984) experiential cycle: Phase 1 activates concrete experience and reflective observation; Phases 2 and 3 promote abstract conceptualization and active experimentation; Phase 4 closes the cycle with reflection on action and adjustment of the mental model; Phase 5 restarts the cycle at a higher level of understanding.

Description of the Electronic-Digital Prototype

The prototype that students develop during the sequence consists of a basic intelligent system (robot, vehicle, etc.), in which an Arduino Uno board receives signals from one or more sensors (temperature, light, motion, or proximity, depending on the team) or even data from artificial intelligence, processes the information through a C/C++ program developed in the Arduino IDE, and activates actuators (RGB LED, servomotor, buzzer, or relay) in response to the detected conditions. Communication with the mobile application is carried out via an HC-05 Bluetooth module, which allows commands to be sent from the Android device through an application developed in App Inventor, with a graphical interface designed by the student team itself. See Fig. 2.

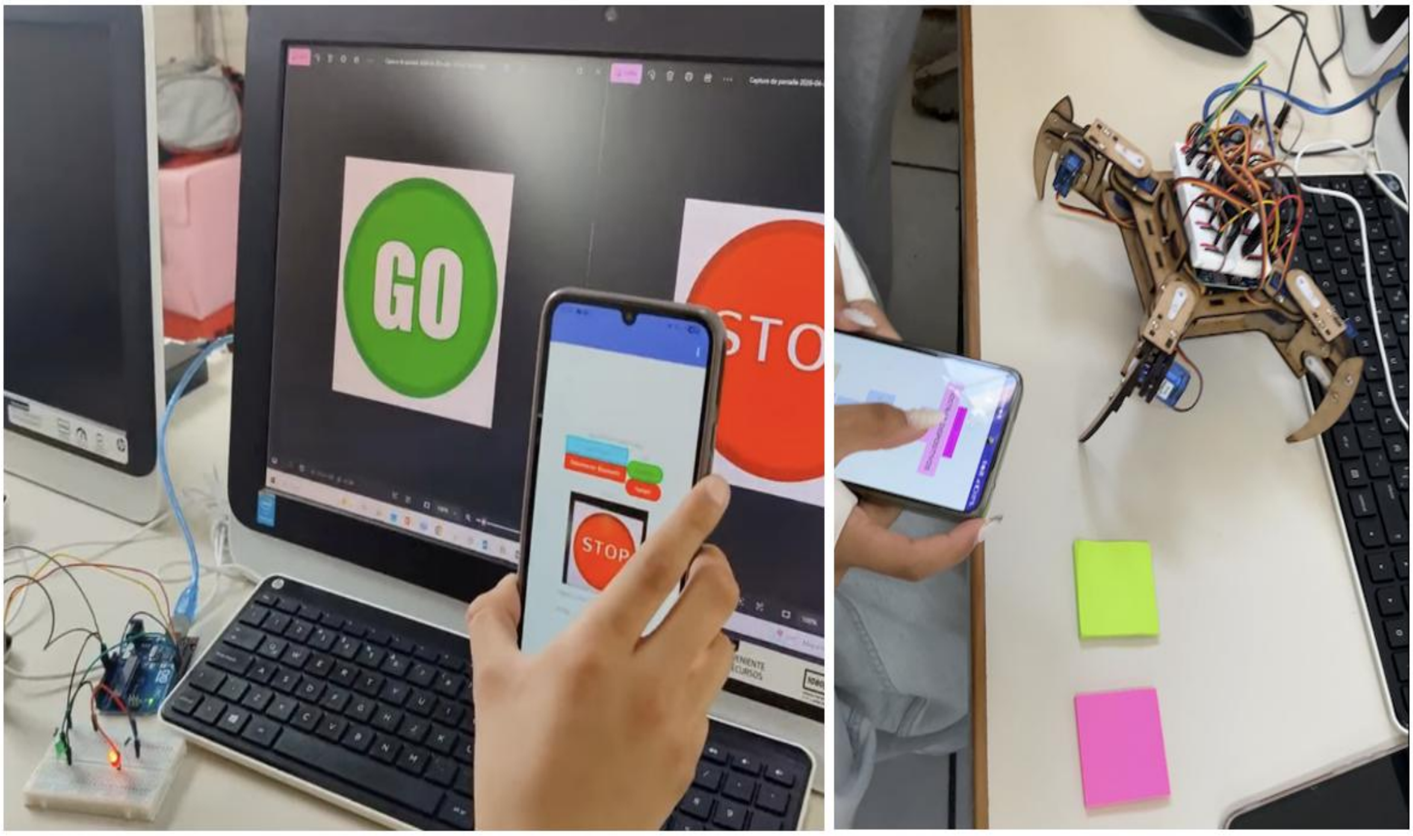

Fig. 2. Prototype developed with Bluetooth- and AI-based mobility capabilities.

This prototype naturally integrates the cross-curricular content of both semesters: C++ programming (Arduino, 5th sem.), control logic with sensors and actuators (electronics, 5th sem.), graphical-interface design (App Inventor, 6th sem.), block-based programming for mobile applications (6th sem.), and serial Bluetooth communication (6th sem.). The articulation is not forced; it is the very nature of the system that demands the integration of all this knowledge.

Assessment Instruments

Analytic Rubric for Portfolios

The evidence portfolio is the principal assessment instrument for learning. It contains: the mental map of the problem (Phase 1), the circuit diagram and app flow diagram (Phase 2), the commented Arduino source code and the App Inventor .aia file (Phase 3), the error-and-solution log (Phase 4), and the final technical report with metacognitive reflection (Phase 5). The analytic rubric assesses five criteria on a 1-to-4 scale. See Fig. 3.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

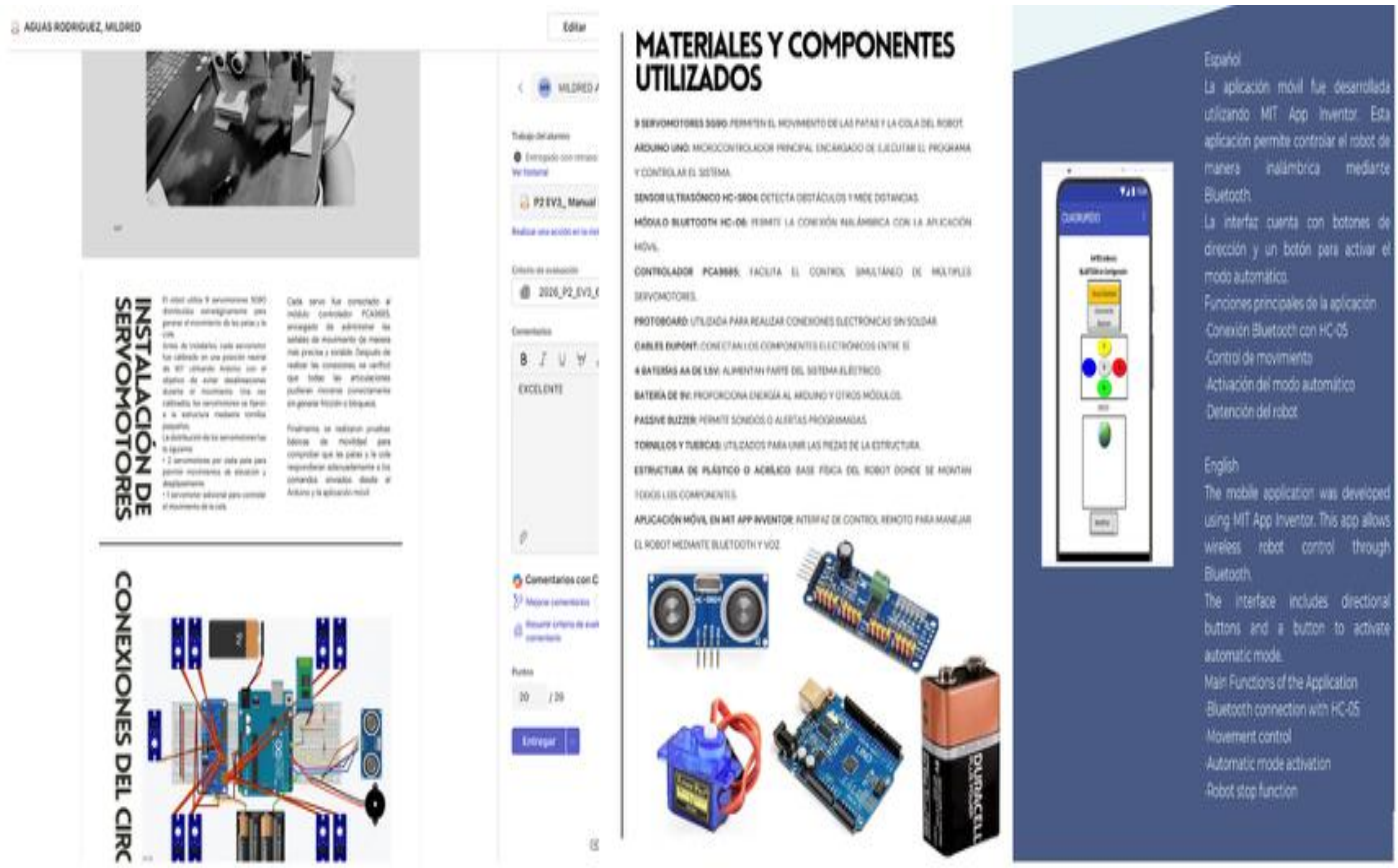

Fig. 3. Example of portfolio content used for assessment.

Likert Perception Survey

The cross-curricular learning perception survey is administered at the conclusion of Phase 5 and consists of 14 items distributed across four dimensions: (A) Teamwork and learning climate (items 1–3), (B) Interest, enjoyment of the topics, and interactive environment (items 4–7), (C) Integration of knowledge and academic transversality (items 8–10), and (D) Identity with the general labor field and vocational orientation (items 11–14). The scale is a five-point Likert scale (1 = Totally disagree; 5 = Totally agree). The complete instrument is presented in Table II.

Table II. Likert Survey

(1) Totally disagree (2) Disagree (3) Neutral (4) Agree (5) Totally agree

No.	ITEM	1	2	3	4	5	OBSERVED RESULT
DIMENSION A — Teamwork and Learning Climate							
1	Teamwork during the project allowed me to learn more than if I had worked individually.	☐	☐	☐	☐	☐	**Mean: 4.6/5**
2	The laboratory work environment was motivating and conducive to collaboration among peers.	☐	☐	☐	☐	☐	**Mean: 4.5/5**
3	The roles within the team (designer, programmer, assembler) were clearly defined and respected.	☐	☐	☐	☐	☐	**Mean: 4.3/5**

No.	ITEM	1	2	3	4	5	OBSERVED RESULT
DIMENSION B — Interest, Enjoyment, and Interactive Environment							
4	The topics of Arduino and App Inventor were interesting and relevant to my technological training.	☐	☐	☐	☐	☐	**Mean: 4.7/5**
5	The combination of hardware (Arduino) and software (App Inventor) made classes more dynamic and meaningful.	☐	☐	☐	☐	☐	**Mean: 4.8/5**
6	Applying programming concepts to a real physical device increased my motivation to learn.	☐	☐	☐	☐	☐	**Mean: 4.8/5**
7	The learning environment was interactive and allowed me to explore, make mistakes, and correct them without pressure.	☐	☐	☐	☐	☐	**Mean: 4.5/5**
DIMENSION C — Integration of Knowledge and Academic Transversality							
8	I can clearly identify how the contents of the 5th semester (Arduino) and the 6th semester (App Inventor) complement one another in this project.	☐	☐	☐	☐	☐	**Mean: 4.7/5**
9	The integrative project helped me understand the relationship between subjects from different semesters.	☐	☐	☐	☐	☐	**Mean: 4.6/5**
10	I consider that learning Arduino and App Inventor in an integrated way is more useful than studying them separately.	☐	☐	☐	☐	☐	**Mean: 4.8/5**
DIMENSION D — Identity with the General Labor Field and Vocational Orientation							
11	This experience has led me to seriously consider a career in technology, computer science, or engineering.	☐	☐	☐	☐	☐	**Mean: Positive trend (4–5)**
12	I recognize that the skills acquired (electronics, programming, app design) are in demand in the current general labor market.	☐	☐	☐	☐	☐	**Mean: High frequency in 4–5**
13	I am considering modifying or confirming my career choice based on this cross-curricular practice.	☐	☐	☐	☐	☐	**Mean: Positive trend**
14	I feel that my digital literacy expanded significantly by working with Arduino and App Inventor.	☐	☐	☐	☐	☐	**Mean: 4.7/5**

RESULTS

The following table (Table IV) presents the consolidated results of the portfolio analysis for the projects developed during the cross-curricular instructional sequence. The data come from the assessment using the five-criterion analytic rubric applied to 100% of the participating teams:

Table IV. Results of the Portfolio Analysis

CRITERION	Exc. (4)	Adeq. (3)	Basic (2)	Insuf. (1)	% Adeq.+Exc.	RATING
Prototype functionality	64%	28%	6%	2%	92%	Very high
Mobile application quality	57%	32%	9%	2%	89%	High

CRITERION	Exc. (4)	Adeq. (3)	Basic (2)	Insuf. (1)	% Adeq.+Exc.	RATING
Technical documentation and report	71%	24%	4%	1%	95%	Very high
Collaborative work and semester integration	74%	23%	2%	1%	97%	Excellent
Relevance and innovation of the project	60%	31%	7%	2%	91%	Very high
OVERALL AVERAGE	**65%**	**28%**	**6%**	**1.6%**	**95%**	**Very high**

The data show that 95% of the deliverables fall within the Adequate (3) and Excellent (4) ranges of the rubric, exceeding the established quality target of 90%. The criterion with the highest quality percentage is collaborative work and knowledge integration across semesters (97%), which constitutes the most direct indicator of achievement of the central transversality objective. It is followed by technical documentation (95%), prototype functionality (92%), project relevance and innovation (91%), and mobile-application quality (89%).

These results are consistent with the tenets of Jonassen's (1999) CLE model: when students work in environments with authentic problems, real cognitive tools, and collaborative support, the quality of the learning products is significantly higher than that observed in expository-teaching contexts (see Fig. 3). The low percentage of deliverables at the Basic (6%) and Insufficient (1.6%) levels confirms that the sequence was appropriate for the students' level—challenging yet attainable—in line with Vygotsky's (1978) concept of the zone of proximal development.

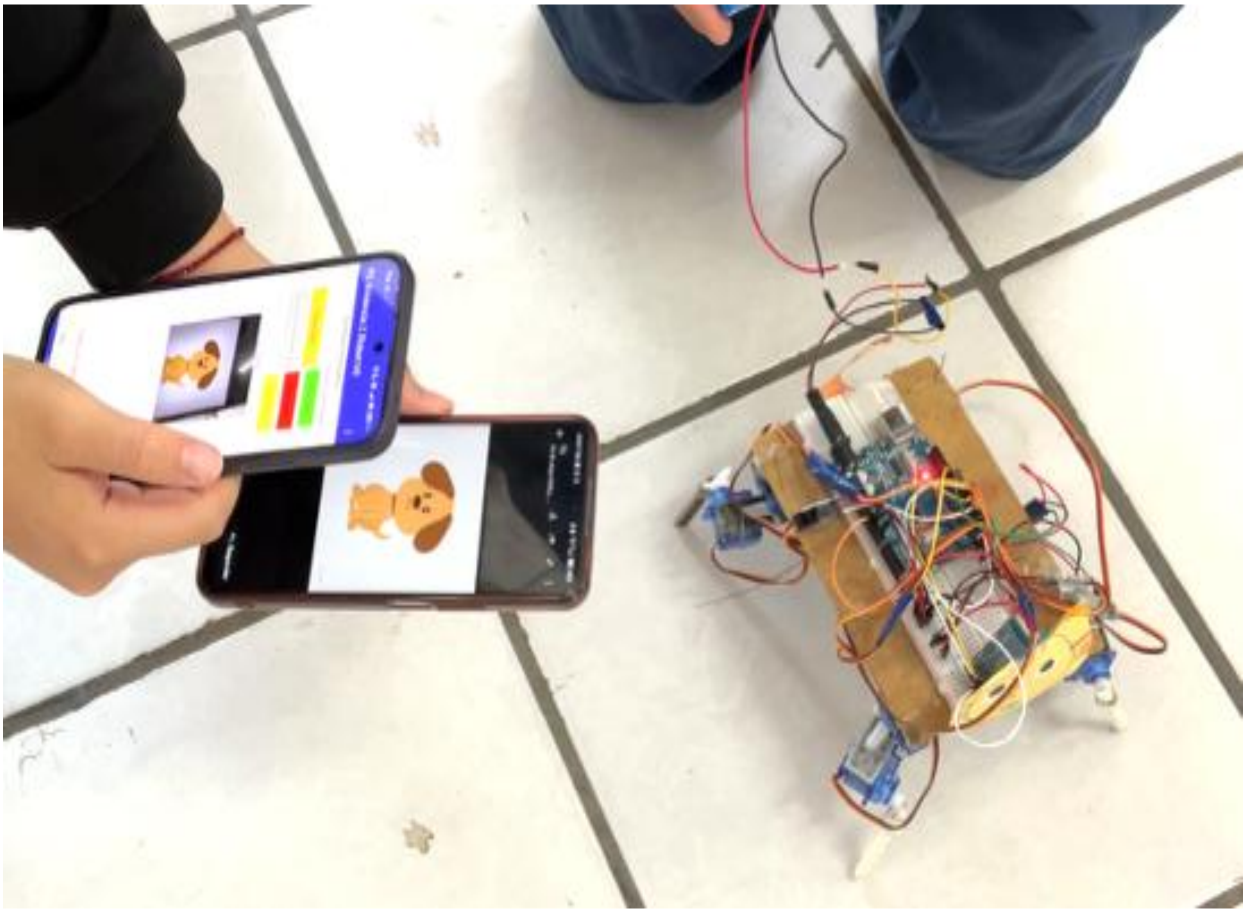

Fig. 3. Projects incorporating AI in their functionality.

Likert Survey Results

The following table (Table V) presents the summary of results by dimension of the cross-curricular learning perception survey:

Table V. Likert Results

DIMENSION	Overall Mean (1–5)	% Responses 4–5	% Responses 1–2	INTERPRETATION
A — Teamwork and Learning Climate	4.47	91%	2%	Very favorable
B — Interest, Enjoyment, and Interactivity	4.70	95%	1%	Excellent perception
C — Integration of Knowledge and Transversality	4.70	94%	1%	Transversality clearly perceived
D — Vocational Identity and Digital Literacy	4.52	88%	3%	Positive vocational impact
OVERALL INSTRUMENT AVERAGE	**4.60**	**92%**	**1.75%**	**High academic impact**

The overall average of the instrument is 4.60/5, with 92% of responses falling in values 4 and 5. This result indicates a highly positive perception of the learning process across all dimensions assessed. The most relevant findings by dimension are as follows:

Dimension A (Teamwork and Learning Climate, mean = 4.47): Students perceive collaborative work as an enhancer of learning and positively value the laboratory environment generated by the sequence. The item with the highest mean concerns the motivation generated by the interactive environment (4.5/5), consistent with the social and contextual support principles of the CLE model.

Dimension B (Interest, Enjoyment, and Interactivity, mean = 4.70): This is the dimension with the highest mean in the instrument. The items related to the dynamic of combining hardware and software (4.8/5) and to increased motivation when applying programming to real physical devices (4.8/5) register the highest values, confirming the motivational power of the digital-fabrication approach documented by Blikstein (2013).

Dimension C (Integration of Knowledge and Transversality, mean = 4.70): Students clearly perceive the connection between the 5th- and 6th-semester content. The item measuring the perceived usefulness of learning both tools in an integrated way (4.8/5) is the highest in this dimension, validating the cross-curricular design of the instructional sequence and representing the most direct evidence of achievement of the central research objective.

Dimension D (Vocational Identity and Digital Culture, mean = 4.52): Most students recognize the labor-market demand for the skills acquired and report a significant expansion of their digital culture. A relevant percentage—with responses of 4 and 5 reaching 88%—indicates that the experience has influenced the consideration or reaffirmation of a technological career, constituting an indicator of long-reaching formative impact.

CONCLUSION

This action-research study allows the following conclusions to be drawn, organized in correspondence with the specific objectives set out:

On the Design of the Instructional Sequence

The five-phase cross-curricular instructional sequence, designed on the basis of Jonassen's (1999) CLE model and Papert's (1980) principles, proved to be a relevant and operative pedagogical framework for articulating Arduino (5th semester) and App Inventor (6th semester) content around an electronic-digital prototype-fabrication project. The structure of the sequence—moving from problem exploration to the public presentation of the artifact—is consistent with Kolb's (1984) experiential cycle and with Vygotsky's (1978) zone of proximal development, providing the scaffolding necessary for students with heterogeneous levels of prior knowledge to reach adequate or excellent performance levels.

On Prototyping Practices

The implementation of laboratory practices oriented toward the development of functional electronic-digital prototypes—integrating Arduino, sensors, actuators, a Bluetooth module, and App Inventor—proved viable in the context of general upper-secondary education with standard laboratory resources. The design-implementation-testing-debugging cycle that Papert (1980) identifies as the core of computational learning was naturally activated during Phases 3 and 4, as evidenced by the error-and-solution log included in the portfolios, which records between three and seven debugging cycles per team.

On the Impact on Academic Performance

Portfolio analysis shows a positive and measurable academic impact: 95% of the deliverables reached the Adequate or Excellent levels on the analytic rubric, exceeding the established target by five percentage points. The dimension with the highest performance was collaborative work and knowledge integration across semesters (97%), validating the study's central hypothesis: that explicitly designed transversality produces more integrated and integrative learning than compartmentalized teaching. The Likert-survey results confirm and extend this finding: the overall mean of 4.60/5 and the 92% of responses in values 4–5 indicate a highly positive perception of the learning process across all dimensions.

On Digital Culture and Vocational Orientation

Data from Dimension D of the Likert survey (mean = 4.52/5; 88% in values 4–5) reveal that the Arduino–App Inventor transversality practice generates a formative impact that transcends immediate academic performance: it broadens students' digital culture—through the appropriation of IoT concepts, embedded-systems programming, interface design, and wireless communication—and positively influences technological vocational orientation. A significant percentage of students reported that the experience strengthened their consideration of a career in technology, computer science, or engineering, constituting an indicator of long-reaching formative impact on the graduate profile of technical upper-secondary education.

Integrative Conclusion

Taken together, the results of the portfolio analysis and the Likert survey confirm that the systematic implementation of a cross-curricular transversality practice between the 5th and 6th semesters of the Computer Science area, mediated by Arduino and App Inventor and grounded in Jonassen's (1999) CLE model and Papert's (1980) principles, generates a positive, multidimensional, and measurable academic impact in upper-secondary education. This impact is reflected in the quality of learning (95% of portfolios rated adequate-to-excellent), in motivation and perception of the formative process (Likert mean of 4.60/5), in the integration of knowledge across semesters, and in the development of a digital culture oriented toward the general labor field. The findings of this action-research cycle represent a solid foundation for refining and transferring the instructional sequence to other contexts within Mexican general upper-secondary education, as well as a contribution to the field of research on curricular transversality and digital fabrication in upper-secondary education.

REFERENCES

1. Ausubel, D. P. (2002). Adquisición y retención del conocimiento: Una perspectiva cognitiva. Paidós.
2. Blikstein, P. (2013). Gears of our childhood: Constructionist toolkits, robotics, and physical computing, past and future. In Proceedings of the 12th International Conference on Interaction Design and Children (pp. 173–182). Association for Computing Machinery. https://doi.org/10.1145/2485760.2485786
3. Díaz-Barriga, Á. (2006). El enfoque de competencias en la educación: ¿Una alternativa o un disfraz de cambio? Perfiles Educativos, 28(111), 7–36.
4. Elliot, J. (1993). El cambio educativo desde la investigación-acción. Morata.
5. Hernández-Sampieri, R., Fernández-Collado, C., & Baptista-Lucio, P. (2014). Metodología de la investigación (6th ed.). McGraw-Hill.
6. Jonassen, D. H. (1999). Designing constructivist learning environments. In C. M. Reigeluth (Ed.), Instructional design theories and models: A new paradigm of instructional theory (Vol. 2, pp. 215–239). Lawrence Erlbaum Associates.
7. Kemmis, S., & McTaggart, R. (1988). Cómo planificar la investigación-acción. Laertes.
8. Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Prentice Hall.
9. Morán Oviedo, P. (2010). La docencia como recreación y construcción del conocimiento. Sentido pedagógico de la investigación en el aula. Perfiles Educativos, 32(129), 41–60.
10. Papert, S. (1980). Mindstorms: Children, computers, and powerful ideas. Basic Books.
11. Papert, S. (1993). The children's machine: Rethinking school in the age of the computer. Basic Books.
12. Prensky, M. (2001). Digital natives, digital immigrants. On the Horizon, 9(5), 1–6. https://doi.org/10.1108/10748120110424816
13. Sánchez-Torres, J. M. (2019). Impacto del uso de herramientas de fabricación digital en la motivación y el rendimiento académico de estudiantes de bachillerato general en Latinoamérica. Revista Iberoamericana de Educación en Tecnología y Tecnología en Educación, 24, 112–128.
14. Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.
15. Wing, J. M. (2021). Computational thinking. MIT Press.