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Diseño e implementación de un robot educativo interactivo
para el apoyo a la enseñanza de las matemáticas en primaria para niños
"A.R.I.M.A.".

Design and implementation of an interactive educational robot for primary
mathematical education support for children "A.R.I.M.A."

Quito-2026

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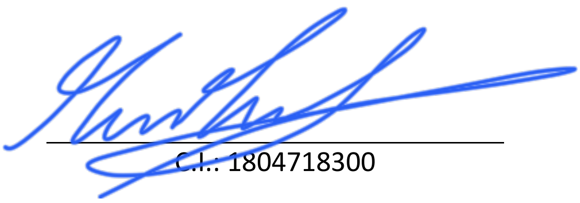

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Chapter 1
INTRODUCTION

The use of technology in education has become extremely common in recent years, supported by artificial intelligence and the ability to access information immediately. This trend has created a need to implement fun and interactive methods that serve as an alternative and reinforcement to traditional teaching at different educational levels. One of the technologies useful for education is educational robots, which are systems that incorporate hardware and software aimed at teaching and use all kinds of interfaces to communicate with students, with the aim of transmitting or reinforcing knowledge. These robots differ from other technological tools such as separate educational software or hardware by combining the benefits of these in a single product.

Education systems in Latin America and the Caribbean (LAC) face major challenges. These include high dropout rates, low secondary school completion rates, low levels of learning in fundamental skills, and a disconnect between what education systems offer and what the labor market demands, as shown by the results of studies such as the Comparative and Explanatory Regional Study (ERCE by its acronym in Spanish), where 48% of third-grade students do not reach the minimum level of performance in mathematics [1]; OECD Program for International Student Assessment (PISA by its acronym in Spanish) 2022 also shows that 75% of 15-year-old students in LAC do not demonstrate basic math skills [2]. In addition, the region has been characterized by high inequality in terms of access, quality of learning, and completion, with lack of access to digital resources for learning being a primary problem. The COVID-19 pandemic also appears to have worsened these structural deficiencies and widened existing gaps. In Ecuador, education problems are contextualized within structural and cultural challenges that have led to changes such as state policies. Test results from National Institute of Educational Evaluation (INEVAL by its acronym in Spanish) on recent 2025 national tests involving more than 47,000 students show scores of 700 out of

1000 on average in several subjects (Mathematics, Language and Literature, Natural and Social Sciences) [3], this shows a deep and persistent problem in the Ecuadorian education system, where “educational revolutions did not touch teaching and learning relationships, the heart of education” [4], resulting in a system that continues to rely on traditional learning methods and remains distant from digital technology. Even years after the pandemic ended, the teaching methods remain stagnant, when they should be advancing and improving hand in hand with technology, as they have been since the advent of the internet [5].

In this context, where regions and countries like Ecuador have shown low overall academic performance, educational robots have emerged as tools to support the acquisition of STEM skills and the development of logical-mathematical thinking at different levels of education, as required by the ministerial authority since 2016 [6], while providing fun and engaging activities for students to capture their attention by applying alternative teaching methodologies. Diverse studies highlight the importance of educational robots in the classroom as learning aids, as they allow the educational process to be expanded through the inclusion of fun and practical activities, thus contributing to the acquisition of STEM skills, especially mathematics [7–13]. These robots promote critical thinking and problem solving, which are useful in the Ecuadorian education system [5]. They can also be used to increase student motivation, interest, and engagement when implemented in engaging and playful ways, in some cases even reducing problems such as study anxiety [8]. The literature reviewed agrees that educational robots are considered a powerful tool for capturing students’ interest and serve as a first approach to STEM by promoting logical-analytical thinking and problem solving. They also highlight the fact that technology should be a pedagogical complement which, together with the support of properly trained teachers, is part of the ideal implementation of educational robotics. It is important to be low-cost and open-source to facilitate its widespread implementation [10, 12, 14]. Although some projects demonstrate a positive impact on mathematical learning [13], this effectiveness depends on how mathematics is integrated into the educational robot and its content. Even its interaction design plays an important and decisive role when interacting with certain age groups. There certainly are contradictions with its effectiveness in the learning of secondary school children [10, 15, 16]

Literature defines gamification as the application of game elements in situations that are not initially related to them, or the use of tools, strategies, and mechanisms to increase engagement and motivation in specific situations. Consequently, a recurring theme in literature is the incorporation of activity adaptation as a pedagogical resource. This principle proposes the use of visual and interactive resources, such as colors and shapes, which have been shown to capture children's attention and promote learning in subjects that are often unattractive in terms of attention, relevance, self-confidence and satisfaction through a better flow experience of the activities to be completed [7, 14, 15, 17]. In the context of this project, it is operationalized as a set of techniques for the adaptation and digitization of children's activities. This contrasts with classic methods like those used in the Ecuadorian Educational system, where the writing, reading and memorization are the day-to-day learning methods, heavily based on books, whiteboards and notebooks [4]. Some authors agree that the gamification of activities and their implementation in educational robots increases student motivation and engagement, also influencing their creativity and computational thinking, thus effectively promoting their learning outcomes, not limited to STEM, but even in subjects such as art, science, and language [7, 17]. In [7], there is a discussion about effectiveness, due to the lack of theoretical explanations for gamification and the alleged "lack of evidence" about gamification, while other authors support these models because they are based on robust theoretical frameworks.

While adapting activities to an interactive digital environment is crucial for motivation, a system's success relies heavily on its physical implementation. The literature establishes that the primary objective of educational robots is to enrich learning and simplify concepts, making them accessible through experimentation and sustained use as a learning companion [11, 16, 18]. Consequently, to fulfill this pedagogical role effectively and ensure practical adoption, the hardware design must prioritize specific functional characteristics:

- Reliability and durability. Educational robots must withstand regular use inside or outside the classroom for extended periods of time, which also entails the use of long-lasting batteries if necessary [14, 18].
- Ease of use. It is essential that the robot be easy to operate, maintain, and repair for students and teachers without advanced technical skills [18].
- Adaptability. Robots must be capable of serving multiple use cases by supporting the teaching of a variety of topics [18].
- Low cost. High cost is a barrier to mass adoption, so it is necessary to design low-cost, open-source educational robots [14].
- Interactive and/or social capabilities. A fundamental feature of educational robots is their ability to interact physically, verbally, and visually with the user, providing feedback and participating in joint learning activities [10, 15].

Although the reviewed literature confirms the benefits of educational robots [14, 17, 18], it also highlights certain gaps in the research and development of these systems. Often, studies have focused on the construction of prototypes and their conceptualization [14], or on discussing the general benefits of robotic applications in education [19], but there is a clear need to document and validate the design and implementation process of these systems. Specifically, there is a gap in the detailed description of methodologies for the development of educational robots that prioritize reliability, ease of use, and cost-effectiveness [18] and that integrate innovative pedagogical features such as concepts like gamification and user-friendly interaction [7,17]. An initial validation of the usability and functionalities of these prototypes in their design and development stage, including the collection of early feedback, is crucial to inform future stages of research beyond the case study or pilot study, and precedes the conduct of rigorous studies with large samples or long-term impact assessment [14, 18].

The COVID-19 pandemic has accelerated digitization in education, highlighting the importance of implementing interactive and innovative teaching methods [2, 5, 6, 9, 12, 16, 20]. In this context, Ecuador and Latin America, in general, have seen educational policies prioritize the development of digital skills for students and teachers [5, 6, 20]. By proposing an educational robot that helps review basic mathematics through interactivity and gamification, this project aligns with this perspective. This project aims to develop a significant support for teachers, especially in classes with a high number of students. It seeks to ensure that the digitization of content is better suited to individual learning needs, both inside and outside the classroom. From a global perspective, the proposed solution contributes directly to the Sustainable Development Goals (SDGs). Specifically, it is linked to SDG 4: Quality Education, as it seeks to improve learning outcomes through an engaging and effective method. Additionally, it relates to SDG 9: Industry, Innovation, and Infrastructure, by applying robotics and technology to generate an educational solution that can be scalable and adaptable. Based on the above, this project proposes the design and implementation of an educational robot as an assistant for reviewing basic mathematics. Through the integration of activity gamification and interactive environments equipped with feedback protocols, the system will allow for interactive adaptation of content to the student's learning process, targeting its audience in basic education and aligning with current national education regulations.

The general objective of this project is: Design and develop an interactive educational robot to support the learning process in elementary school

In order to achieve this primary objective, three specific objectives have been stated:

- Design an interactive system that allows the representation of gamified educational concepts through the selection of sensors, actuators and interfaces as well as the development of a physical structure based on ISO 8124 and providing visual feedback to the user

- Implement the functional prototype of the gamified system, integrating the complete system to execute interactive mathematical activities.
- Conduct functional tests of the system in a laboratory environment, focused on verifying the correct interaction between sensory elements, actuators, and visual feedback, as well as the system's response to proposed mathematical activities

Chapter 2

METHODOLOGY AND DESIGN

The development methodology for this project was structured according to the VDI 2206 guideline (Design methodology for mechatronic systems), employing its ’V-Model’ framework [21], to ensure a systematic integration of mechanical, electronic, and software domains, as seen in Figure 2.1 .

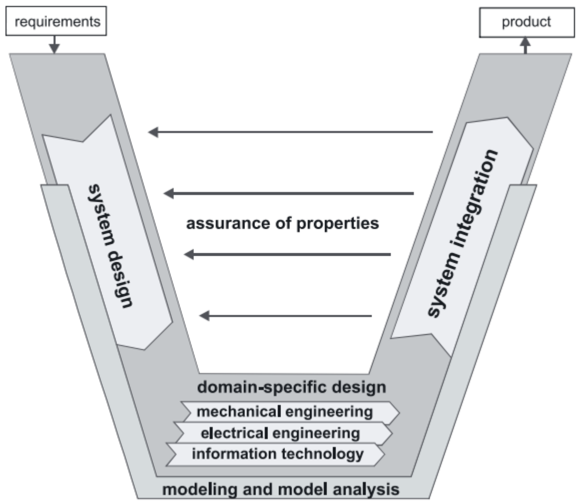


Figure 2.1. *The V-Model methodology (VDI 2206) applied to the mechatronic design cycle of the A.R.I.M.A. prototype*

The process began with the definition of functional and non-functional requirements to guide the successful design, implementation, and testing of the prototype. The conceptual design consisted of sketching alternatives to address physical and logical constraints, as well as defining the robot’s interface, thus establishing the system architecture. The detailed design phase delved into the software, mechanical, and electronic subsystems, applying ISO standards in CAD modeling, utilizing programming libraries, and performing component sizing. Finally, the testing criteria focused on evaluating each subsystem’s performance under specific user scenarios

1 Requirements

There was created a set of Functional, Non-Functional requirements and restriction to guide the developing and fulfill the scope of this project:

1.1 Functional Requirements

- The system shall offer two (2) courses, and one (1) tutorial.
- The system shall record the exercises in which the user makes a mistake.
- The user must be able to choose an initial difficulty level (beginner for addition, multiplication, and pairs; intermediate for sets, days of the year, and entrepreneurship; advanced for six-digit addition and logic problems).
- Upon completion of practice or evaluation activities, the program shall automatically return to the mode selection menu.
- The 'Practice Mode' shall present a list of activities to be reviewed and start reviewing on selected ones.
- The 'Practice Mode' shall collect all failed exercises from previous lessons and present them again until the user answers them correctly.
- The 'Evaluation Mode' shall present a predetermined set of 18 exercises in a completely random order and only once each one.

1.2 Non-functional Requirements

- The system must display a graphical interface on a 7-inch or larger LCD screen with a resolution of at least 800x480 pixels. This interface must include a home screen, an activity selection menu, a settings menu, and clear navigation buttons (Back, Next, Menu). Instructions for each activity must be visible on the same screen.

- Visual and auditory feedback must be activated instantaneously upon user input (Less than 1000 miliseconds after user input).
- The system must be operable with a mouse, allowing buttons and options to be selected with a click. Navigation through menus and interaction with drag-and-drop elements must be enabled. The keyboard will be used for numerical data entry in exercises that require it.
- The text messages for feedback on each activity must be in natural language and must indicate whether the user's answer is correct or incorrect.
- The main navigation buttons (e.g., "Main Menu," "Next," "Exit") must be in the same area of the screen, with the same size and shape in all program's interfaces. The color palette of the design shall remain consistent throughout all activities.
- The LCD interface shall display buttons with labels that are legible and recognizable from one meter and shall have a color palette that contrasts sharply with the background. The font size for instructions and button labels shall not be less than 24 points.
- The 'approval' and 'error' signals, through mechanical movements, must be clearly perceptible from up to 3 meters. This will be achieved through broad and well-defined movements of the servomotors.
- The language, instructions, and symbols used in the interface must be designed for the comprehension level of a sixth-grade student. Simple analogies and examples related to the subject curriculum will be used.
- Each time the user clicks on a button or response option, a distinctive video game sound will be emitted to confirm the action. This will serve as auditory feedback.
- The system will display 'celebration' slides of the robot upon completion of a block of exercises (the number of which is subject to user choice).

1.3 Restrictions

- The system will be developed on python 3 and available libraries
- The system will be developed based on Raspberry Pi's Python 3 interface
- The body of the robot will be made from PLA
- The screen to be used is 7-inch non-capacitive.
- The sounds used for feedback are retrieved from internet sources
- The robot will be developed in less than 5 months

2 Conceptual Design

2.1 System Abstraction (Functional Architecture)

Based on the established requirements, the system's function structure was defined via black-box method. The primary objective is to facilitate user interaction through physical and digital feedback. The abstraction illustrated on Figure 2.2 identifies two main input flows: Information Flow (user commands via peripherals) and Energy Flow (electrical supply). The system's core function is the transformation of these inputs into an Information Output manifested as visual and/or auditive feedback. The specific technical proposals made to achieve these transformations are detailed in the next sections.

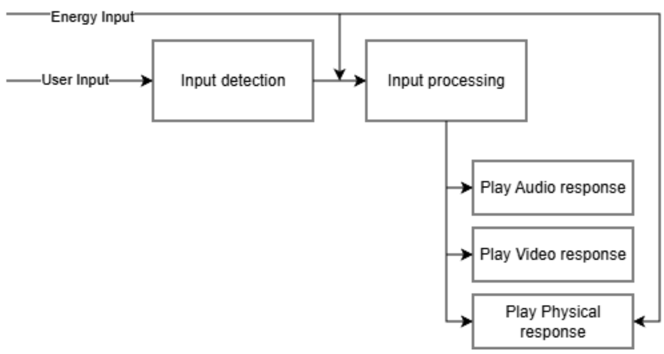


Figure 2.2. *System Function Structure*

2.2 Solution Variants

Two conceptual proposals were generated based on the requirement set and the system abstraction, and are detailed next:

Variant A: Hybrid system (NAO Robot + Interactive Whiteboard)

The first conceptual variant proposed a Distributed System. This solution consisted of a NAO robot implementation acting as the primary system for physical and auditory feedback, operating alongside an external interactive whiteboard for extra visual support. This design aimed to augment the visual appeal of the NAO's motion and sound capabilities to engage the user, while the independent display managed the activity review interface. Technically, this architecture relied on the programming capabilities of the NAO software to establish the necessary interconnection and synchronization between both independent systems, and an illustration of how it shall look is shown in Figure 2.3.

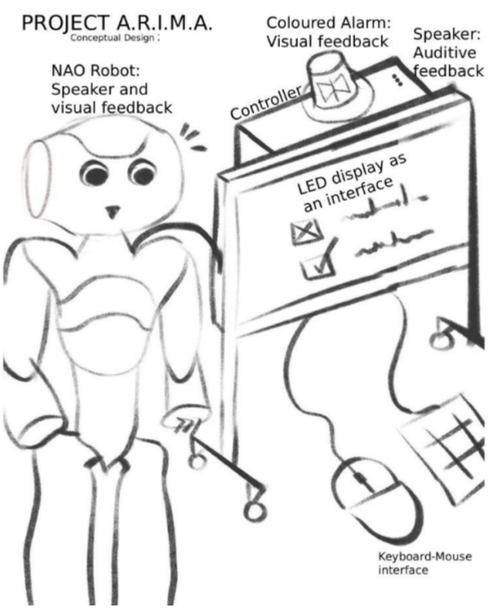


Figure 2.3. *Variant A: NAO and Interactive Whiteboard*

Variant B: All-in-One bunny system

The second conceptual variant proposed an Self-Contained System. This solution is based of a main screen as the primary interface of the system and actuators performing mechanical gestures as response of user input. This design aimed to include every component inside a chassis and leverage its anthropomorphic shape of this enclosure and its movements as the main user engagement mechanism. Technically, this architecture relied on a unified hardware configuration and a software capable of unifying feedback sources and input logic. An illustration representing this variant is shown on Figure 2.4.

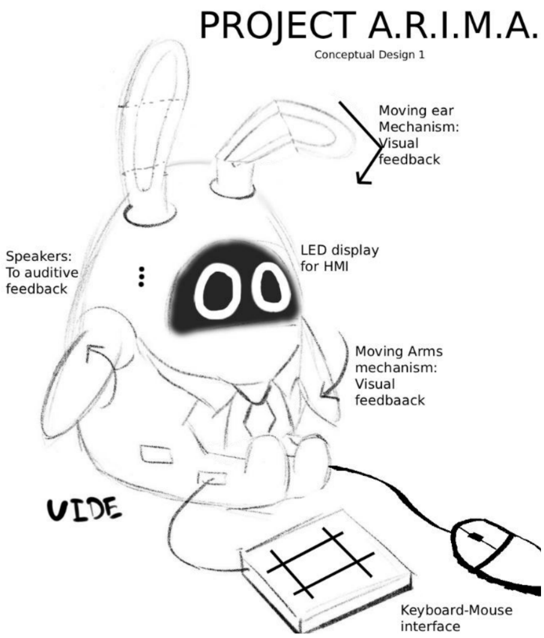


Figure 2.4. *Variant B: Modular Stand-Alone bunny design*

2.3 Concept Selection

For the selection of the architecture to be implemented, both variants were analyzed under criteria such as economic feasibility, software implementation complexity, and user experience; as Table 2.1 indicates:

Table 2.1. *Concept Selection Matrix (Pugh Matrix)*

Evaluation Criteria	Variant A: Bunny System	Variant B: NAO + Whiteboard
Hardware Integration	+	−
System Complexity	+	−
Visual Feedback	0	0
Physical Interaction	-	+
Manufacturing Cost	+	−
Maintenance	+	−
Aesthetics	0	0
Total Positives (+)	4	1
Total Negatives (-)	1	4
Total Same (S)	2	2
Net Score	**3**	**-3**

Legend: (+) Better than adversary, (-) Worse than adversary, (S/0) Same as adversary.

NAO + Whiteboard Variant presented a high implementation cost and integration complexity when synchronizing the two systems, and provided no substantial benefit on interactivity against the Unified architecture. Bunny System Variant was chosen because it meets both visual and auditory requirements in a segmented but self-contained structure, greatly reducing costs and programming time while maintaining a high level of interactivity. Furthermore, it enables a more intuitive user interaction, prioritizing the robot's personality through a centralized system design.

2.4 Architecture of the Selected System

The selected architecture is defined as a centralized and self-contained system. While externally presenting a unified form-factor to the user, the internal mechanical design follows a modular proposal. This approach consolidates all processing, interface, and actuation units within a single housing, while allowing for the independent access of subsystems for maintenance purposes. Thus, this robot achieves the robustness of an integrated device with the flexibility of a modular assembly. Functionally, the system operates under a centralized control topology. A main processor orchestrates the interaction between user inputs and the system's multi-modal feedback, synchronizing the digital (visual) response with auditory and mechanical actuators.

First, a main script manages the entire system via a function calling protocol based on the user's interaction. Then, there exist three principal modes, on which the user can know how to operate the system, review activities or take a quiz. All of these modes perform error detection, provide a visual or auditory feedback and register the error, and then each activity mode performs a different response to errors.

2.5 Logical Architecture

The system operates based on a simple state machine, it starts by presenting a video and a welcome interface, then goes into 'waiting' mode until it receives an input signal from the user. The operational logic changes depending on the active mode, in three workflows:

- Tutorial Mode: Allows the user to familiarize themselves with the various interfaces and controls of the robot.
- Practice Mode: Allows the user to select a level of difficulty and the number of activities to practice.
- Evaluation Mode: Performs a reorganization of all available activities and displays them to the user one by one.

To ensure pedagogical validity, the activities were designed in strict alignment with the National Curriculum for Basic General Education established by the Ecuadorian Ministry of Education [22] with permission for the official use of such activities (see APPENDIX C). The exercises constitute a digital and gamified adaptation of standard educational resources, ensuring content relevance for the target academic level. This strategy is materialized through four core interaction mechanics:

1. Direct Association (Connecting Lines): Links abstract concepts with graphic representations.

2. Logical Sequencing (Completing Series): Reinforces algorithmic thinking by identifying patterns.

3. Spatial Classification (Pick and Place): Develops fine motor skills through drag-and-drop actions.

4. Knowledge Validation (Quiz): Direct evaluation via multiple-choice selection.

From a technical perspective, the system architecture classifies these mechanics into two distinct interaction categories: Numerical Input Activities (requiring data entry via the numeric keypad) and Graphical Selection Activities (requiring spatial interaction via mouse).

Furthermore, a closed-loop error detection mechanism runs transversally across all modes. This logic utilizes internal flags to monitor performance in real-time; upon detecting an incorrect response, it registers the event to either trigger an immediate replay loop (Practice) or log the data for the final report (Evaluation).

Finally, it should be noted that this logical architecture integrates physical mechanisms as active feedback channels. The system maps logical states (e.g.'Success', 'Error') to predefined movement patterns, ensuring that the robot's kinetic behavior acts as a synchronized extension of the digital interface. Figure 2.5 shows the logical distribution of each game mode.

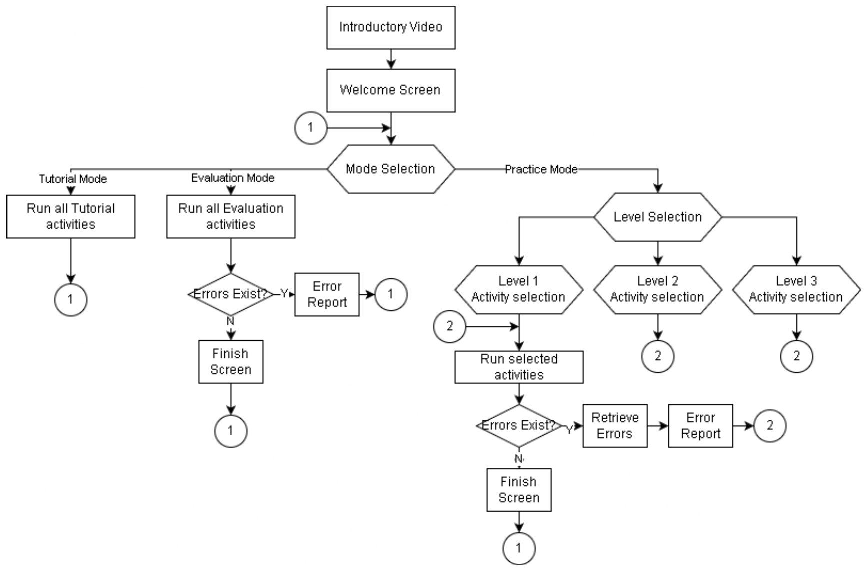


Figure 2.5. *Logical Architecture Diagram*

2.6 Physical Architecture

To ensure a design that meets the established requirements, the physical architecture was developed by integrating electronic systems and custom-made structures. Electronically, the topology was designed around a Single Board Computer (SBC) controller, which acts as the central processing unit and is responsible for synchronizing standard port peripherals with their respective outputs, while simultaneously managing the graphical interface and control signals for actuators. This architecture also includes an energy management strategy that decouples the logic load from the power stage in order to obtain total control over the power supply to the actuators, as it can be seen on Figure 2.6.

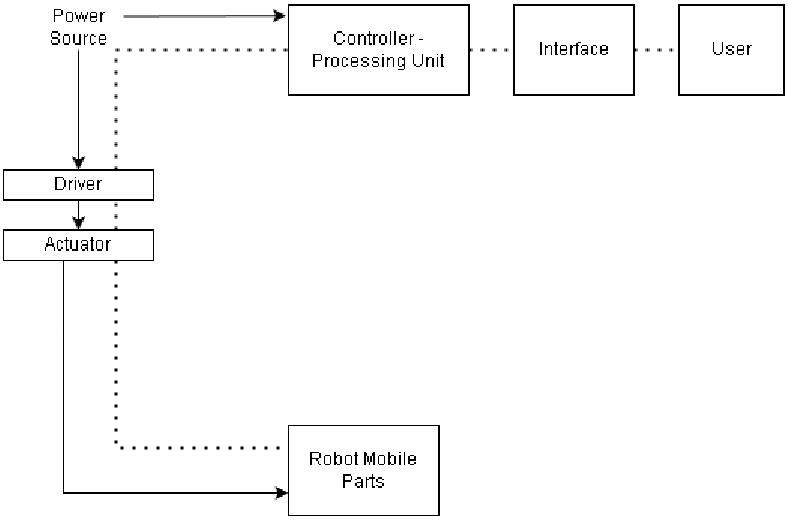


Figure 2.6. *Physical Architecture Diagram*

The components are housed in a custom chassis consisting of a cylindrical shape with a dome-shaped head. The geometric selection minimized sharp edges, prioritizing design principles for toys. The internal layout follows a strategic component distribution, with the display embedded in the front section of the head, while ports and inputs are located behind the body. In addition, the robot's personality is physically manifested through mechanisms located at the top of the head that resemble ears. The actuation system implements a remote motion transmission strategy, using active and passive tension elements to transfer motion from the base to the appendages. The arm mechanism used a direct-drive coupling to connect both limbs to the body. An illustration of the given description is shown in Figure 2.7.

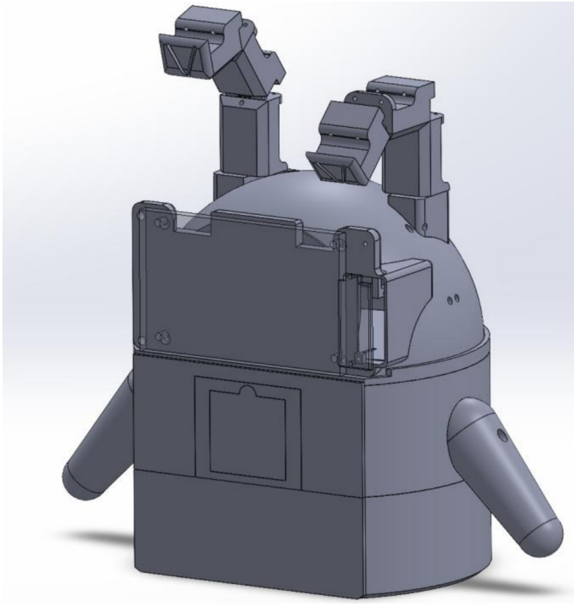


Figure 2.7. *Physical Architecture: Mechanical Layout and Morphological Configuration*

Finally, the transition from this conceptual architecture to the detailed engineering phase follows an iterative development strategy. Rather than isolating disciplines, the following Specific Design chapter details the materialization of the prototype in the sequence it was executed: prioritizing the definition of control logic and electronic validation first, which then established the geometric constraints for the mechanical design of the head, neck, and body.

3 Specific Design

Having defined the conceptual architecture and the transversal modularity strategy in the previous chapter, this section presents the technical dimensioning and implementation of the hardware and software components integrated within the robot

3.1 Software design

The first stage consisted of establishing the mind of the system. Python 3 was selected as the programming language due to its versatility and native compatibility with a wide variety of controllers.

To equip the robot with its interactive capabilities, the following key libraries were used:

- Pygame: For developing the graphical user interface (GUI) and managing user events (clicks and keyboard).
- Adafruit-Servokit: For I2C communication with the actuators.
- OpenCV: For video playback at the beginning of the interface.

To maintain a decentralized and modular logic, the software was not written as a single block, but rather divided into specific scripts according to their function. A main program is responsible for calling secondary programs and managing the overall execution flow of the system.

The development of the logical subsystem underwent iterative process to resolve scalability and stability limitations. This process was divided into two distinct architectural phases:

- **First Iteration: Linear Execution Architecture** In the initial stage, the prototype operated under a paradigm of direct sequential calls, with control flow transferred “in chain”: the video module imported and executed the intro() function, which in turn imported and called jugar() and continued with the implementation of activities and menus. This structure created a rigid dependency where the “parent” module had to know and contain the “child” module. When attempting to implement a return logic (e.g., returning from the game to the menu), fatal circular import errors occurred, as both files attempted to load each other. In addition, event management and the initialization of libraries such as Pygame and OpenCV were fragmented across scripts, making it difficult to control the system globally.
- **Second Iteration: State Machine Architecture (Final Implementation)** To resolve dependency conflicts, the system was migrated into a Modular (FSM) architecture centralized in the Controller script.

- Direct calls between functions were eliminated. Instead, each module (Menu, Video, Activity) returns a state identifier (e.g., ‘intro’, ‘gameModes’) to the Central Controller. The main loop (while running) evaluates this identifier and dispatches execution to the corresponding module without creating permanent links between them.
- Under this robust structure, the multimedia startup requirement was integrated. The system starts in a ‘Video Intro’ state, where the OpenCV library is used to decode and render the welcome animation frame by frame on the Pygame surface. Upon completion of playback, the state automatically transitions to the initial screen, initiating user interaction smoothly and without risk of blocking.

So, when describing the code done for the second iteration, the main script called Controller.py acts as the central orchestrator. Its first task is to initialize the base libraries and configure the display window to full resolution (800x480). It then executes the main loop, which implements a finite state machine. The controller constantly monitors the state variable (current-state) and, depending on its value, dynamically invokes the corresponding external modules.

The controller constantly monitors the state variable (current-state) and, depending on its value, dynamically invokes the corresponding external modules. In addition, it manages the logic of the activity-queue during practice mode, sequentially dispatching the exercises mapped in the activity-mapping dictionary and managing the visual and auditory transitions between the different screens using the transition-to-state function.

To achieve this architecture, the code imports and coordinates the following proprietary modules:

Navigation and Menu Modules:

- intro.py: Responsible for the startup sequence. Renders the decoded introductory video and displays the welcome screen (“Press Start”), initializing the interaction cycle.

- modosJuego.py: Manages the central navigation menu. Implements event detection logic to branch the flow to the three operating modes (Tutorial, Practice, Evaluation).

Mode Logic Modules:

- modo-tutorial.py: Execute the guided flow to teach the user how to interact with the robot's peripherals and interfaces
- modo-evaluacion.py: Manages the exam logic, randomizing questions and collecting errors without allowing immediate retries.
- selector-nivel.py and selector-actividad.py: Configuration interfaces for practice mode that allow the user to set the parameters for the session, selecting the difficulty and filling the queue of activities to be performed.
- interludio.py and repaso.py: Handle the intermediate screens between activities and the feedback or error repetition logic.
- repaso.py: Implements the logic of the Review Loop. This script queries the volatile error database and determines the next step in execution: if there are pending activities in the failure queue, it returns the identifier of the next activity to be repeated; otherwise, it directs the user to the completion screen.

Closing Modules and Visual Feedback:

- final-1.py and final-tutorial.py: Manage the session conclusion screens. They are responsible for stopping background processes (music), rendering celebration animations by exchanging frames, and clearing temporary progress flags before returning to the menu.
- resultados-evaluacion.py: A conditional display module where if the user passes, it displays success animations; if they fail, it dynamically generates a paginated

interface that lists the failed activities textually, allowing the user to navigate through their error report if it exceeds the capacity of a single screen (more than 5 items).

Educational Activity Modules (Bank of Activities):

- PNP-x.py, LJ-x.py, NUM-x.py, QZ-x.py: Independent scripts containing the game logic, graphic assets, and answer validation for each exercise. They function as "black boxes" that receive control, execute the activity, and return a success or failure status to the orchestrator.

Cross-cutting and Data Management Modules (Logical Backend):

- progreso.py: Acts as the system's State Manager. It keeps a real-time record of user performance (error dictionary), manages global flags (such as MODE-EVALUATION-ACTIVE), and provides methods for initializing batches, recording results, and resetting progress at the end of a session.
- spritesheet.py: Graphic utility for resource optimization. It allows dynamic loading and cropping of sub-images from spritesheets, facilitating the creation of smooth animations without overloading memory with multiple individual image files.
- funciones.py: Shared utility libraries for standardizing fonts, visual transitions (fade-in/fade-out).

Actuation Control Modules and Concurrent Feedback (Advanced Drivers)

- sonidos.py: Acts as the unified feedback manager. Its critical function is to synchronize the auditory response with the kinetic response. It implements a multi-threading system that allows complex physical movements (e.g., "celebration") to be launched in parallel with audio playback, ensuring that the graphical interface remains responsive (non-blocking). In addition, it uses mutual exclusion mechanisms (threading.Lock) to prevent conflicts of access to the I2C bus if multiple events attempt to move the motors simultaneously.

- Orejas.py (Kinetic Library): Encapsulates the low-level logic for controlling the servomotors. It defines pre-programmed movement profiles (e.g., orejas-tristes, brazos-celebrando, saludo) that translate abstract emotional states into precise sequences of PWM angles. It includes safety features such as torque release (soltar-servos) that deactivates the electrical pulse at the end of a movement to prevent motor overheating and unnecessary energy consumption.

To illustrate the dynamic interaction between the scripts described, Figure 2.8 presents the system's data flow diagram. Unlike a static hierarchical architecture, the diagram shows how the Controller delegates the flow to the Navigation scripts, which act as logic distributors to the Activities or Logic modules. Additionally, the precense of the Feedback modules in various stages is highlighted, which are called bidirectionally by both the navigation interface and the cores of the educational activities.

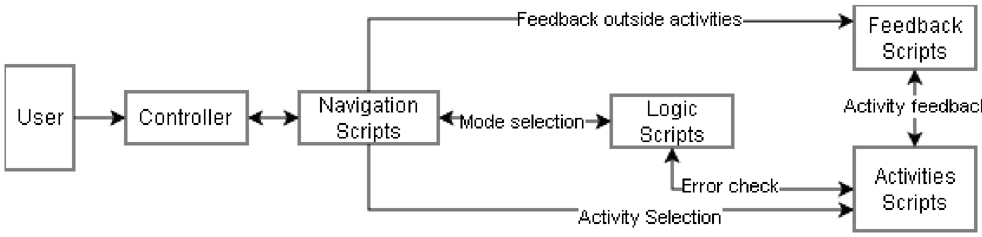


Figure 2.8. *Data Flow Diagram and Dependencies between Software Modules*

3.2 Security and Regulatory Compliance Considerations

The morphological and mechanical development of the robot was strictly governed by the safety principles established in ISO 8124-1 (Safety of toys - Part 1: Mechanical and physical properties) [23]. Although this prototype does not seek immediate commercial certification, its CAD design integrates the following engineering guidelines to ensure safe interaction:

- Safe Geometry: All sharp edges, burrs, and accessible sharp points were eliminated by applying radii ($R > 2$mm) to the outer casing, preventing accidental cuts or punctures.

- Entrapment Prevention: In the moving mechanisms (ears and covers), the joint clearances were dimensioned to avoid pinch points, ensuring that the separations are less than 5 mm or greater than 12 mm throughout the range of motion.
- Protrusions and Stability: The dome and cylindrical body morphology minimizes dangerous rigid protrusions in the event of the user falling on the robot. Likewise, the weight distribution (batteries in the base) ensures static stability under moderate inclinations.
- Mechanical and Thermal Risk Management: The maximum torque of the actuators was limited to prevent compression injuries, and passive thermal dissipation was ensured to prevent excessive heating of accessible surfaces.
- Component Safety: The battery and electronics compartment was designed with tool-required closures to restrict child access. In addition, the structural integrity of small parts (such as buttons or covers) was ensured to mitigate the risk of detachment and suffocation.

3.3 Display Housing design

Following the definition of the control logic, the mechanical development commenced with the integration of the 7-inch LCD screen. As the primary Human-Machine Interface (HMI), the physical dimensions of this component established the geometric baseline for the robot's upper section.

To secure this interface, a dedicated screen housing was designed first. This enclosure is dimensionally proportional to the display's diagonal and acts as an independent module that manages the routing of USB power and HDMI signal connections. By decoupling this housing from the main head structure, the design ensures that the visual component functions as a self-contained unit, facilitating testing and assembly prior to its integration into the final head structure. Figure 2.9 shows the iterations made into the design procedure, being the final a design that corrected unnecessary structures and tolerance errors.

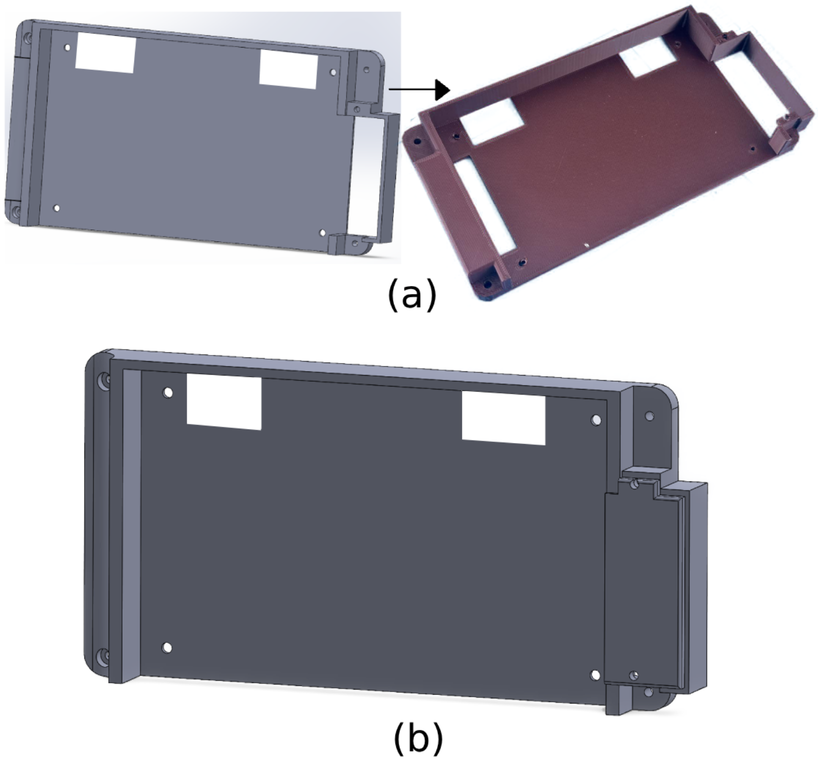


Figure 2.9. *Quick prototyping iteration: First (a) and final (b) screen housing design*

3.4 Ears design

As a secondary element of interaction with the user, a three-link mechanism with active tendon and passive retraction was designed to achieve contraction through servomotors and passive retraction through elastic. It is biologically inspired by the functioning of phalanges and also by hand prostheses specialized in gripping, where a circular movement translates into a linear movement and a contraction. These links have hinge-type joints, which allow for constant and repeatable contraction and expansion of the mechanism, ensuring a fixed trajectory. Mechanical movement restrictions were also included in the links to ensure a final position at the moment of expansion.

Regarding the joint definition, the hinge mechanism utilizes PLA pins of 2.75 mm diameter as rotational axes. To minimize friction and wear inherent to the PLA-PLA pair, a specific dimensional tolerance of 0.28 mm was applied to the CAD geometry. Furthermore, the design incorporates internal routing channels and concealed anchor points within each link to secure the nylon tendon and the retraction elastic, ensuring that the actuation elements remain guided and do not interfere with the external aesthetics or safety of the device.

Critically, the geometry of these joints is based on, but not limited to the principles of ISO 8124-1. Residual risks are mitigated by a torque limitation safety strategy, a supervised use context, and the prototype nature of the device.

Prior to the final geometric definition, the ear link component underwent an iterative design optimization process to try different mechanism couplings. Initial prototypes (Figure 2.10 (a)) utilized a pin coupling with diameter 30mm on the base, and defining a 3 movement link, while robust, imposed an unnecessary gravitational load on the actuator and provoked excessive contractions when activated. Contractions that contributed no benefit to the personality overall. The second iteration resolved these problems by reducing the rotation scope onto only two links and using embedding as the joint principle of the base link, Figure 2.10 shows the first and last iteration of the ear design.

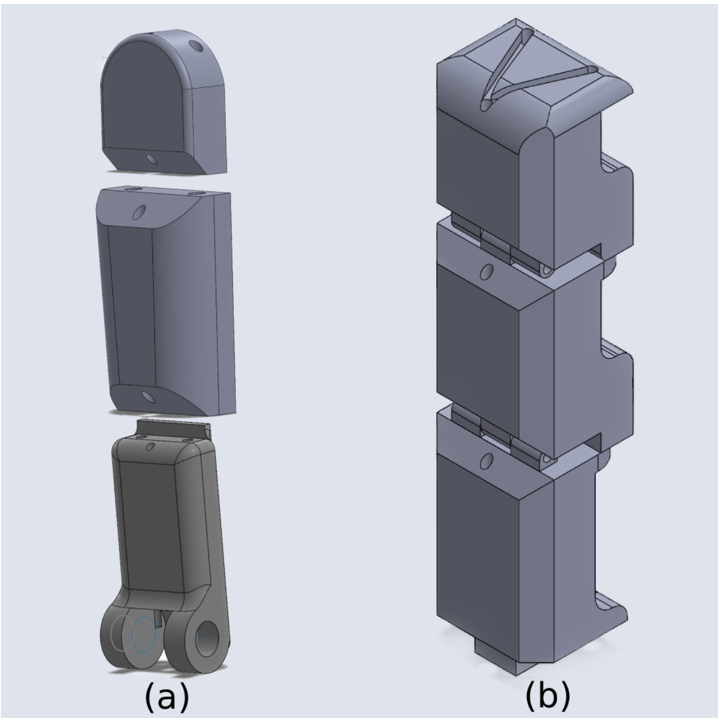


Figure 2.10. *Ear design iteration: (a) First Ear Mechanism Iteration, (b) Final Ear Mechanism Iteration*

For the manufacture of all quick and final prototypes of parts on this document, the Fused Deposition Modeling (FDM) process using colored PLA (Polylactic Acid) was selected. This choice allowed the infill density to be optimized to reduce the inertia of the mechanism, a critical factor for the dimensioning of the actuators detailed below.

Based on the geometric constraints and the mass defined by the manufacturing process, the required torque was calculated to ensure reliable operation. Using the CAD model and SOLIDWORKS software, the center of mass for the ear assembly was located at a distance of 25 mm from the main pivot. The design parameters were defined as follows:

- $m_{assembly} = 0.045$ kg: Total mass of the ear link assembly.
- $r_{cm} = 2.5$ cm: Distance from the main pivot to the center of mass.

Thus, by selecting a 4% infill density for each link of the final mechanism inside a Slicer Software as Ultimaker Cura, in preparation for FDM manufacturing, a total mass of approximately 0.045 kg per ear assembly was achieved as Figure 2.11 shows. This physical parameter is fundamental for the subsequent dimensioning of the actuators, as minimizing the moving mass reduces the torque required to overcome the elastic return force.

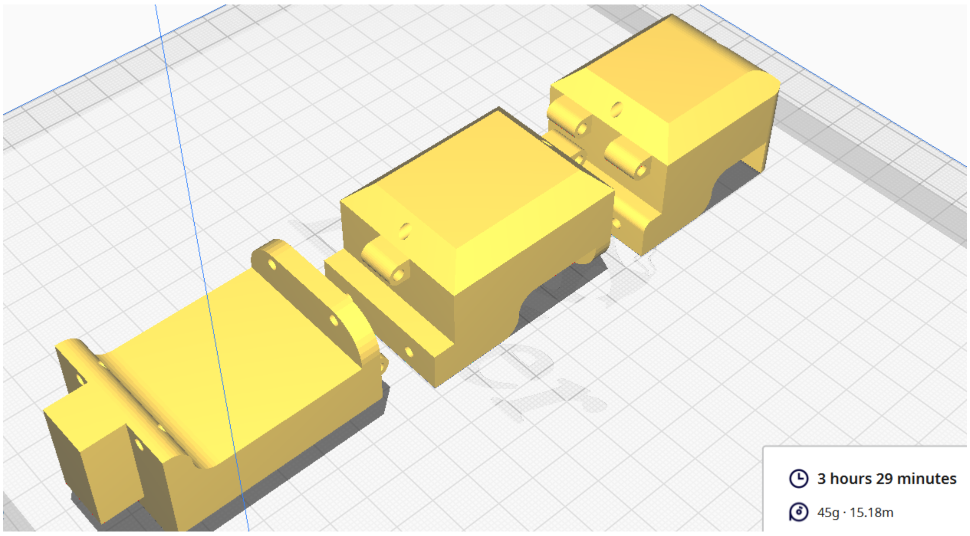


Figure 2.11. *Mass of each ear using UltiMaker Cura Slicer*

Consequently, the static gravitational torque ($T_{gravitational}$) represents the baseline load required to lift the mechanism:

$$T_{gravitational} = m_{assembly} \times r_{cm} \tag{2.1}$$

$$T_{gravitational} = 0.045 \text{ kg} \times 2.5 \text{ cm} = 0.1125 \text{ kg-cm} \tag{2.2}$$

However, the actuation system must not only lift this mass but also overcome the opposing force of the passive retraction elastic ($T_{elastic}$). Since the design condition requires $T_{elastic} > T_{gravitational}$ to ensure passive return, the servo selection condition is governed by the inequality:

$$T_{servo} > T_{elastic} + T_{friction} \tag{2.3}$$

Under these conditions, the gravitational torque serves as the minimum reference load. Although micro-servos such as the SG-90 theoretically satisfy this baseline torque, the HS-311 standard servo was selected based on thermal management criteria (Stall Torque). Analysis indicated that maintaining the ear in a ”contracted” position against the elastic force would compel an SG-90 to operate at over 60% of its capacity, leading to rapid overheating and reduced lifespan. In contrast, the HS-311 operates at less than 10% of its capacity under the same load. This safety margin ensures that the actuator can hold positions for extended periods without thermal degradation, a critical requirement for a robot intended for constant educational interaction.

In order to handle these servomotors, a dedicated driver was dimensioned. The primary objective with this selection is to separate both logical and power circuits, thereby reducing electrical noise and preventing voltage drops on the main controller. Consequently, the PCA9685 module was chosen. While its 16-channel capacity exceeds the immediate requirement for the four actuators (ears and arms described later on this document), this dimensioning prioritizes system scalability. Furthermore, this driver manages PWM signal generation autonomously via I2C communication, effectively offloading processing tasks from the Raspberry Pi’s CPU to ensure smoother operation.

3.5 Head design

Prior to the final manufacture of the head, an incremental validation strategy was implemented to verify the dimensional tolerances and concepts of the actuator housings. Since the integration of servomotors requires precise mechanical adjustment to ensure the torque transmission, the CAD model was geometrically segregated.

Critical cross-sections containing only the mounting brackets and rotation shafts were isolated and manufactured. These rapid prototyping iterations allowed for physical verification of the fit of the electronic components and correction of clearances in the digital design before committing resources to printing the total volume of the head.

An illustration of the process followed in quick prototyping for the head is shown in Figure 2.12.

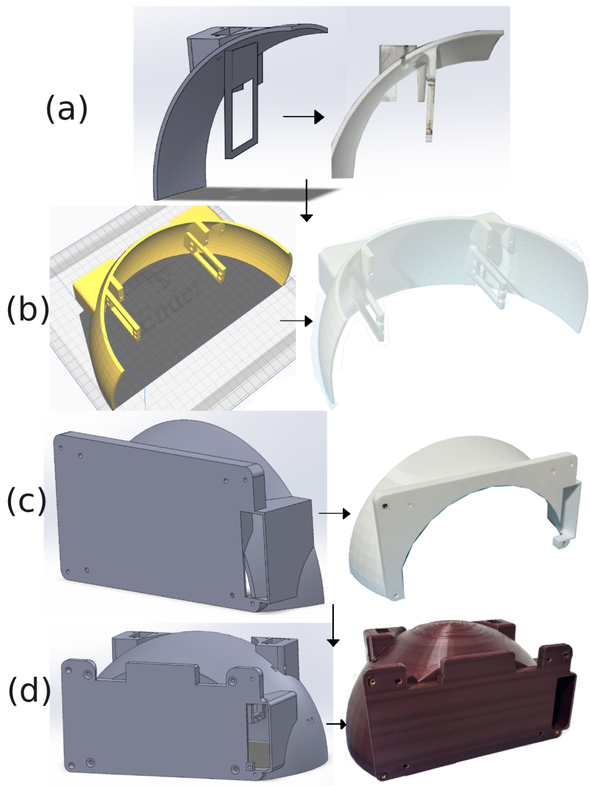


Figure 2.12. *Quick prototyping iteration: Physical validation of single servo fitment (a), both servo fitment (b), Visor fitment (c), Head without visor and ears (d), using FDM methods with PLA*

Finally, the physical integration of the subsystem components is consolidated in a 121 mm diameter upper dome structure designed to house both the ear mechanism and the LCD screen as Figure 2.13 shows. From a morphological perspective, the design prioritizes user safety by eliminating sharp edges and minimizing pinch points, based on the principles of ISO 8124-1 for toy safety.

In terms of construction, the structure strictly follows the principle of modularity to facilitate the assembly and maintenance of the prototype. This is implemented through two fastening strategies:

- Component Fastening: Bolts and threaded inserts are used to secure the screen and its connection ports, allowing for easy replacement of the visual interface if necessary.
- Quick Access: For the connection between the dome (head) and the main chassis (body), magnetic snap-on fasteners on the bottom of the dome were incorporated. This design decision allows the head to be quickly detached from the body, ensuring immediate access to the internal electronic components for maintenance tasks. The joint between the ears and the dome is made via a embedding of separate parts.

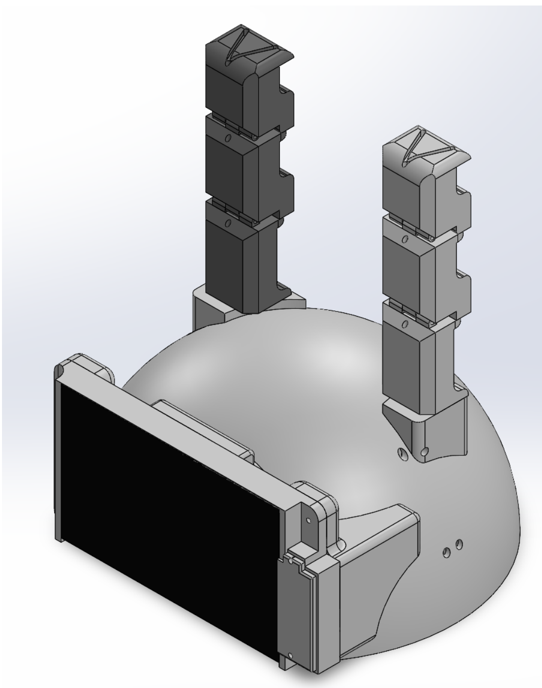


Figure 2.13. *Upper Expression subsystem CAD design*

The connection between the head subsystem and the body (neck), utilizes an array with magnets on opposite polarity to the ones on the dome. To validate this coupling, design iterations were performed using rapid prototyping to verify dimensional tolerances and movement constraints.

The first iteration attempted a ”male-female” interference fit, where the dome acted as a male connector fitting into a circular contour slot. This design proved inefficient due to its high dependency on tight manufacturing tolerances and the difficulty it presented for user manipulation. Both of this designs integrated a sectioning for Servo-Driver embedding, leaving room for cable management for signal and power. This in order to position the driver halfway between head and body actuators. Figure 2.14 shows the iterative process made onto the neck design.

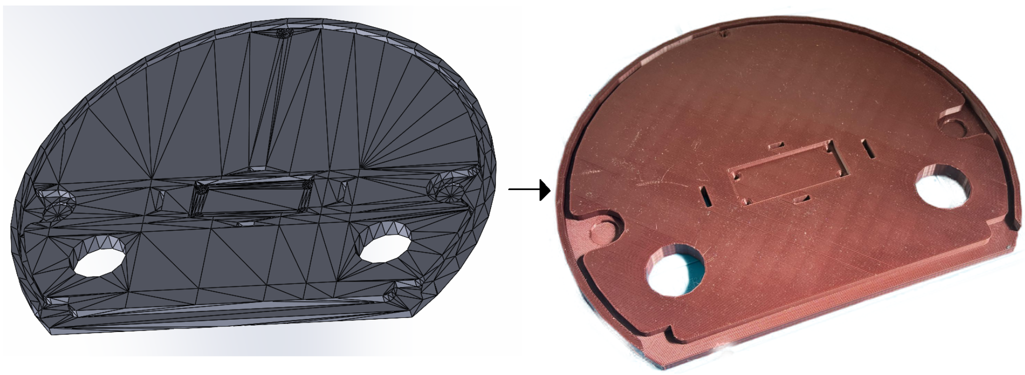


Figure 2.14. *First quick prototyping iteration: Physical validation of neck design*

The second iteration consisted of a design with fewer restrictions, focusing more on the positioning of magnets and now relying solely on the outer diameter of the dome for centering, while accounting for the clearance volume required by the LCD screen components. This resulted in a significantly easier and more accessible connection mechanism, as Figure 2.15

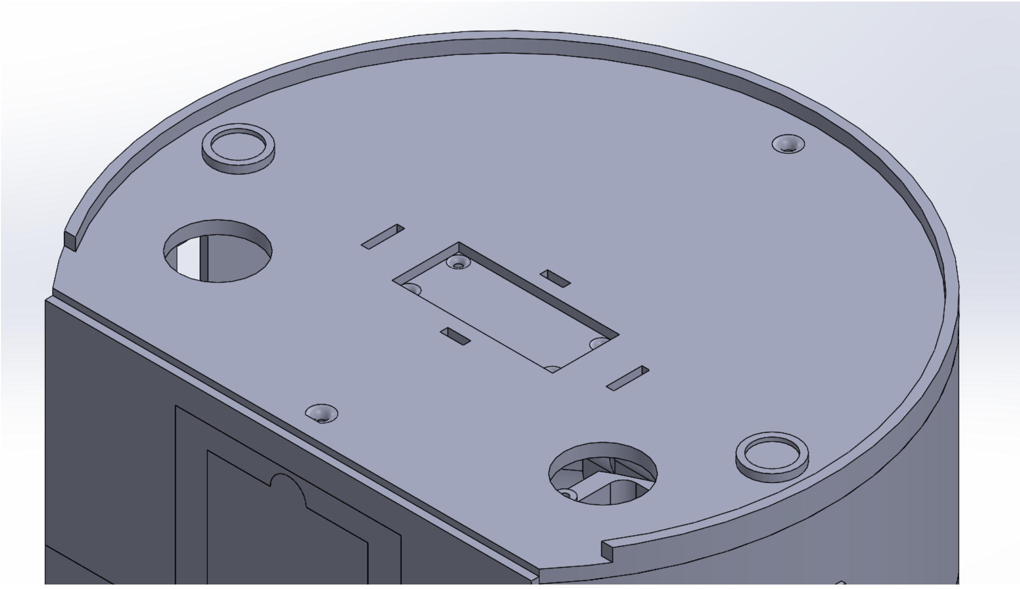


Figure 2.15. *Final design iteration of neck design*

3.6 Controller dimensioning

After defining the software architecture and interaction requirements, the technical requirements for the processing hardware were established based on requirements and restrictions. The system required a controller capable of supporting three simultaneous critical loads:

- **Graphics Processing (HMI):** Operation of a multi-menu graphical interface on a 7-inch screen via HDMI port.
- **Peripheral Management:** Native connectivity for numeric keypad and mouse via generic USB ports.
- **Software execution:** Direct compatibility with Python 3, Pygame library for Interface, OpenCV for video display, multi-threading libraries for multi-actuator movement at the same time.
- **Communication protocols and I/O:** Availability of GPIO ports for driver communication and support for I2C protocols or similar.

During the conceptual phase, proximity sensors were considered. However, their implementation was ruled out in favor of a passive safety strategy based on three factors that justify the absence of a sensor in this iteration of the design:

- Mechanical Limitation: Low-power micro-servomotors are used for the arms (detailed sizing in Section 3.8). Their limited locking torque prevents the system from generating enough force to cause physical damage, eliminating the need for active emergency stop systems.
- Operating Distance: The use of a wired numeric keypad and mouse forces the user to naturally stay outside the range of the mechanisms in order to view and operate the screen comfortably.
- Resource Optimization: The elimination of environmental sensors prevents erroneous readings and frees up processing resources and GPIO ports, prioritizing the stability of the graphical interface and audiovisual synchronization.

Based on these criteria, the Raspberry Pi 5 (8GB of RAM model) was selected. This choice is justified by its superior processing power for rendering the Pygame interface without latency, its dual micro-HDMI video ports, and its 40-pin GPIO header, which is essential for I2C communication with the servomotor driver.

Now, in order to potentiate this SBC and its peripherals, a power source was dimensioned. To select the appropriate one, an energy balance was performed considering the worst-case scenario, where the processor, screen, and peripherals operate simultaneously. The nominal values considered were:

- Raspberry Pi 5: 5.0 A (Peak consume).
- 7” LED display: 2.0 A.
- USB peripherals: 0.2 A (combined).
- **Total maximum instantaneous consume $\approx$ 7.2A**

The theoretical maximum consumption analysis yielded a peak value of 7.2 A. However, this scenario represents a worst-case scenario that assumes the simultaneous concurrence of the Raspberry Pi under maximum CPU/GPU load and the screen operating at maximum brightness and volume levels.

Given that the educational software's execution profile does not demand these resources continuously, it was determined that the nominal consumption in actual operation remains below 7.2 A. Based on this criterion, the official 27 W Raspberry Pi power supply (USB-C PD) was selected, capable of supplying a stable current of 5 A. This power supply provides the power necessary to sustain the designed logical load under standard conditions of use, given that the probability of a full load scenario occurring is negligible in this application context.

3.7 Body design

Following the definition of the neck interface, the main body was dimensioned. A cylindrical shape approximately 150 mm high was established, a dimension calculated based on the size established for the head, in order to maintain an appropriate shape.

The design began in the upper section (immediately below the neck), where the structural anchor points were defined. Slots for threaded inserts were incorporated, allowing for a bolted connection between the body and the neck. This design decision creates an area accessible only with tools, where the internal wiring and connection between the controller and driver are concentrated.

To secure the Raspberry Pi 5, a mounting base was designed for the bottom of the chassis. Using the controller's technical schematics, support towers were modeled for M2 inserts and screws, ensuring a rigid hold. Strategically, the controller was positioned toward the rear of the chassis. This orientation prioritizes direct access to the embedded USB ports, facilitating peripheral connection and maintenance.

The design process underwent a validation phase using rapid prototyping (FDM) as is shown onto Figure 2.16 to verify manufacturing tolerances in PLA. The first iteration revealed dimensional conflicts: the initial design did not allow for the necessary clearance for all of the rear ports or the appropriate height relative to the base, making it difficult to connect USB heads. Based on this, the CAD model was corrected by adjusting the hole tolerances and raising the position of the plate.

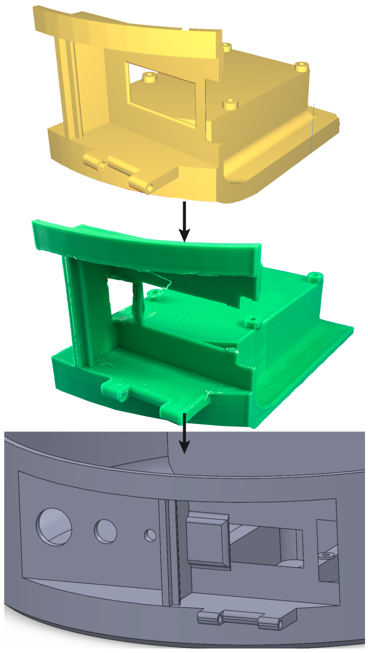


Figure 2.16. *Physical validation of port alignment: Detection of interference in the first iteration and solution in the final iteration*

Additionally, to protect these ports, a hinged cover system was designed and iterated using a PLA filament shaft, as Figure 2.17 shows. This cover was designed to fit the round shape of the backside of the robot's body.

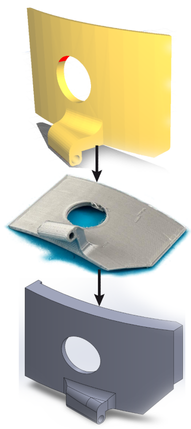


Figure 2.17. *Physical validation of cover design: Geometry and tolerance errors in the first iteration and solution in the final iteration*

Finally, because the rear positioning of the Raspberry Pi left its native power button out of reach, an external control interface was integrated into the chassis. Specific housings were designed for an accessible power push button and two status LED indicators:

- Orange LED: Power indicator (Standby).
- Green LED: Indicates that the operating system is running (Active).

Next, an image of the designed case that includes sectioning for USB ports, Push button and indicator leds, with also a coupling location for the neck, is shown in Figure 2.18.

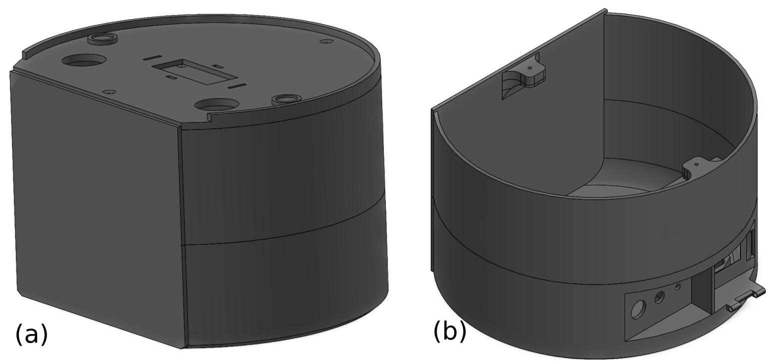


Figure 2.18. *Cad design of the body sectioning design for USB ports, Push Button, LED indicators and Neck Coupling. (a) Body with neck, (b) Body wihtout the neck*

3.8 Arms design

Once the geometry of the main body had been defined and its dimensions validated through rapid prototyping, the upper limbs were designed. Using the conceptual design sketches as a reference, the CAD modeling was oriented towards a conical morphology with rounded ends.

During the geometric definition, a non-perpendicular angle of incidence was established with respect to the body. This design decision gives the arms a natural outward opening, improving the visibility of gestures and avoiding mechanical interference with the chassis or actuator couplings during movement.

The design underwent a period of iteration to refine the geometry and include sections for assembly, as Figure 2.19 shows. For the first and the final iteration, FDM printing parameters were established, highlighting the use of 5% infill.

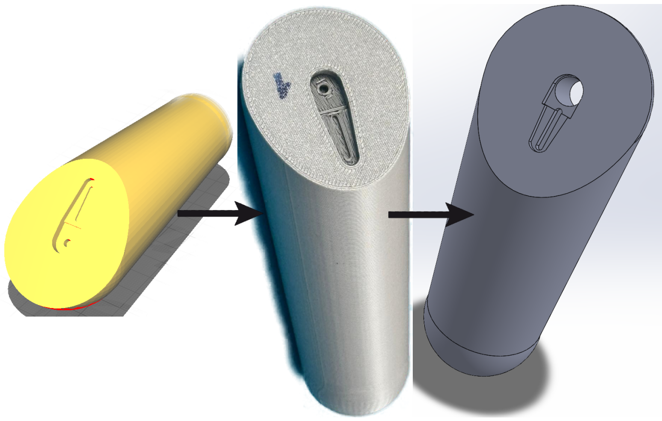


Figure 2.19. *Physical validation of arm design: Geometry errors in the first iteration and solution in the final iteration*

Based on the defined printing parameters, an operating mass of 0.04 kg per arm was obtained. With this value, the actuator required to perform repetitive visual feedback movements such as celebratory gestures or greetings was dimensioned.

The analysis considered the maximum load scenario (lifting perpendicular to the axis). The following physical parameters obtained from the CAD model were used:

- $L = 130$ [mm]: Maximum arm length.
- $W = 47$ [mm]: Arm width.
- $CenterOfMass = 63.84$ [mm]: Distance to center of mass.
- $M = 0.04$ [kg]: Arm mass.

The moment of inertia of the load (J_L) was calculated assuming rotation from one of the extremes of the arms:

$$J_L \approx \frac{1}{3}ML^2 \tag{2.4}$$

$$J_L = 2.2672 \times 10^{-4} \text{ [kg} \cdot \text{m}^2\text{]} \tag{2.5}$$

The acceleration torque (T_a) was determined for a target angular velocity of 60 rpm in 0.5 seconds:

$$T_a = 0.00285 \text{ [Nm]} \tag{2.6}$$

Additionally, the load torque (T_L) required to overcome gravity at the position of greatest effort (arm being totaly horizontal) was calculated:

$$T_L = M \times g \times r_{cm} \tag{2.7}$$

$$T_L = 0.04 \text{ kg} \times 9.81 \text{ m/s}^2 \times 0.06384 \text{ m} = 0.0250 \text{ [Nm]} \tag{2.8}$$

The Total Required Torque (T_{req}), applying a Safety Factor (SF) of 1.5, resulted in:

$$T_{req} = (T_a + T_L) \times 1,5 = 0,042 \text{ [Nm]} \tag{2.9}$$

Unlike the ear mechanism, where complex variables such as elastic restitution and hinge friction introduced uncertainty into the load, the arm system made it possible to determine a specific, deterministic torque value to be exceeded. The analysis established a peak requirement of 0.042 Nm.

Having determined the torque value on which the actuator has to perform, the SG-90 are chosen as the suitable servo-motor, this because its 0.1765 Nm torque is four times the needed torque, even with a 1.5 safety factor.

It should be noted that the design calculation assumed the most critical scenario possible: lifting the limb in a position completely perpendicular to the side of the body. However, the final implementation of the design uses an open geometry (with an angle of incidence inclined relative to the body), which reduces the effective moment arm. As a result, the actual operating load is lower than calculated, ensuring that the motor operates in a zone of low mechanical stress and can be used for more time until replacement or maintenance.

Having dimensioned the servo-motors that lift the arms, a correct coupling to the body is also realized. This coupling consisted on a personalize embedding onto each side of the body, and a mechanical fixation using Phillips screws (3mm). A quick prototype also was used to validate geometry before the final design. Figure 2.20 shows the iterations realized and the final cut made onto the body for servo positioning.

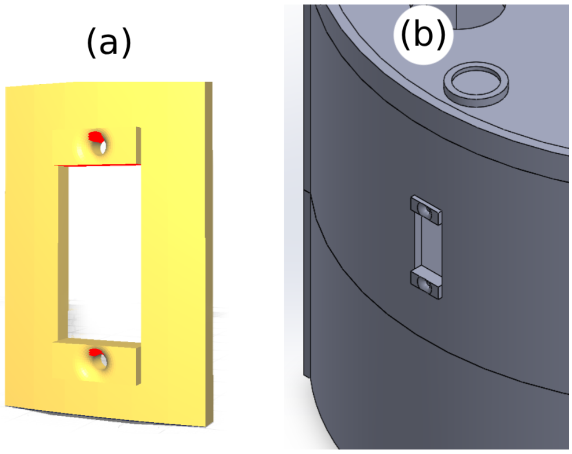


Figure 2.20. *Physical validation of servo housing design: (a) Tolerance verification in the first iteration and (b) inclusion on body of the final iteration*

3.9 Power source dimensioning

An energy decoupling strategy was implemented in order to separate the actuator's power consume from the logic power souce. The battery bank sized in this section is intended exclusively for the power stage (PCA9685 driver and 4 servomotors). The process compared critical load requirements with the actual usage profile.

The actuation system consists of two HS-311 servomotors and two SG-90 micro-servos. To determine the maximum current (I_{max}), the worst-case load scenario was considered, defined as the sum of the simultaneous stall currents:

- HS-311 ≈ 700 mA (according to manufacturer specifications).
- SG-90: ≈ 650 mA (estimated for maximum load).

$$I_{max} = (2 \times 0.7 \text{ A}) + (2 \times 0.65 \text{ A}) = 2.7 \text{ A} \tag{2.10}$$

An initial theoretical operating target of 1 hour ($t = 1h$) was established. Applying the adjustment factors for Nickel-Metal Hydride (NiMH) batteries—the technology selected for its rechargeability—an efficiency (η) of 70% and a Depth of Discharge (DoD) of 80% were used.

The Adjusted Energy (E_{adj}) theoretically required under maximum continuous load would be:

$$E_{adj} = \frac{P_{peak} \times t}{\eta \times DoD} = \frac{12.96 \text{ Wh}}{0.70 \times 0.80} \approx 23.14 \text{ Wh} \tag{2.11}$$

To achieve the operating voltage of 4.8 V, a bank of 4 AA cells was configured in series.

A homogeneous arrangement was implemented using four identical 2000 mAh cells. In a series configuration, the voltage is added up while the current capacity remains constant, equal to that of a single cell. Therefore, the total nominal capacity of the power bank results in:

$$C_{array} = 2000 \text{ mAh} \quad (2.0 \text{ Ah})$$

When comparing this installed capacity ($2.0Ah$) with the theoretical requirement calculated in the previous step for one hour of maximum continuous charging ($4.82Ah$), it can be seen that the nominal capacity covers approximately 41% of the worst-case theoretical scenario.

It is critical to verify that the selected battery bank can supply the peak blocking current ($2.7A$) without suffering voltage drop or thermal damage. Standard high-capacity NiMH batteries support safe discharge rates of up to 3C.

$$I_{safe\_discharge} = C_{rate} \times Capacity \tag{2.12}$$

$$I_{safe\_discharge} = 3 \times 2.0 \text{ A} = 6.0 \text{ A} \tag{2.13}$$

When comparing this limit with the maximum demand of the system:

$$2.7\ \text{A}(PeakLoad) < 6.0\ \text{A}(MaxPeakCurrent)$$

The 2000 mAh power bank offers a safety margin of over 50% compared to peak consumption, ensuring that even if all motors are simultaneously blocked, the integrity of the cells and the stability of the power supply remain intact.

Although the maximum load calculation suggests limited autonomy, the design contemplates an estimated Duty Cycle of 25%. Applying this estimated usage factor to the peak load, the projected average current consumption (I_{avg_proj}) was calculated. This estimation assumes that the actuators draw maximum current only during the active phase of the duty cycle, while remaining in a low-power idle state for the remainder:

$$I_{avg\_proj} \approx I_{max} \times \text{Duty Cycle} \tag{2.14}$$

$$I_{avg\_proj} \approx 2.7\ \text{A} \times 0.25 = 0.675\ \text{A} \quad (675\ \text{mA}) \tag{2.15}$$

Consequently, the theoretical autonomy under these realistic usage conditions is projected to extend beyond the worst-case baseline:

$$t_{proj} = \frac{C_{array}}{I_{avg\_proj}} = \frac{2.0\ \text{Ah}}{0.675\ \text{A}} \approx 2.96\ \text{h} \tag{2.16}$$

Being that the motors were selected and sized so as not to operate in continuous lock-up at maximum load, it is projected that the 2000 mAh configuration will be enough to cover the designed One hour session, validating this statement on the Results section of this document. In order to allocate this batteries on the body, a sectioning was realized based on a 4 AA battery holder. This was made via quick prototyping as Figure 2.21 shows.

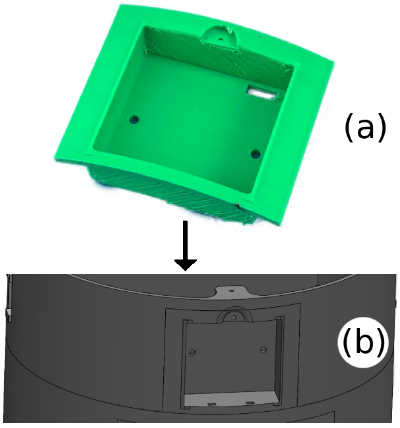


Figure 2.21. *Physical validation of Battery housing design: (a) Tolerance verification in first iteration and (b) body inclusion of final iteration*

The integration of this last component, together with the definition of the upper interface (neck) and the lateral mechanisms (arms), consolidated the final geometry of the structural subsystem. The resulting morphology of the main body is shown in Figure 2.22.

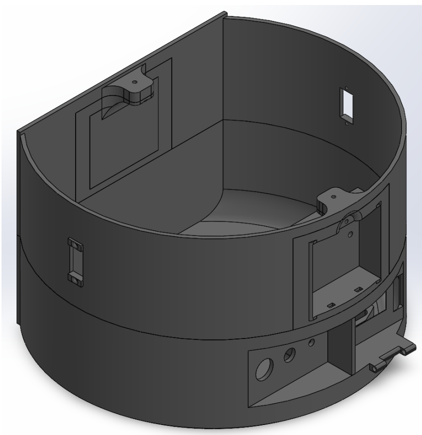


Figure 2.22. *Final CAD design of the main chassis (body) integrating the housings for control, power, and actuation after the iteration process.*

A base for this cylindrical body was designed to provey the robot with a more detailed morphology, as is shown in Figure 2.23.

Figure 2.23. *Legs designed to fit the body and provey morphological shape*

Finally, the specific design process culminated in the physical and logical integration of all the subsystems developed. Following a Modular Integration strategy, the validated electronic components (Raspberry Pi, Drivers, Batteries) were assembled within the optimized mechanical structure (Body and Head), consolidating the hardware into a self-contained unit. Simultaneously, the final software architecture was deployed on the controller, linking the control logic with the actuators and the HMI interface. This convergence of design and implementation resulted in the materialization of the functional A.R.I.M.A. prototype as Figure 2.24 and 2.25 shows, ready to undergo the verification and technical validation phases detailed in the following section. The detailed technical drawings for all the designed pieces detailed before are allocated on APPENDIX B.

Figure 2.24. *A.R.I.M.A. prototype after hardware and software integration*

Figure 2.25. *A.R.I.M.A. prototype after final assembly*

Chapter 3
RESULTS

Following the final integration of the mechanical, electronic, and software subsystems described in the previous chapter, the prototype underwent experimental verification and validation. This process was performed incrementally in a controlled environment, beginning with unit tests of individual components (actuators, sensors, and code modules) and progressively scaling up to subsystem integration tests and validation of the complete system.

The results obtained from a set of tests, designed to certify compliance with the established functional and non-functional requirements, are presented below.

1 Subsystems Verification

In order to evaluate the operability of the integrated subsystems (Head, Body, and Control), a functional validation protocol was executed in a controlled environment. For this purpose, Technical Verification Matrices were established to evaluate qualitatively the integrity of the data input interfaces (HMI) and the response of the feedback actuators.

In total, 141 multi-variable tests were documented, evaluated under a binary compliance criterion (Pass/Fail). The distribution of these tests covers both software logic and electromechanical performance,as detailed below:

- Tutorial Mode: 20 tests
- Practice Mode: 60 tests
- Evaluation Mode: 34 tests
- Menu interactivity: 7 tests

- Corrective Maintenance Verification: 20 tests

For the Technical Verification matrices included in the APPENDIX section, the PASS/FAIL acceptance criterion is defined as a qualitative functional validation. The tests were performed used a fully recharged set of batteries and did not use metrological instrumentation to measure angular accuracies or decibels, but were based on visual and operational inspection of the system's behavior under the following parameters:

- Actuators (Ears and Arms): A visual check was performed to ensure that the servomotors executed the entire programmed trajectory consistently and without mechanical obstructions. The success criterion focused on the consistency of the movement rather than the exact precision of the final angle.
- Audio and Graphic Interface: Audio files were checked to ensure they were audible and distinguishable, and graphic elements (buttons and text) were checked to ensure they rendered correctly on the screen without overlaps or visual errors.
- Input Peripherals (Keyboard/Mouse): Correct data capture was validated, verifying that user inputs were recorded without insertion errors or noticeable delays.
- Error Management: The logic was evaluated on two levels:
  - Detection: Immediate confirmation of incorrect response.
  - Accounting: Verification that the error was stored in memory for later use in review activity loops or final reports.

For this, each table evaluate a specific scenario based on user's response to a question under a certain game mode.

This tables were synthesized onto bar graphs and shown next. Empty bars indicate N/A tests onto certain response type (e.g. Error Detection wasn't tested on a Right Answer Scenario).

Figure 3.1 shows the testing results onto Tutorial Game mode. Table A.1 indicates the case where the user responded correctly to Tutorial Mode Activities,Table A.2 indicates the case where the user responded wrongly to Tutorial Mode Activities.

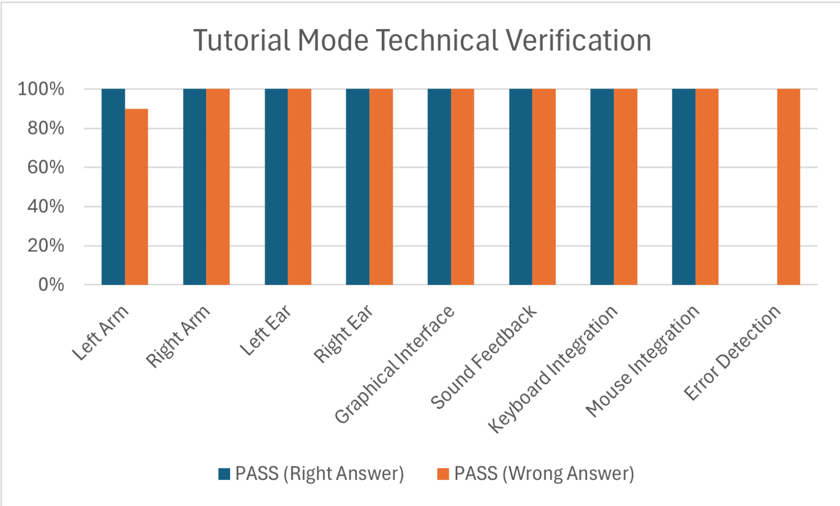


Figure 3.1. *Tutorial Mode technical verification results. The chart displays the success rate (PASS) across various modules under two testing conditions: processing a correct answer and handling an incorrect answer*

Figure 3.2 shows the testing results onto Practice Game Mode. Table A.3 indicates the case where the user responded correctly to Practice Mode Activities, Table A.4 indicates the case where the user responded wrongly to Practice Mode Activities.

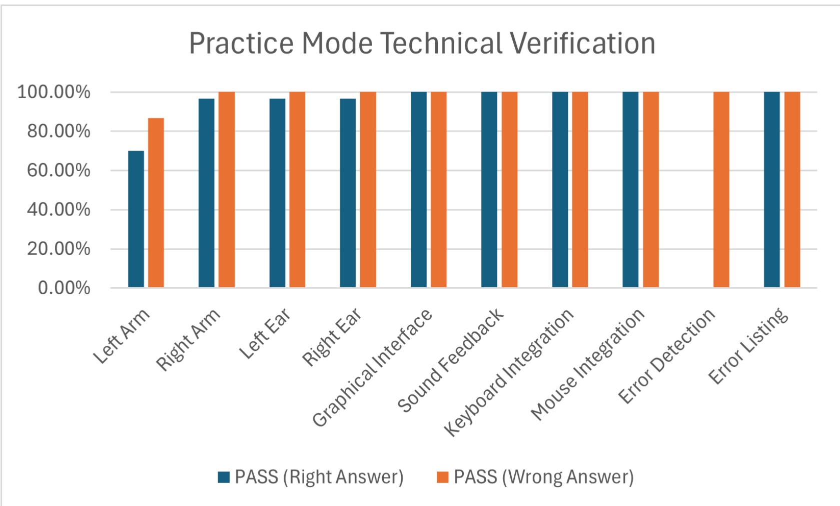


Figure 3.2. *Practice Mode technical verification results. The chart displays the success rate (PASS) across various modules under two testing conditions: processing a correct answer and handling an incorrect answer*

Figure 3.3 shows the testing results onto Evaluation Game mode. Table A.5 indicates the case where the user responded correctly to Evaluation Mode Activities and Table A.6 indicates the case where the user responded wrongly to Evaluation Mode Activities.

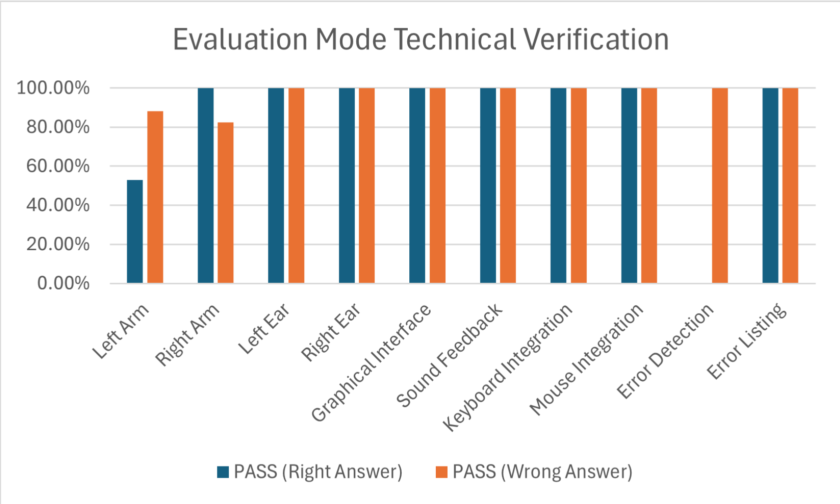


Figure 3.3. *Evaluation Mode technical verification results. The chart displays the success rate (PASS) across various modules under two testing conditions: processing a correct answer and handling an incorrect answer*

Both Figure 3.4 and Table A.7 indicates the results of tests done onto Menu Interactivity Verification.

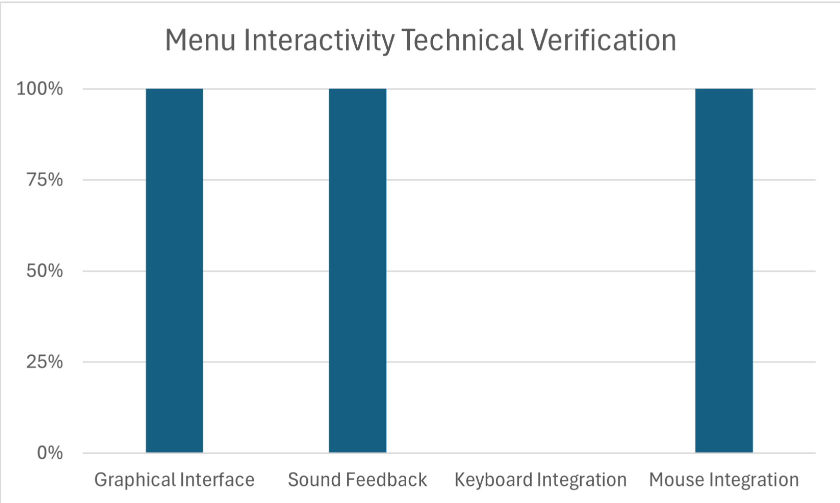


Figure 3.4. *Menu Interactivity technical verification results. The chart displays the success rate (PASS) across menu testing*

As the test proceeded, malfunctions were detected in the arms servomotors.

To identify the cause, the quality of the control signal was first evaluated by installing capacitive filters on the power lines, which ruled out the presence of electrical noise as the error persisted. It was then determined that the fault was internal mechanical damage to the SG-90 servomotor components (potentiometer or gears), caused by excessive axial force applied to the shaft during the press-fit assembly of the arms. As a corrective measure, the defective actuators were replaced with new units with the same technical specifications (model SG-90). Subsequently, 20 additional test cycles were performed to verify the operability of the replaced components under normal conditions. The results of this verification are shown in the Figure 3.5, and detailed on the APPENDIX correspondent table A.8.

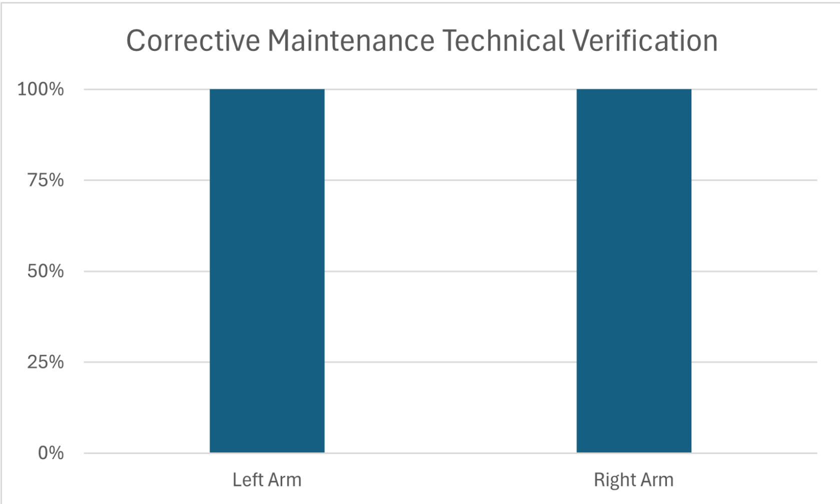


Figure 3.5. *Corrective Maintenance technical verification results. The chart displays the success rate (PASS) across left and right arm testing with new actuators*

In addition to the functional tests shown, a stress test was performed to validate the sizing of the battery bank under continuous operating conditions. For this purpose, a usage profile simulation script (Endurance Script) was developed, programmed to run random sequences of movements (arm and ear gestures) and audio playback in an infinite loop, replicating the mechanical activity of a standard educational session but eliminating the idle times associated with waiting for user response. The system was subjected to this uninterrupted operating regime starting from a full charge. The test recorded an operating autonomy of more than 4 hours, at which point the test was manually interrupted without the equipment showing any faults due to brownouts or degradation in the speed of the actuators. This empirical result validates the Utilization Factor proposed in the specific design. The average consumption inferred during the dynamic test ($I_{avg} \approx 500$ mA) confirms that the 2000 mAh battery has sufficient capacity to sustain the system's demand for extended periods, exceeding the initial 1 hour requirement.

2 Requirement Validation

Following technical verification of the subsystems, comprehensive validation of the prototype was carried out against the list of requirements defined initially. The purpose of this phase is to certify that the final system complies with the functional and operational specifications set out earlier in the document.

The Requirement Validation Tables included in APPENDIX A (Tables A.9 for functional requirements and A.10 for non-functional requirements) links each requirement with the specific tests that demonstrated its compliance, establishing the final validation status of the A.R.I.M.A. project.

Analysis of the matrices presented shows 100% compliance with the functional and non-functional requirements established in the design phase. All critical tests, including the integration of educational modes and interactivity through peripherals and the robot's response to inputs, exceeded the defined acceptance criteria. Consequently, the A.R.I.M.A. prototype is declared a technically validated system under controlled operating conditions.

3 Results Discussion

Based on the empirical evidence gathered during the verification and validation phase, this section presents a critical analysis of the performance of the A.R.I.M.A. system compared to theoretical design estimates. The most relevant findings that define the technical and operational feasibility of the final prototype are then discussed. The experimental result of an operating autonomy of more than 4 hours validates the Duty Cycle hypothesis proposed in the design. This performance, which exceeds conservative theoretical estimates, is attributed to the convergence of two technical factors:

- Operational Intermittency: The robot's actual usage profile is not continuous; it alternates between short periods of kinetic action and long intervals of waiting (idle) and auditory explanation.
- Load Optimization: The final geometry of the arms (inclined) and the reduction of mass in the ears limit the holding torque to values below 50% of the nominal capacity of the actuators.

These findings confirm that the 2000 mAh battery bank is correctly sized, and even offers a positive safety margin, to support extended educational sessions without the risk of premature discharge. In the mechanical domain, the geometric optimization strategy proved effective. The reduction in moving parts and the use of lightweight profiles enabled smooth movements, validating the selection of SG-90 and HS-311 servomotors for this specific application. Regarding the ear mechanism, although the PLA-printed hinge system demonstrated operational functionality during testing, it is recognized that the quality of the joint critically depends on manufacturing tolerances and the tribological (friction) behavior of the material. While the results confirm the validity of this solution for the scope of an academic prototype, friction wear is identified as an area for improvement for future commercial iterations. Testing revealed a design flaw in the joint between the arms and the SG-90 actuators. The use of a direct press-fit coupling required excessive force during assembly, which transmitted a damaging axial load to the servo's internal gears, causing the reported movement malfunctions. For future iterations, it is recommended to implement an indirect coupling or a standard horn interface. This design change would decouple assembly forces from the actuator's internal components, preventing damage and simplifying both assembly and maintenance. Also, the implementation of magnetic interfaces for head access significantly facilitated assembly and maintenance tasks. The operational benefits of this quick access outweighed the design challenges, validating the modularity strategy for components that require frequent review. The total absence of crashes during testing confirms the technical superiority of the State's based architecture over the initial linear programming. This structure not only ensured stability in use, but also demonstrated a high capacity for scalability, allowing for the modular integration of new activities without compromising the core of the system. Additionally, the implementation of concurrent execution (threading) onto the coding solved the challenge of audiovisual synchronization. The ability to execute complex movements simultaneously with audio playback, without perceptible latency, gave the robot a level of interactivity and "physical presence" that overcomes the limitations of a static screen interface.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

1 Conclusions

- The interactive robot A.R.I.M.A. was designed and developed to support mathematics teaching in primary schools. Applying the VDI 2206 methodology, a functional prototype was obtained that integrates mechanical and electronic systems and displays gamified activities with response feedback.
- The design of an educational robot in the shape of a rabbit was completed, integrating kinetic, and audiovisual response to user inputs, basing the design onto ISO 8124-1 normative. Thus, obtaining a system capable of executing gamified activities and providing feedback without the need for external sensors.
- The subsystems were successfully integrated using a modular design, FDM process and quick prototyping techniques, along with software architecture based on State Machines that ensures stable navigation, also facilitating maintenance and future expansions of the prototype.
- The system's functionality was checked through 141 technical tests, which included ears, arms, display, interface and peripheral testing, and were the starting point for succesfully validating compliance with the set of functional and non-functional requirements.

2 Recommendations

- Since this work was limited to technical and functional verification, it is recommended that a pedagogical validation study be conducted with end users (elementary school children). This phase should measure the real impact of the robot on the learning curve in a real classroom environment, complementing the engineering validation with educational metrics.

- It is also recommended to include sensors to monitor the remaining battery life and the angle of movement of objects, as well as to improve safety during use.
- Gamification of activities covering different educational topics such as art, music, sports, and science is recommended, with the aim of expanding the robot's educational capabilities.
- Other recomendation is the creation and implementation of an activity creation interface, where a teacher can upload images, text, and other files to create a personalized activity.
- The implementation of an embedded voice with the ability to read aloud the statements in gamified activities is recommended to increase accessibility and facilitate learning for students with special needs.

REFERENCES

[1] E. Arias Ortiz, C. Giambruno, A. Morduchowicz, y B. Pineda, “The state of education in latin america and the caribbean 2023,” Inter-American Development Bank, Tech. Rep., jan 2024.

[2] E. Arias Ortiz *et al.*, “El aprendizaje no puede esperar,” Banco Interamericano de Desarrollo and Banco Mundial, Tech. Rep., 2024.

[3] C. Mora. Ni matemáticas ni literatura, este es el resultado de evaluación a escuelas y colegios en ecuador. [En línea]. Disponible: https://www.primicias.ec/sociedad/ineval-resultados-evaluacion-estudiantes-colegios-escuelas-ecuador-95034/ [Fecha de consulta: apr 2025] Accessed: Sept. 17, 2025.

[4] J. F. Juárez, “Calidad de la educación en ecuador. ¿mito o realidad?” vol. 6, 2020.

[5] M. Altamirano-Pazmiño, J. Guaña-Moya, Y. Arteaga-Alcívar, L. Patiño-Hernández, L. Chipuxi-Fajardo, y P. Flores-Cabrera, “Uso de las herramientas digitales en la educación virtual en ecuador.”

[6] N. C. Chamorro-Benavides y G. H. Cuesta-Ormaza, “La educación en ecuador, retos y perspectivas,” *Polo del Conocimiento*, vol. 7, no. 8, 2022.

[7] Q.-F. Yang, L.-W. Lian, y J.-H. Zhao, “Developing a gamified artificial intelligence educational robot to promote learning effectiveness and behavior in laboratory safety courses for undergraduate students,” *International Journal of Educational Technology in Higher Education*, vol. 20, no. 1, p. 18, apr 2023.

[8] T. Sapounidis y D. Alimisis, “Educational robotics for stem: A review of technologies and some educational considerations.”

[9] P. N. Mwangi, C. M. Muriithi, y P. B. Agufana, “Exploring the benefits of educational robots in stem learning: A systematic review,” *International Journal of Engineering and Advanced Technology (IJEAT)*, vol. 11, no. 6, pp. 5–11, aug 2022.

[10] F. Ouyang y W. Xu, “The effects of educational robotics in stem education: a multilevel meta-analysis,” *International Journal of STEM Education*, vol. 11, no. 1, p. 7, feb 2024.

[11] A. Rakhmanina *et al.*, “The usage of robotics as an element of stem education in the educational process,” *International Journal of Computer Science and Network Security*, vol. 22, no. 5, pp. 645–651, may 2022.

[12] D. Chaldi y G. Mantzanidou, “Educational robotics and steam in early childhood education,” *Advances in Mobile Learning Educational Research*, vol. 1, no. 2, pp. 72–81, 2021.

[13] M. C. Popa y D. Biclea, “Promoting effective math learning with educational robots,” *Educatia 21*, no. 25, pp. 38–47, nov 2023.

[14] J. B. H. Saravia Maradiaga, Y. A. Eguigure Torres, N. C. Rodríguez Valenzuela, y W. Sauceda Alemán, “Hormigabot: Diseño de un robot educativo,” *Paradigma*, vol. 29, no. 47, pp. 9–26, jun 2022.

[15] A. B. Perucho, “Social robots in secondary education: Can robots assist young adult learners with math learning?” 2023.

[16] M. I. Ahmad, M. Khordi-moodi, y K. S. Lohan, “Social robot for stem education,” in *Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*. Cambridge, United Kingdom: ACM, mar 2020, pp. 90–92.

[17] T.-I. Chen, S.-K. Lin, y H.-C. Chung, “Gamified educational robots lead an increase in motivation and creativity in stem education,” *Journal of Baltic Science Education (JBSE)*, vol. 22, no. 3, pp. 427–438, jun 2023.

[18] R. Williams, S. Ali, R. Alcantara, T. Burghleh, S. Alghowinem, y C. Breazeal, "Doodlebot: An educational robot for creativity and ai literacy," in *Proceedings of the 2024 ACM/IEEE International Conference on Human-Robot Interaction*. Boulder, CO, USA: ACM, mar 2024, pp. 772–780.

[19] F. B. V. Benitti, "Exploring the educational potential of robotics in schools: A systematic review," *Computers & Education*, vol. 58, no. 3, pp. 978–988, apr 2012.

[20] UNICEF y CEPAL, "La encrucijada de la educación en américa latina y el caribe: Informe regional de monitoreo ods4-educación 2030," *Perfiles Educativos*, vol. 44, no. 178, pp. 182–199, oct 2022.

[21] Verein Deutscher Ingenieure, "Vdi 2206:2004 entwicklungsmethodik für mechatronische systeme (design methodology for mechatronic systems)," Verein Deutscher Ingenieure (VDI), Düsseldorf, Germany, Richtlinie (Guideline), Jun. 2004.

[22] Ministerio de Educación del Ecuador, *Guía para Docentes: Matemática - Nivel de Educación General Básica Subnivel Elemental*, primera ed. Quito, Ecuador: Ministerio de Educación del Ecuador, 2023.

[23] International Organization for Standardization, "Iso 8124-1:2022 safety of toys — part 1: Safety aspects related to mechanical and physical properties," International Organization for Standardization, Geneva, Switzerland, Standard, 2022. [En línea]. Disponible: https://www.iso.org/standard/81266.html

6. APPENDIX

Table A.1. *Tutorial Mode Technical Verification Matrix: Case Right Answer form user*

Test #	Left Arm	Right Arm	Left Ear	Right Ear	Graph. Interface	Sound Feedback	Keyboard Integ.	Mouse Integ.	Error Detect.
1	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A
2	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A
3	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
4	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A
5	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A
6	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A
7	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A
8	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
9	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A
10	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A

Observations: Servo arm vibrates when returning to its initial position on all Left Arm "FAIL" instances.

Table A.2. *Tutorial Mode Technical Verification Matrix: Case Wrong Answer form user*

Test #	Left Arm	Right Arm	Left Ear	Right Ear	Graph. Interface	Sound Feedback	Keyboard integration	Mouse Integration	Error Detection
11 (TUT1)	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS
12 (TUT2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS
13 (TUT3)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
14 (TUT4)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS
15 (Fin TUT)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS
16 (TUT1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS
17 (TUT2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS
18 (TUT3)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
19 (TUT4)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS
20 (Fin TUT)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS

Observations: Servo arm vibrates when returning to its initial position on all Left Arm ”FAIL” instances.

Table A.3. *Practice Mode Technical Verification Matrix: Case Right Answer form user*

Test #	Left Arm	Right Arm	Left Ear	Right Ear	Graph. Interface	Sound Feedback	Keyboard integration	Mouse Integration	Error Detection	Error Listing
1 (LVL 1.1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
2 (LVL 1.2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
3 (LVL 1.3)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
4 (LVL 1.4)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
5 (Fin LVL1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS
6 (LVL 2.1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
7 (LVL 2.2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
8 (LVL 2.3)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
9 (LVL 2.4)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
10 (LVL 2.5)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
11 (Fin LVL2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS
12 (LVL 3.1)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
13 (LVL 3.2)	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
14 (LVL 3.3)	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
15 (Fin LVL3)	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS
1 (LVL 1.1)	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
2 (LVL 1.2)	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
3 (LVL 1.3)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
4 (LVL 1.4)	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
5 (Fin LVL1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS
6 (LVL 2.1)	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
7 (LVL 2.2)	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
8 (LVL 2.3)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
9 (LVL 2.4)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
10 (LVL 2.5)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
11 (Fin LVL2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS
12 (LVL 3.1)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
13 (LVL 3.2)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
14 (LVL 3.3)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
15 (Fin LVL3)	FAIL	FAIL	FAIL	FAIL	PASS	PASS	N/A	PASS	N/A	PASS

Observations: On the last row, the button to continue to the final screen was pressed before the motion sequence of the activity was completed.

Table A.4. *Practice Mode Technical Verification Matrix: Case Wrong Answer form user*

Test #	Left Arm	Right Arm	Left Ear	Right Ear	Graph. Interface	Sound Feedback	Keyboard integration	Mouse Integration	Error Detection	Error Listing
1 (LVL 1.1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
2 (LVL 1.2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
3 (LVL 1.3)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
4 (LVL 1.4)	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
5 (Fin LVL1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS
6 (LVL 2.1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
7 (LVL 2.2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
8 (LVL 2.3)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
9 (LVL 2.4)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
10 (LVL 2.5)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
11 (Fin LVL2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS
12 (LVL 3.1)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
13 (LVL 3.2)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
14 (LVL 3.3)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
15 (Fin LVL3)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS
1 (LVL 1.1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
2 (LVL 1.2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
3 (LVL 1.3)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
4 (LVL 1.4)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
5 (Fin LVL1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS
6 (LVL 2.1)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
7 (LVL 2.2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
8 (LVL 2.3)	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
9 (LVL 2.4)	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
10 (LVL 2.5)	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
11 (Fin LVL2)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS
12 (LVL 3.1)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
13 (LVL 3.2)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
14 (LVL 3.3)	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
15 (Fin LVL3)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS

Observations: Servo arm vibrates when returning to its initial position on all Left Arm ”FAIL” instances.

Table A.5. *Evaluation Mode Technical Verification Matrix: Case Right Answer form user*

Test #	Left Arm	Right Arm	Left Ear	Right Ear	Graph. Interface	Sound Feedback	Keyboard integration	Mouse Integration	Error Detection	Error Listing
1	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
2	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
3	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
4	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
5	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
6	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
7	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
8	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
9	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
10	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
11	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
12	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
13	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
14	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
15	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
16	FAIL	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	N/A
17 (Fin evaluacion)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS

Observations: Servo arm vibrates when returning to its initial position on all Left Arm ”FAIL” instances.

Table A.6. *Evaluation Mode Technical Verification Matrix: Case Wrong Answer form user*

Test #	Left Arm	Right Arm	Left Ear	Right Ear	Graph. Interface	Sound Feedback	Keyboard integration	Mouse Integration	Error Detection	Error Listing
1	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
2	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
3	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
4	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
5	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
6	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
7	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
8	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
9	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
10	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
11	PASS	FAIL	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
12	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
13	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
14	FAIL	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
15	FAIL	FAIL	PASS	PASS	PASS	PASS	N/A	PASS	PASS	N/A
16	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	N/A
17 (FIN EVAL)	PASS	PASS	PASS	PASS	PASS	PASS	N/A	PASS	N/A	PASS

Observations: Servo arm vibrates when returning to its initial position on all Left Arm and Right Arm ”FAIL” instances.

Table A.7. *Menu Interactivity Technical Verification Matrix*

Test #	**Graph. Interface**	**Sound Feedback**	**Keyboard integration**	**Mouse Integration**
1 (Main Menu)	PASS	PASS	N/A	PASS
2 (Mode Selection)	PASS	PASS	N/A	PASS
3 (Practice Level 1 activity selection)	PASS	PASS	N/A	PASS
4 (Practice Level 2 activity selection)	PASS	PASS	N/A	PASS
5 (Practice Level 3 activity selection)	PASS	PASS	N/A	PASS
6 (Practice Error Listing)	PASS	PASS	N/A	PASS
7 (Evaluation Error Listing)	PASS	PASS	N/A	PASS

Table A.8. *Corrective Maintenance Technical Verification Matrix*

Test #	Left Arm	Right Arm
1	PASS	PASS
2	PASS	PASS
3	PASS	PASS
4	PASS	PASS
5	PASS	PASS
6	PASS	PASS
7	PASS	PASS
8	PASS	PASS
9	PASS	PASS
10	PASS	PASS
11	PASS	PASS
12	PASS	PASS
13	PASS	PASS
14	PASS	PASS
15	PASS	PASS
16	PASS	PASS
17	PASS	PASS
18	PASS	PASS
19	PASS	PASS
20	PASS	PASS

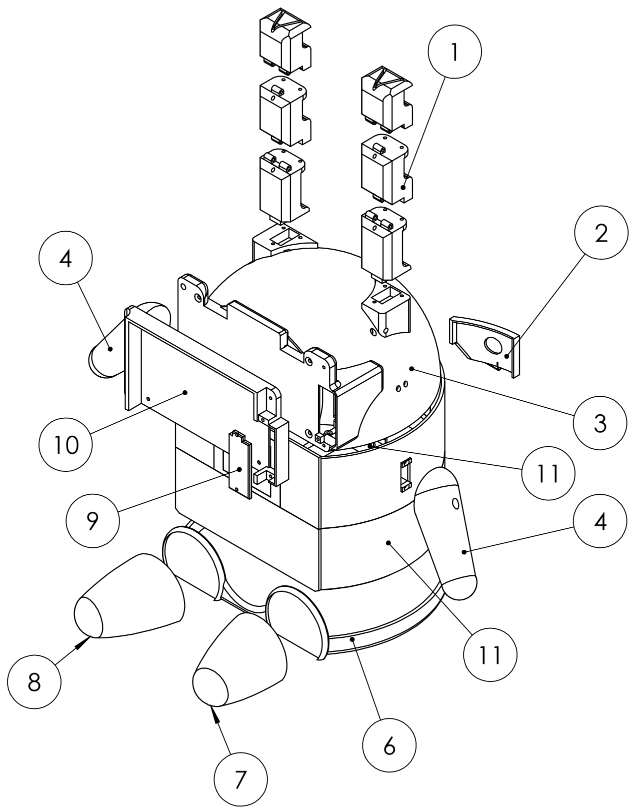
Table A.9. *Functional Requirements Validation Matrix*

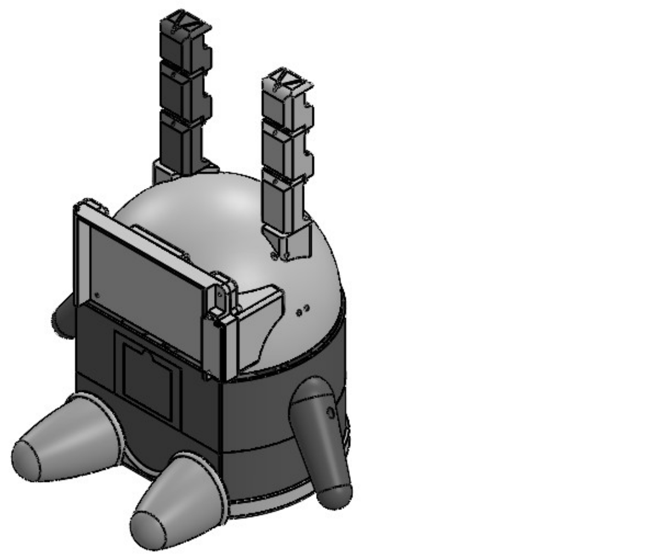
Req. ID	**Requirement Description**	**Validation Method / Associated Test**	**Status**
FR 1.1	Offer two (2) courses and one (1) tutorial.	**Menu interactivity, Practice and Evaluation Tests:** Successful execution of complete workflows in Practice, Evaluation, and Tutorial modes.	**PASS**
FR 1.2	Record exercises with mistakes.	**Practice Mode and Evaluation mode Test:** Verification of error flags in `progreso.py` and error report generation.	**PASS**
FR 1.3	Choose difficulty level (Beginner to Advanced) with specific topics.	**Menu interactivity Test:** Selecting levels 1, 2, and 3 correctly deploys the corresponding numerical/logical activities.	**PASS**
FR 1.4	Automatic return to menu upon completion.	**Menu interactivity Test:** Automatic return verified upon completion of batches in Practice and Evaluation modes.	**PASS**
FR 1.5	Practice mode: List and review selected activities.	**Menu interactivity Test and Practice Test:** Activity queue loads and executes only the items selected by the user.	**PASS**
FR 1.6	Practice mode: Represent failed exercises until correct.	**Practice Mode Test:** Verification of immediate *Replay Loop* upon incorrect answers.	**PASS**
FR 1.7	Evaluation mode: 18 random exercises, no repeats.	**Evaluation Mode Test:** Verification of randomness (*shuffle*) and item count in the evaluation queue.	**PASS**

Table A.10. *Non-Functional Requirements Validation Matrix*

Req. ID	Requirement Description	Validation Method / Associated Test	Status
NFR 1.1	Graphical interface on 7-inch LCD (Home, Menu, Settings).	**Visual Inspection:** Interface correctly displayed at native 800x480 resolution on final hardware.	**PASS**
NFR 1.2	Feedback activated within 1000 ms (Instantaneous).	**Qualitative Inspection:** Immediate perceptual response of audio/motion following user input.	**PASS**
NFR 1.3	Mouse/Keyboard operation without bugs.	**Tutorial, Practice, Menu interactivity and Evaluation Tests:** Data entry and click events validated across all numerical and graphical activities.	**PASS**
NFR 1.4	Natural language feedback messages.	**Qualitative Inspection:** Validation of feedback text accuracy on screen and audio output.	**PASS**
NFR 1.5	Consistent UI design (Buttons, Size, Shape).	**Qualitative Inspection:** Visual coherence verified across all Pygame interface modules.	**PASS**
NFR 1.6	Legibility from 0.5 meters and color contrast.	**Qualitative Inspection:** Verification of font legibility and contrast under normal lighting conditions.	**PASS**
NFR 1.7	Mechanical signals perceptible from 3 meters.	**Qualitative Inspection:** Arm and ear movements are clearly distinguishable from a distance.	**PASS**
NFR 1.8	Content designed for 6th-grade comprehension.	**Qualitative Validation:** Display math gamified exercises based on online children activities.	**PASS**
NFR 1.9	Distinctive video game sounds for actions.	**Qualitative Inspection, Tutorial, Practice, Menu interactivity and Evaluation :** Auditory verification of distinct ”Success”, and ”Error” sound effects.	**PASS**
NFR 1.10	Display ’celebration’ slides upon block completion.	**Qualitative Inspection,Tutorial, Practice, Menu interactivity and Evaluation :** Execution of celebration animation loop upon completion of the selected exercise block.	**PASS**

2 APPENDIX B: Technical Drawings





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2	D02-003		1
3	D02-004		1
4	D02-005		2
5	D02-006		1
6	D02-007		1
7	D02-008		1
8	D02-009		1
9	D02-010		1
10	D02-011		1
11	D02-012		1

UNIVERSIDAD INTERNACIONAL DEL ECUADOR
ESCUELA DE INGENIERIA MECATRONICA

DIBUJANTE/DRAFTMAN: Martin Molina Gomez	10/10/2025
DISEÑADOR/DESIGNER: Martin Molina Gomez	10/10/2025
REVISADO/REVIEWED BY: Ing. Guillermo Mosquera	10/10/2025
APROBACION FINAL/APPROBATION BY/: Ing. Guillermo Mosquera	10/10/2025

ASIGNATURA/SUBJECT: Integration Curricular Seminary

PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

TAMAÑO/PAPER SIZE: A3
ESCALA/SCALE: 1:5
DIBUJO N°/DRAWING N°: D02-001

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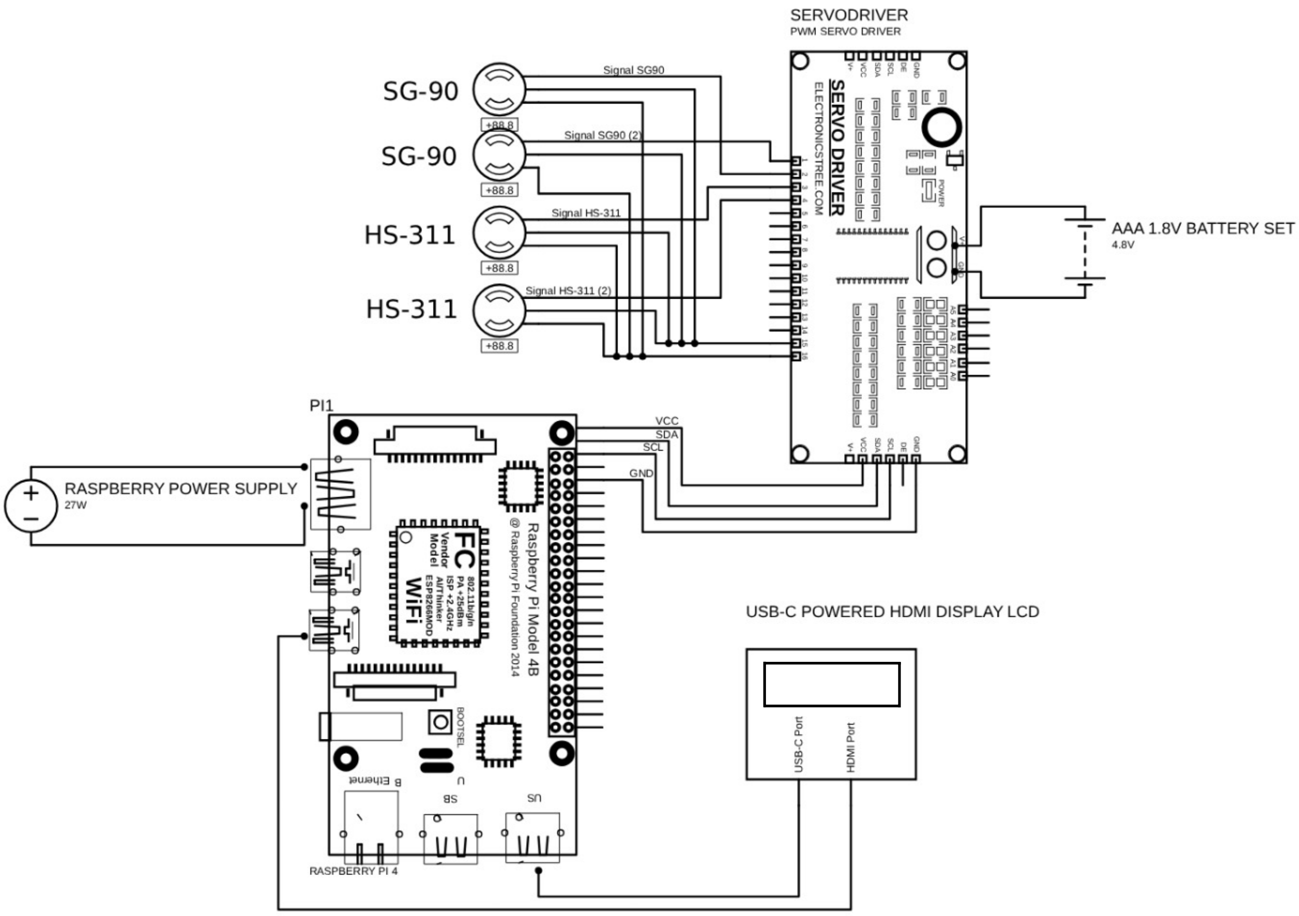

NOTAS GENERALES/GENERAL NOTES:

REGISTRO/REGISTER:	FECHA/DATE:
DIBUJANTE/DRAFTMAN: Martin Molina	10/10/2025
DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025

TAMAÑO/PAPER SIZE:A4
ESCALA/SCALE: S/E

UNIVERSIDAD INTERNACIONAL DEL ECUADOR

ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Curriculum Integration Seminary

PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

DIBUJO Nº/DRAWING Nº: D01-001

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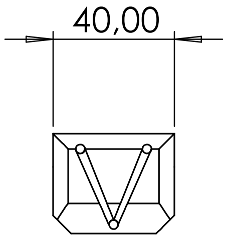

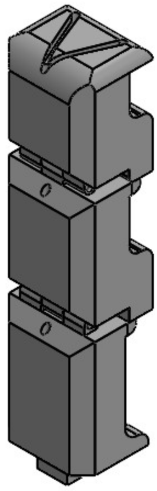

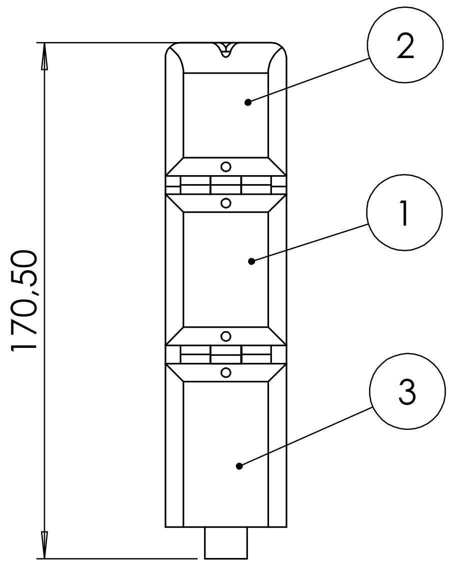

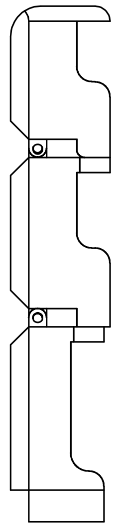

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2	D02-102		1
3	D02-302		1

NOTAS GENERALES/GENERAL NOTES:	REGISTRO/REGISTER:	FECHA/DATE:
	DIBUJANTE/DRAFTMAN: Martin Molina	10/10/2025
	DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025

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ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Seminario de integración curricular

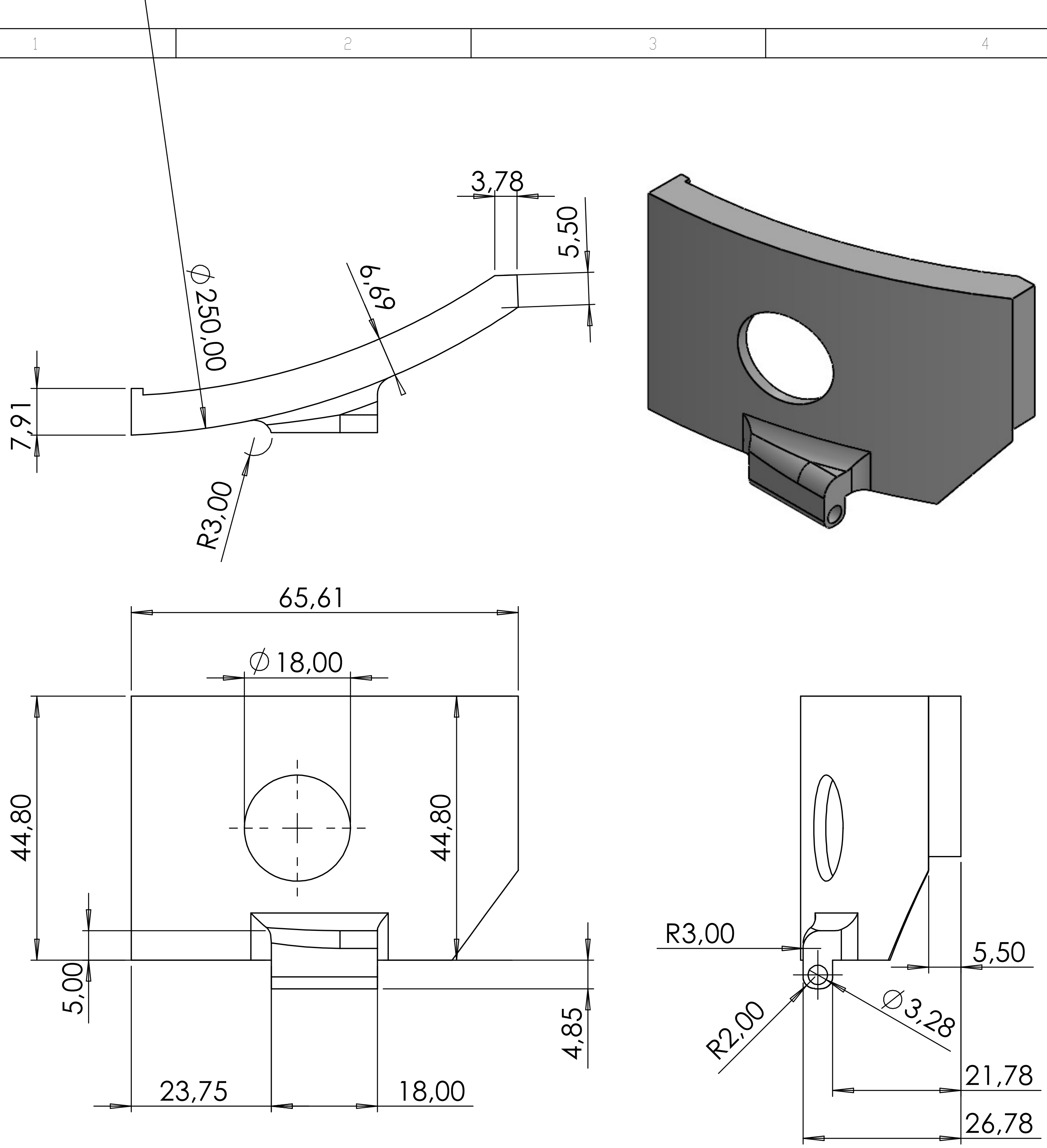
PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION: EARS ASSEMBLY

TAMAÑO/PAPER SIZE: A4

ESCALA/SCALE: 1:2.5

DIBUJO Nº/DRAWING Nº: D02-002



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MATERIAL: PLA (Polylactic Acid).	DIBUJANTE/DRAFTMAN: Martin Molina	10/10/2025
LAYER HEIGHT: 0.2 mm.	DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
INFILL: 20% (Gyroid or Grid pattern recommended). WALLS: Minimum 3 wall lines (to make it resistant to screw tightening).	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
SUPPORTS: NO	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025

UNIVERSIDAD INTERNACIONAL DEL ECUADOR

ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Seminario de integración curricular

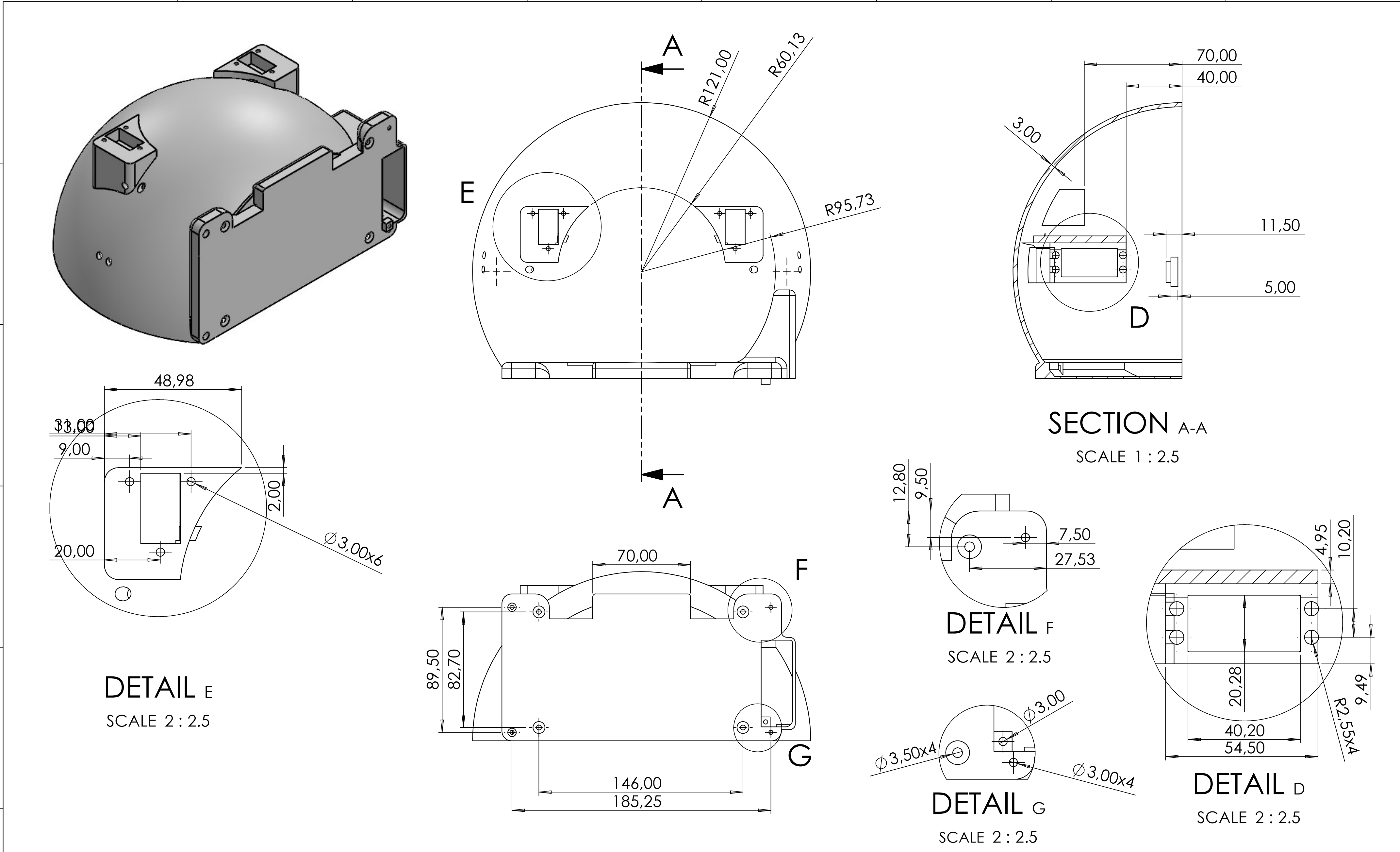
PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

TAMAÑO/PAPER SIZE: A4

ESCALA/SCALE: 1:1

DIBUJO Nº/DRAWING Nº: D02-003



DIBUJANTE/DRAFTMAN: Martin Molina Gomez	10/10/2025
DISEÑADOR/DESIGNER: Martin Molina Gomez	10/10/2025
REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
APROBACION FINAL/APPROBATION BY/: Guillermo Mosquera	10/10/2025

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ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Integration Curricular Seminary

PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

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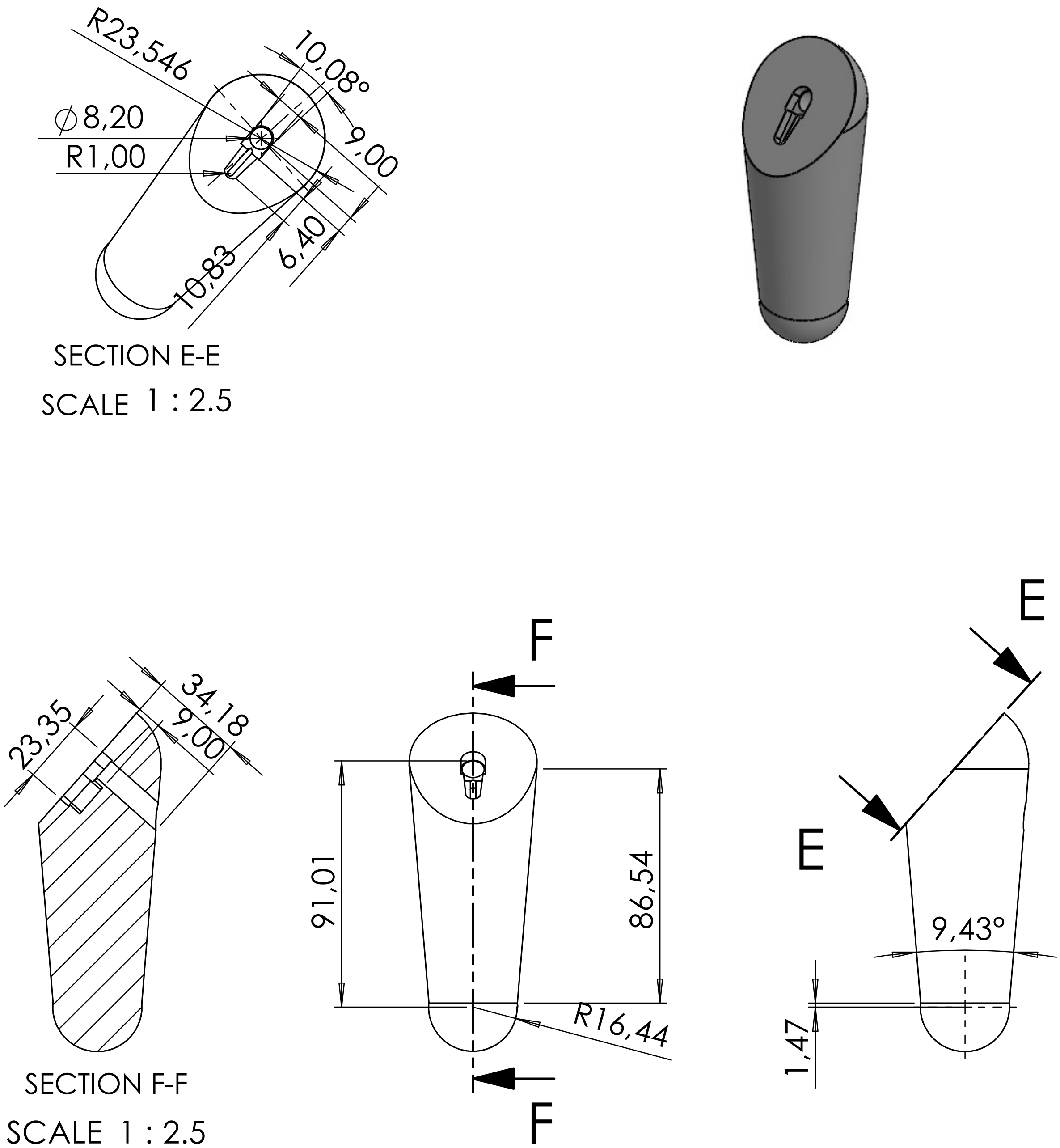
ESCALA/SCALE: 1:2.5
DIBUJO Nº/DRAWING Nº: D02-004



NOTAS GENERALES/GENERAL NOTES:	REGISTRO/REGISTER:	FECHA/DATE:
MATERIAL: PLA (Polylactic Acid).	DIBUJANTE/DRAFTMAN: Martin Molina	10/10/2025
LAYER HEIGHT: 0.2 mm.	DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
INFILL: 20% (Gyroid or Grid pattern recommended).	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
WALLS: Minimum 3 wall lines (to make it resistant to screw tightening).	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
SUPPORTS: NO		

UNIVERSIDAD INTERNACIONAL DEL ECUADOR
ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT:	Seminario de integración curricular
PROYECTO/PROYECT:	Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."
DESCRIPCION/DESCRIPTION:	
TAMAÑO/PAPER SIZE:	A4
ESCALA/SCALE:	1:2.5
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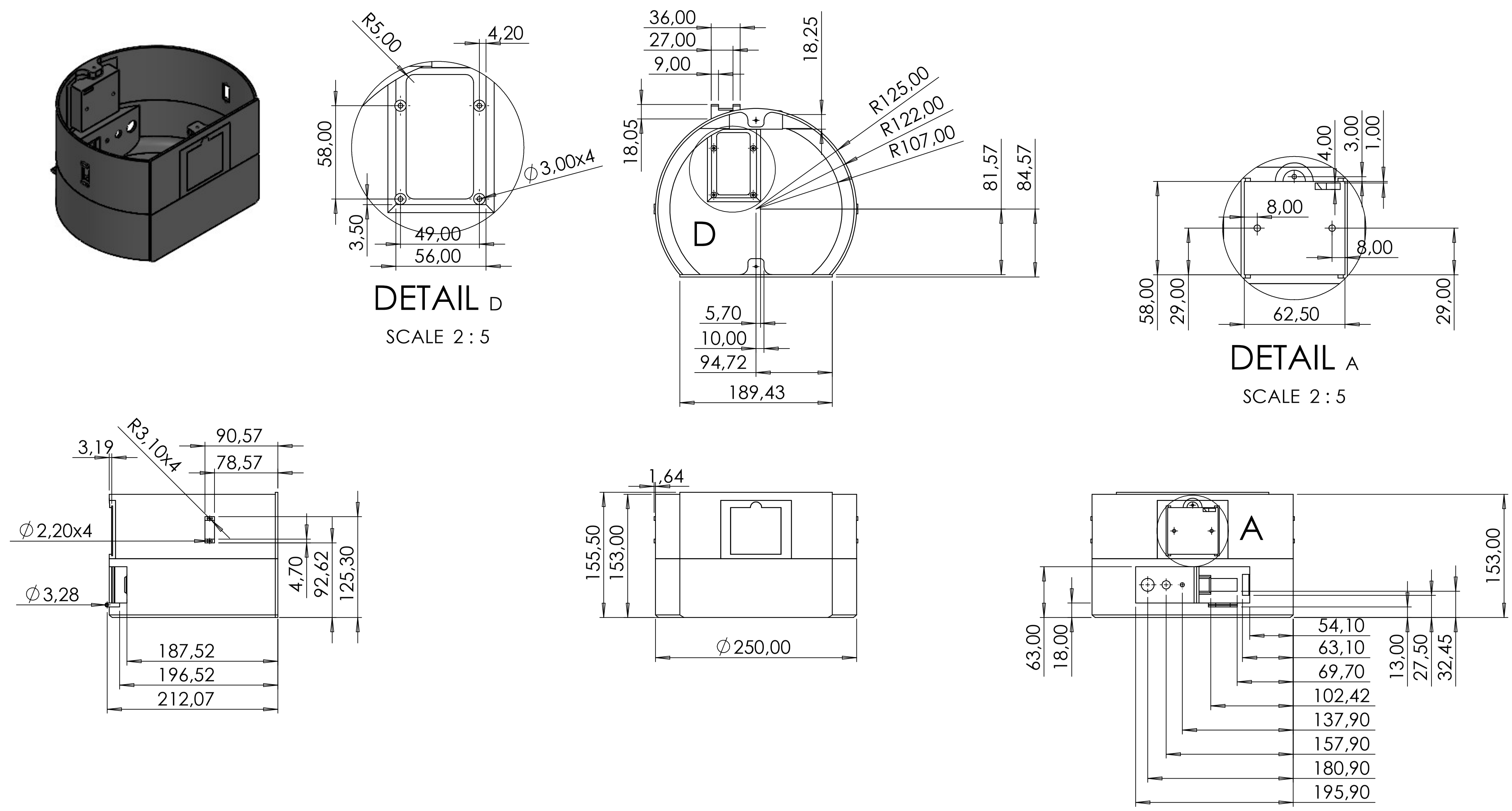

REGISTRO/REGISTER:	FECHA/DATE:
DIBUJANTE/DRAFTMAN: Martin Molina Gomez	10/10/2025
DISEÑADOR/DESIGNER: Martin Molina Gomez	10/10/2025
REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
APROBACION FINAL/APPROBATION BY/: Guillermo Mosquera	10/10/2025

TAMAÑO/PAPER SIZE: A3
ESCALA/SCALE: 1:5

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ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Integration Curricular Seminary

PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

DIBUJO Nº/DRAWING Nº: D02-006

NOTAS GENERALES/GENERAL NOTES

PLANOS DE REFERENCIA/REFERENCE DRAWINGS	
ITEM Nº	DESCRIPCION/DESCRIPTION

REVISIONES/REVIEWS				
REV.	DESCRIPCION/DESCRIPTION	FECHA/DATE	DIBUJANTE/DRAWN BY	APROBADO/APPROVED BY
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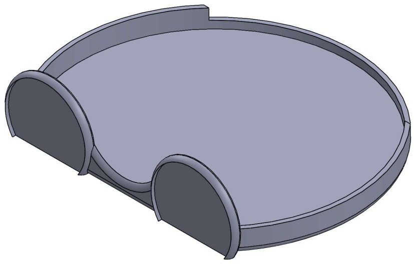

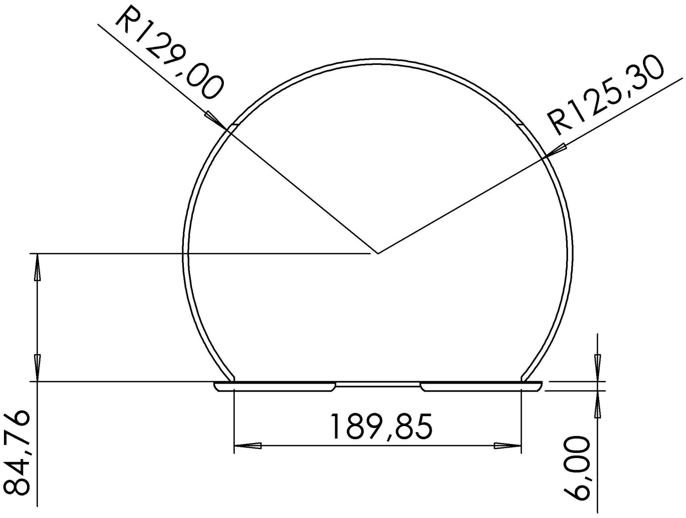

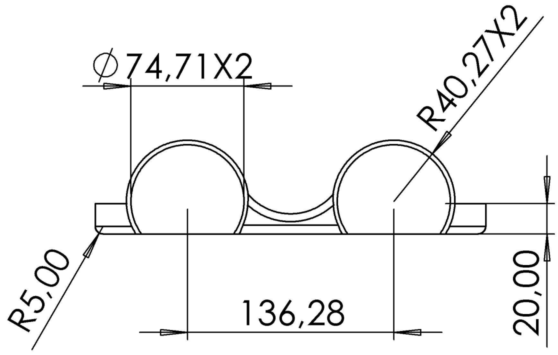

NOTAS GENERALES/GENERAL NOTES:	REGISTRO/REGISTER:	FECHA/DATE:
MATERIAL: PLA (Polylactic Acid).	DIBUJANTE/DRAFTMAN: Martin Molina	10/10/2025
LAYER HEIGHT: 0.2 mm.	DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
INFILL: 20% (Gyroid or Grid pattern recommended).	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
WALLS: Minimum 3 wall lines (to make it resistant to screw tightening). SUPPORTS: NO	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025

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ESCUELA DE INGENIERIA MECATRONICA

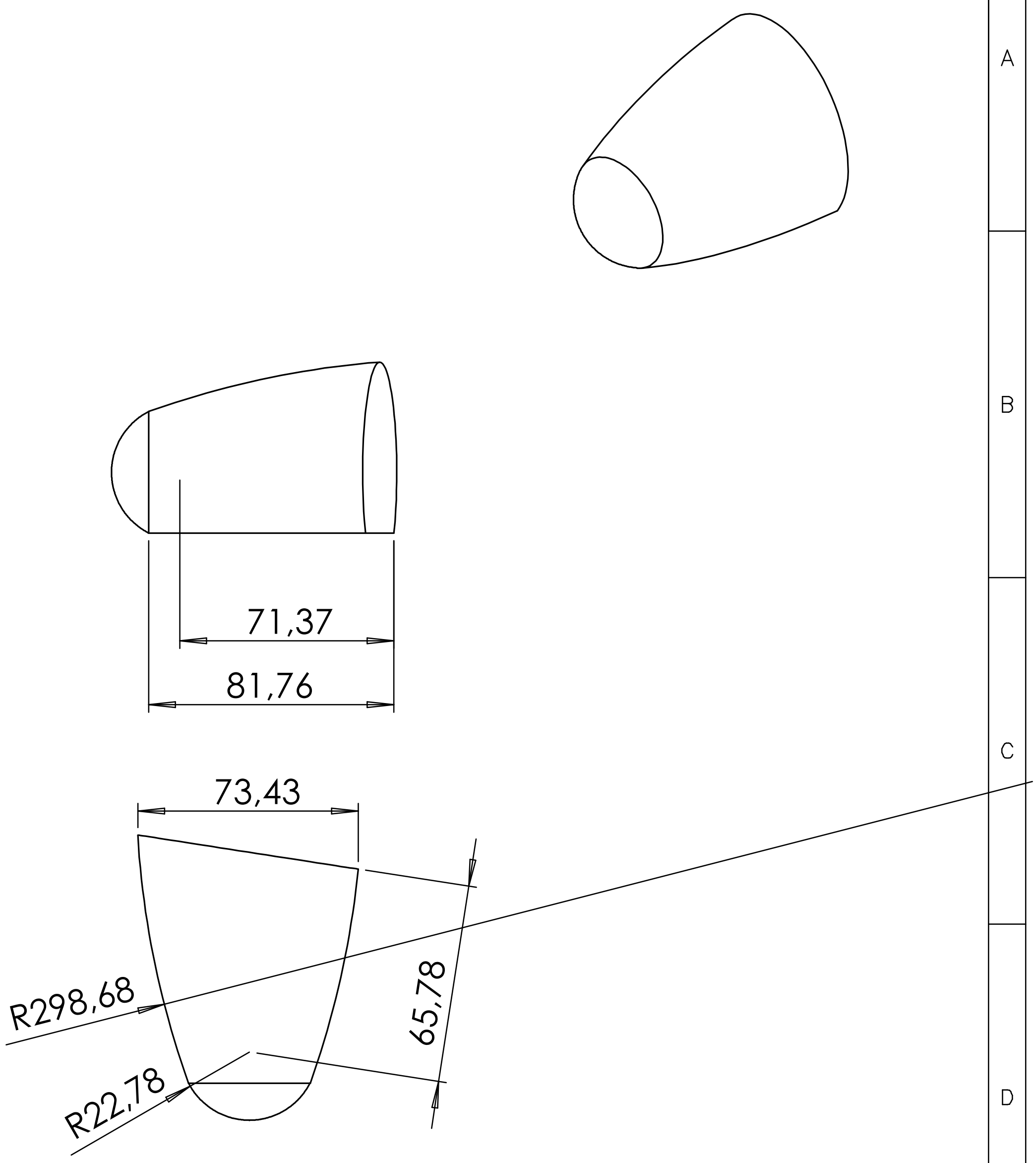
ASIGNATURA/SUBJECT: Seminario de integración curricular

PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

TAMAÑO/PAPER SIZE: A4
ESCALA/SCALE: 1:5

DIBUJO Nº/DRAWING Nº: D02-007



NOTAS GENERALES/GENERAL NOTES:

MATERIAL: PLA (Polylactic Acid).

LAYER HEIGHT: 0.2 mm.

INFILL: 20% (Gyroid or Grid pattern recommended).

WALLS: Minimum 3 wall lines (to make it resistant to screw tightening).

SUPPORTS: NO

REGISTRO/REGISTER:	FECHA/DATE:
DIBUJANTE/DRAFTMAN: Martin Molina	10/10/2025
DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025

TAMAÑO/PAPER SIZE: A4
ESCALA/SCALE: 1:2.5

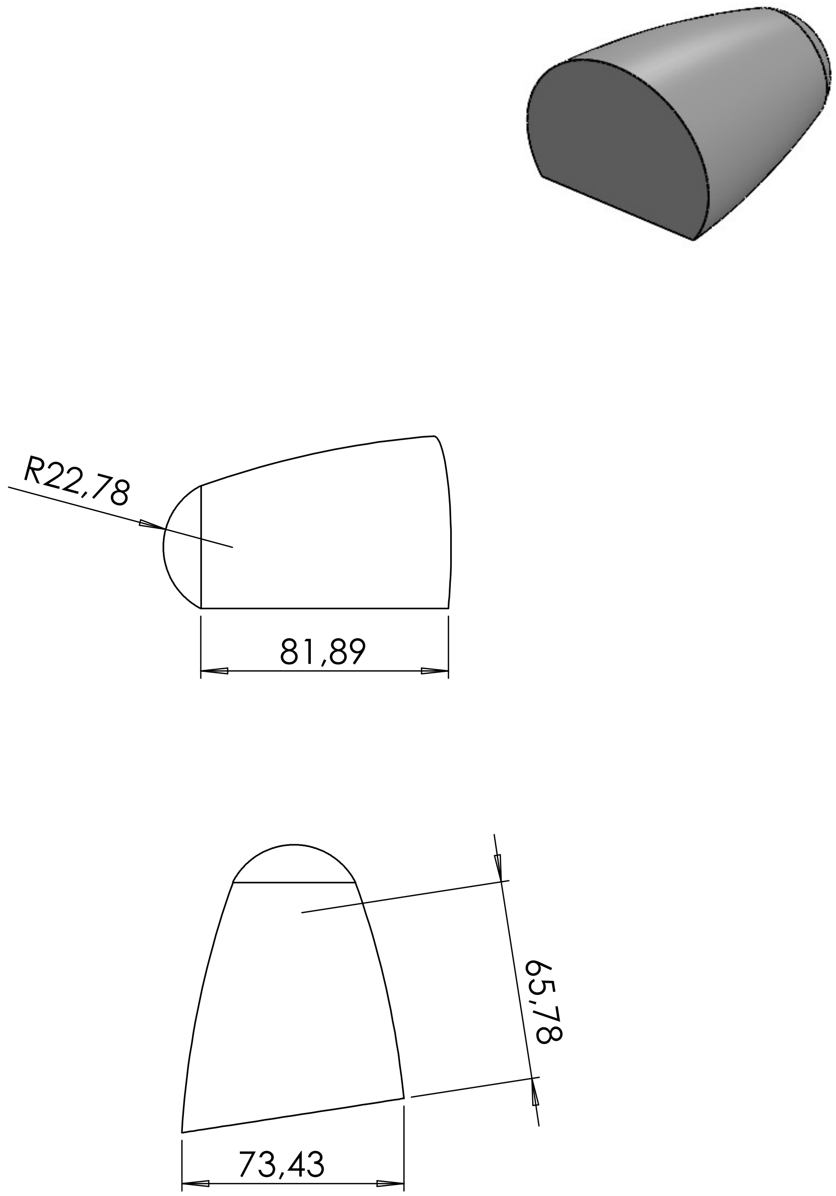
UNIVERSIDAD INTERNACIONAL DEL ECUADOR
ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Seminario de integración curricular

PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

DIBUJO Nº/DRAWING Nº: D02-008



NOTAS GENERALES/GENERAL NOTES:	REGISTRO/REGISTER:	FECHA/DATE:
MATERIAL: PLA (Polylactic Acid).	DIBUJANTE/DRAFTMAN: Martin Molina	10/10/2025
LAYER HEIGHT: 0.2 mm.	DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
INFILL: 20% (Gyroid or Grid pattern recommended).	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
WALLS: Minimum 3 wall lines (to make it resistant to screw tightening).	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
SUPPORTS: NO		

UNIVERSIDAD INTERNACIONAL DEL ECUADOR

ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Seminario de integración curricular

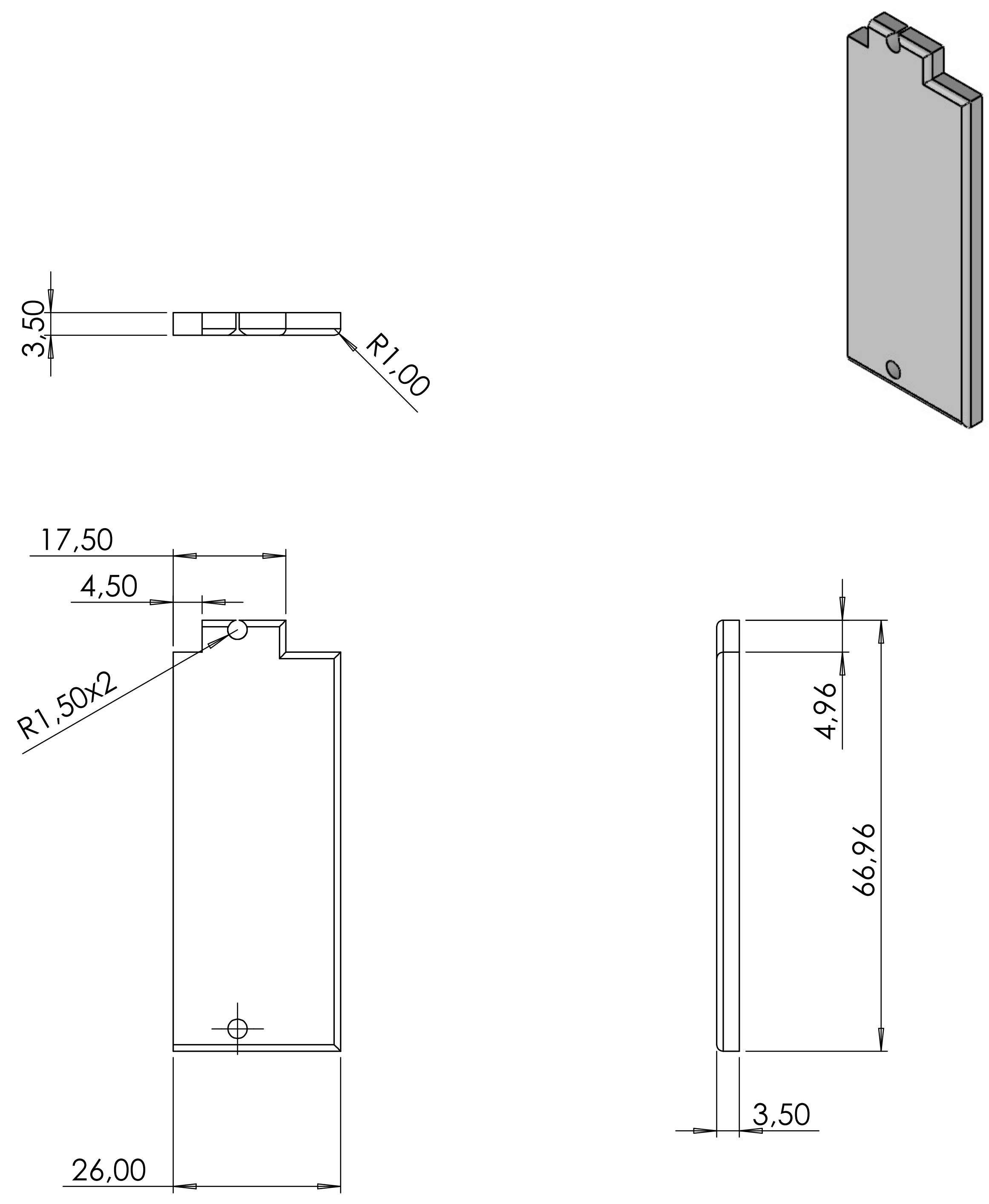
PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

TAMAÑO/PAPER SIZE: A4

ESCALA/SCALE: 1:2.5

DIBUJO Nº/DRAWING Nº: D02-009



NOTAS GENERALES/GENERAL NOTES:	REGISTRO/REGISTER:	FECHA/DATE:
MATERIAL: PLA (Polylactic Acid). LAYER HEIGHT: 0.2 mm. INFILL: 20% (Gyroid or Grid pattern recommended). WALLS: Minimum 3 wall lines (to make it resistant to screw tightening). SUPPORTS: NO	DIBUJANTE/DRAFTMAN: Martin Molina	10/10/2025
	DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025

TAMAÑO/PAPER SIZE: A4
ESCALA/SCALE: 1:1

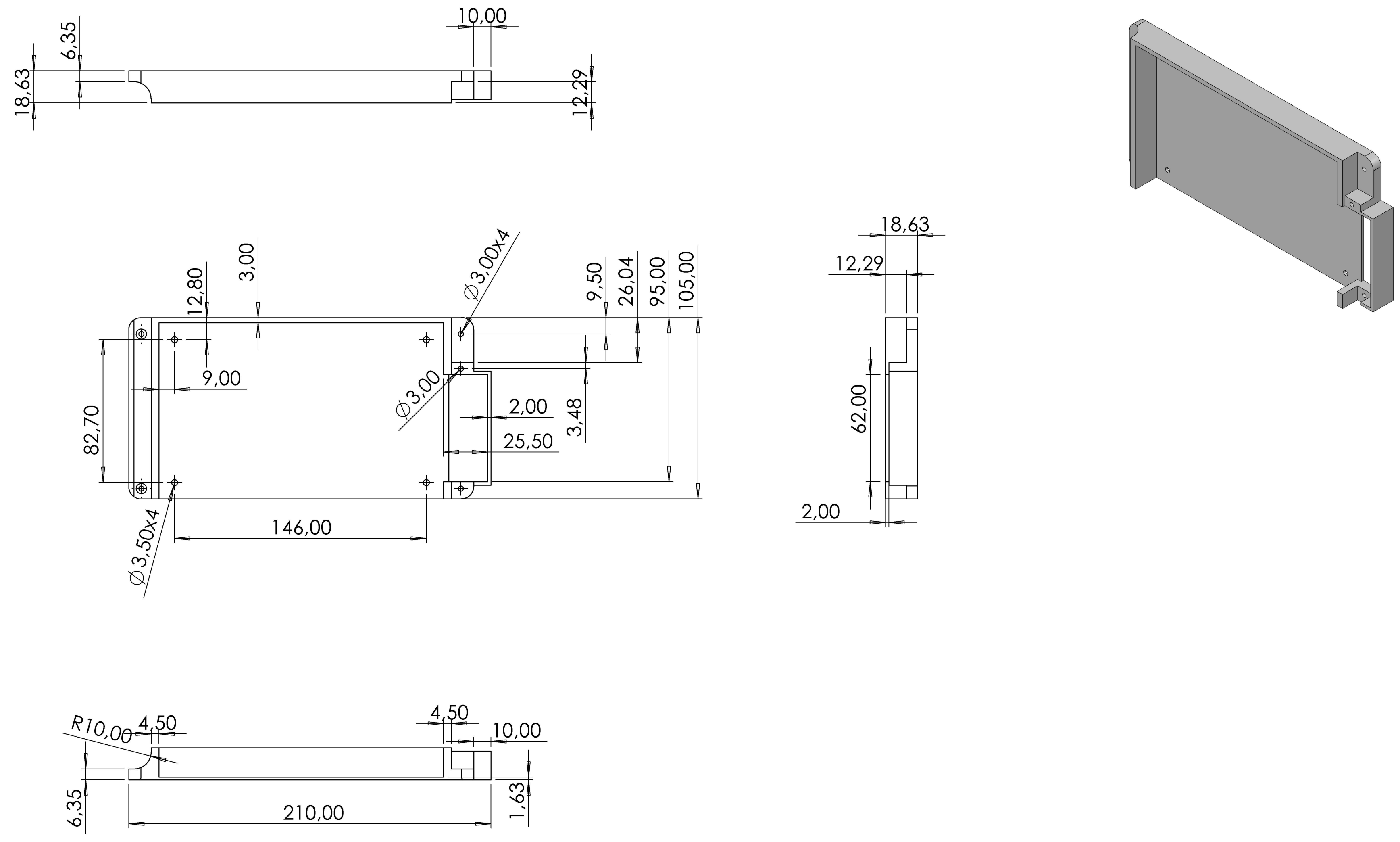
UNIVERSIDAD INTERNACIONAL DEL ECUADOR
ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Seminario de integración curricular

PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

DIBUJO Nº/DRAWING Nº: D02-010



NOTAS GENERALES/GENERAL NOTES:

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PLANOS DE REFERENCIA/REFERENCE DRAWINGS:	
ITEM Nº:	DESCRIPCION/DESCRIPTION:

REVISIONES/REVIEWS:					
REV.	DESCRIPCION/DESCRIPTION:	FECHA/DATE:	DIBUJADO/DRAWN BY:	REVISADO/REVIEWED BY:	APROBADO/APPROVED BY:
A1					

REGISTRO/REGISTER:	FECHA/DATE:
DIBUJANTE/DRAFTMAN: Martin Molina Gomez	10/10/2025
DISEÑADOR/DESIGNER: Martin Molina Gomez	10/10/2025
REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
APROBACION FINAL/APPROBATION BY: Guillermo Mosquera	10/10/2025

TAMAÑO/PAPER SIZE: A3
ESCALA/SCALE: 1:2.5

UNIVERSIDAD INTERNACIONAL DEL ECUADOR
ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Integration Curricular Seminary

PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

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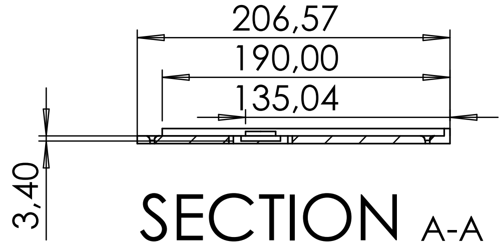
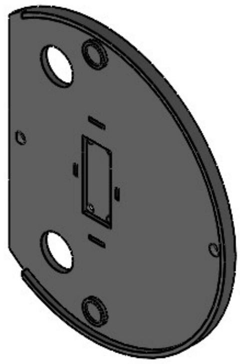
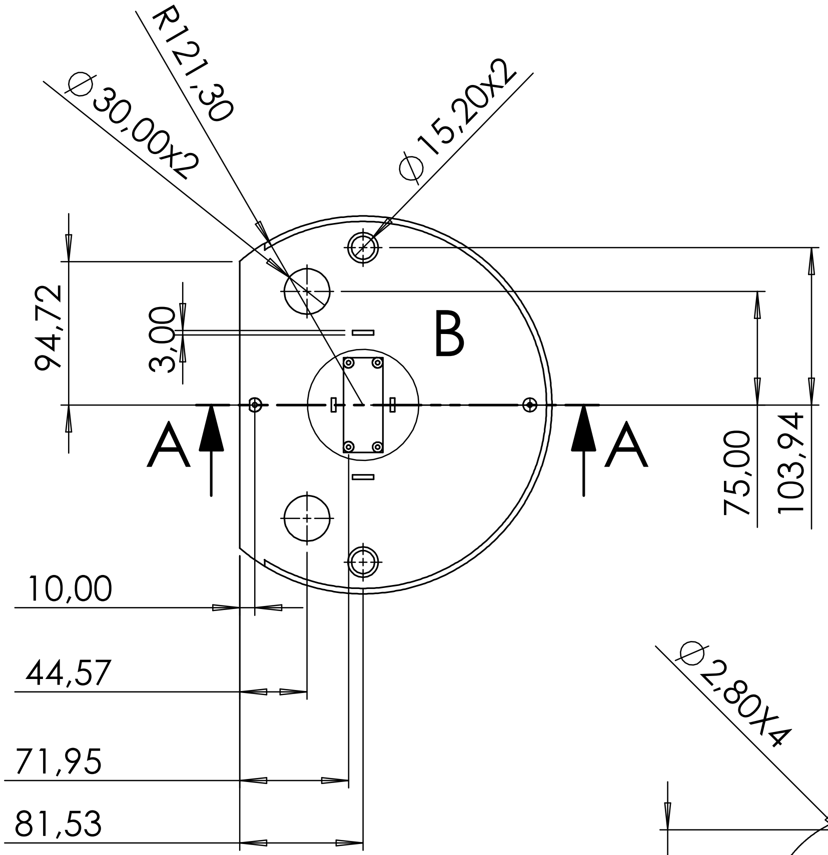
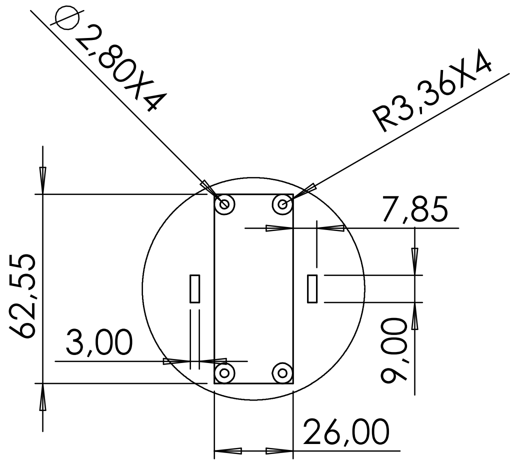


SECTION A-A







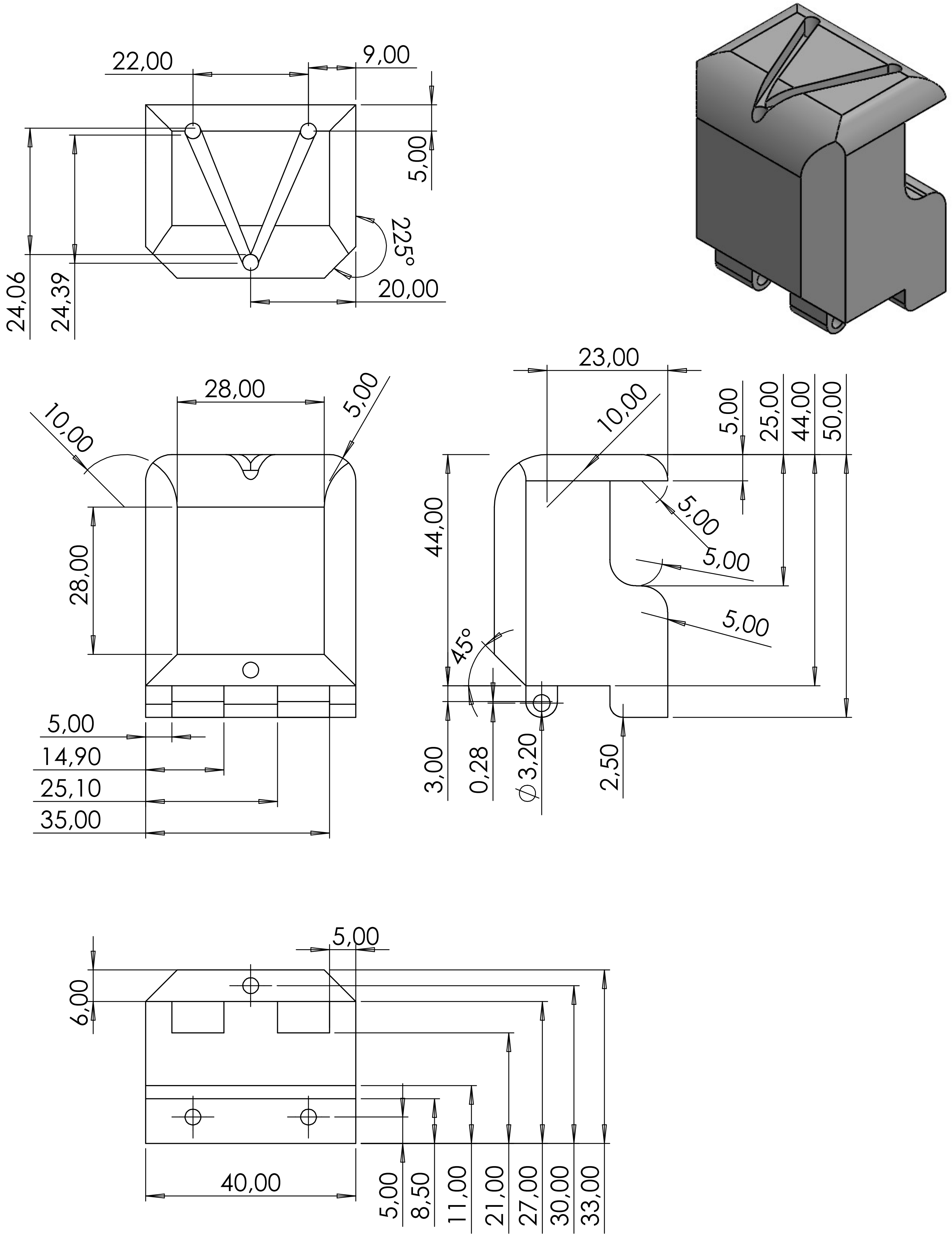
DETAIL B

SCALE 2 : 5

NOTAS GENERALES/GENERAL NOTES:	REGISTRO/REGISTER:	FECHA/DATE:
MATERIAL: PLA (Polylactic Acid).	DIBUJANTE/DRAFTMAN: Martin Molina	10/10/2025
LAYER HEIGHT: 0.2 mm.	DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
INFILL: 20% (Gyroid or Grid pattern recommended).	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
WALLS: Minimum 3 wall lines (to make it resistant to screw tightening). SUPPORTS: NO	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025

UNIVERSIDAD INTERNACIONAL DEL ECUADOR
ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT:	Seminario de integración curricular
PROYECTO/PROYECT:	Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."
DESCRIPCION/DESCRIPTION:	
DIBUJO Nº/DRAWING Nº:	D02-012
TAMAÑO/PAPER SIZE:	A4
ESCALA/SCALE:	1:5



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INFILL: 20% (Gyroid or Grid pattern recommended).	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
WALLS: Minimum 3 wall lines (to make it resistant to screw tightening).	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
SUPPORTS: NO		

TAMAÑO/PAPER SIZE: A4
ESCALA/SCALE: 1:1

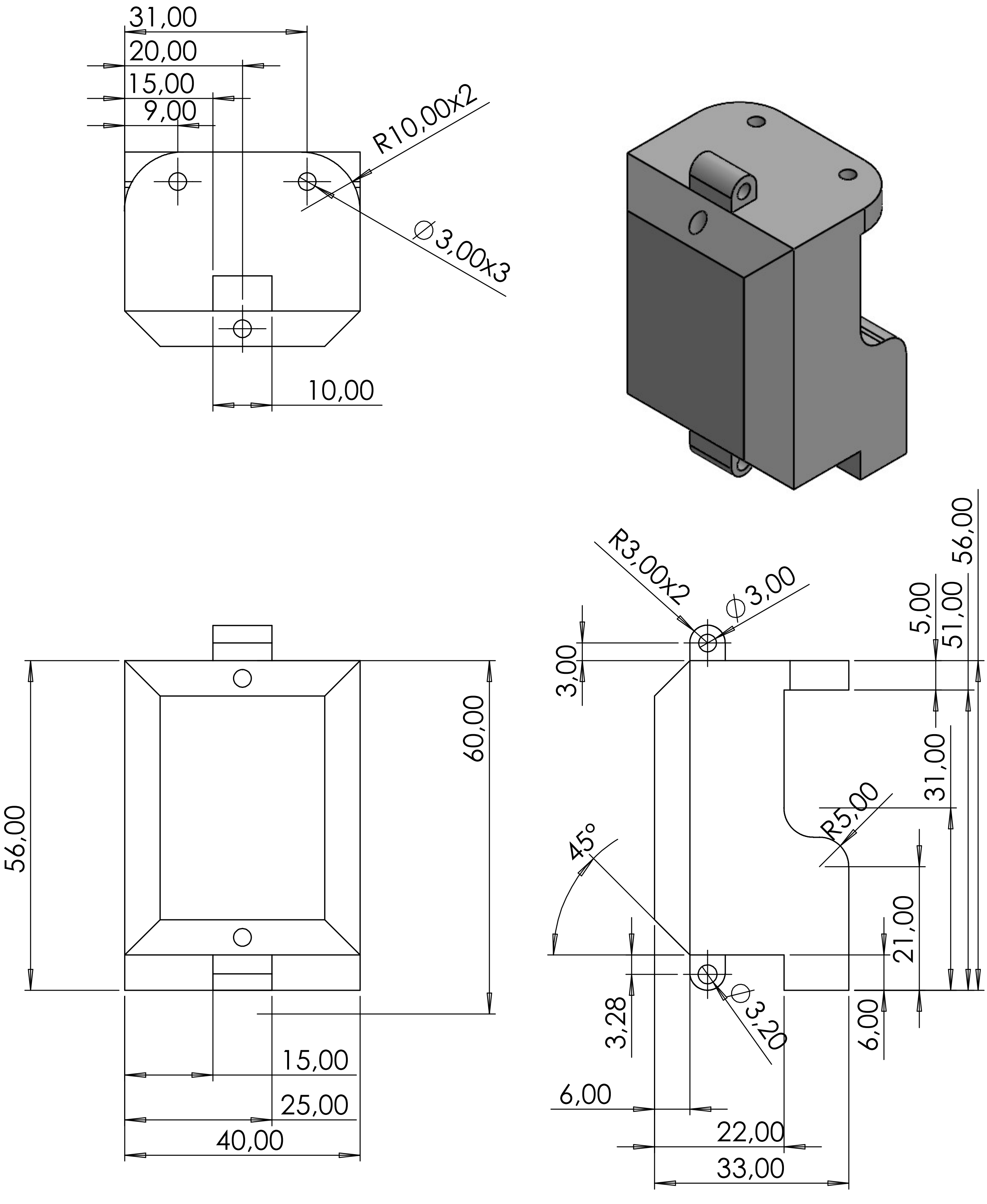
UNIVERSIDAD INTERNACIONAL DEL ECUADOR
ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Seminario de integración curricular

PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

DIBUJO Nº/DRAWING Nº: D02-102



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	DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025

UNIVERSIDAD INTERNACIONAL DEL ECUADOR

ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Seminario de integración curricular

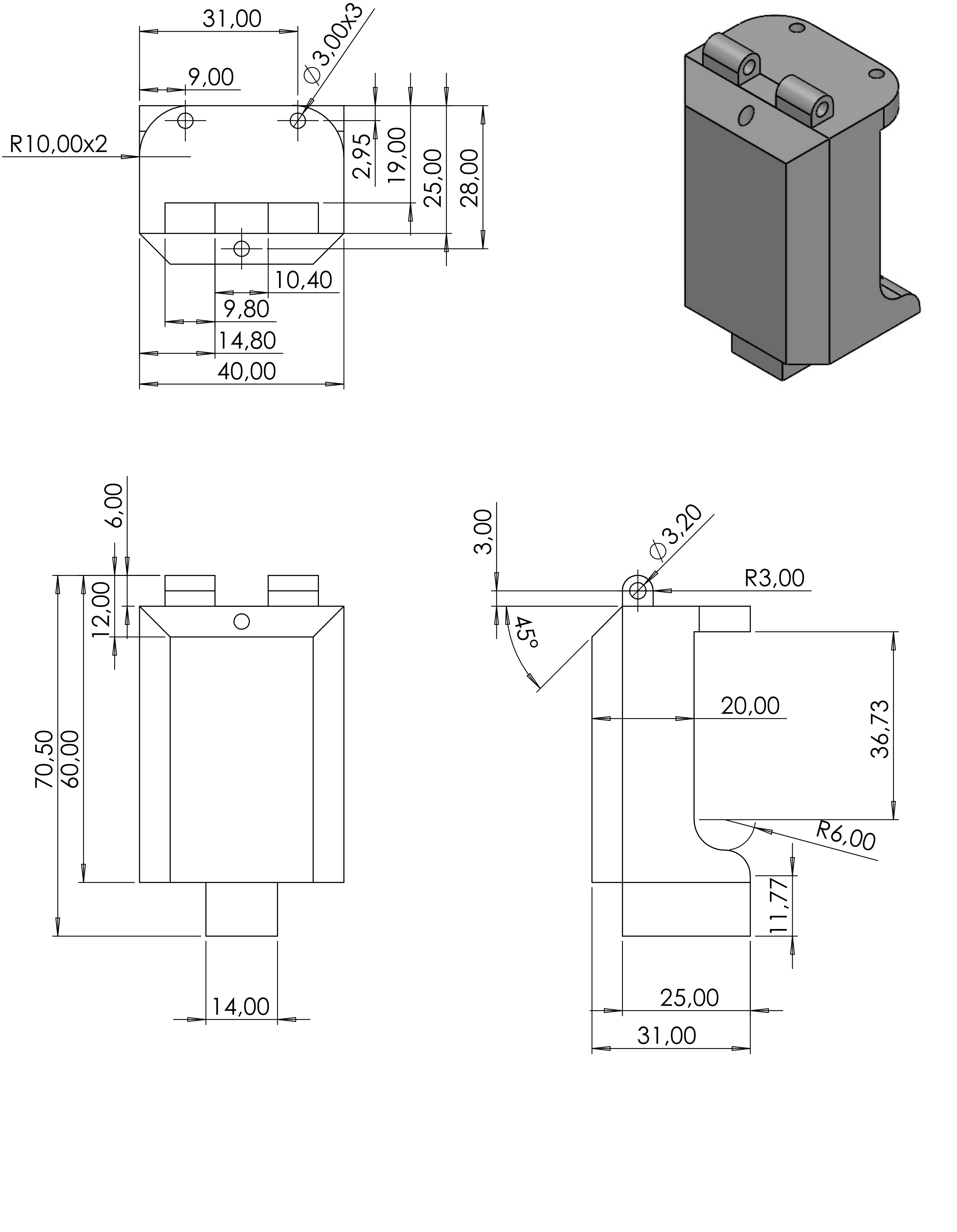
PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

TAMAÑO/PAPER SIZE: A4

ESCALA/SCALE: 1:1

DIBUJO Nº/DRAWING Nº: D02-202



NOTAS GENERALES/GENERAL NOTES:	REGISTRO/REGISTER:	FECHA/DATE:
MATERIAL: PLA (Polylactic Acid).	DIBUJANTE/DRAFTMAN: Martin Molina	10/10/2025
LAYER HEIGHT: 0.2 mm.	DISEÑADOR/DESIGNER: Martin Molina	10/10/2025
INFILL: 20% (Gyroid or Grid pattern recommended).	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025
WALLS: Minimum 3 wall lines (to make it resistant to screw tightening). SUPPORTS: NO	REVISADO/REVIEWED BY: Guillermo Mosquera	10/10/2025

TAMAÑO/PAPER SIZE: A4
ESCALA/SCALE: 1:1

UNIVERSIDAD INTERNACIONAL DEL ECUADOR
ESCUELA DE INGENIERIA MECATRONICA

ASIGNATURA/SUBJECT: Seminario de integración curricular

PROYECTO/PROYECT: Interactive educational robot for primary mathematical education support for children "A.R.I.M.A."

DESCRIPCION/DESCRIPTION:

DIBUJO Nº/DRAWING Nº: D02-302

3 APPENDIX C: Official Documents

Oficio Nro. MINEDEC-SFE-2026-00003-OF

Quito, D.M., 13 de enero de 2026

Asunto: Respuesta - Solicitud de autorización para uso de contenido bibliográfico con fines académicos y de investigación en proyecto de ingeniería mecatrónica - Martín Josué Molina Gómez

Martín Josué Molina Gómez
En su Despacho

De mi consideración:

En atención al documento S/N, mediante el cual el señor Martín Josué Molina Gómez, estudiante de la carrera de Ingeniería Mecatrónica de la Universidad Internacional del Ecuador (UIDE), solicita al Ministerio de Educación, Deporte y Cultura (MINEDEC) la autorización para el uso, digitalización y adaptación de los contenidos del texto oficial del Ministerio titulado "Guía para Docentes – Matemática" (Primera Edición, 2023), para su trabajo de titulación (tesis) denominado "DISEÑO E IMPLEMENTACIÓN DE UN ROBOT EDUCATIVO INTERACTIVO PARA EL APOYO EN LA EDUCACIÓN MATEMÁTICA ELEMENTAL DE NIÑOS 'A.R.I.M.A ".

Informamos lo siguiente:

Constitución de la República del Ecuador:
Art. 18, numeral 2: Establece que todas las personas tienen derecho a "Acceder libremente a la información generada en entidades públicas o en las privadas que manejen fondos del Estado...".

LOEI y sus reformas recientes (2021 y su Reglamento de 2023):
Art. 6, literal j (Obligaciones del Estado): "Garantizar la disponibilidad, accesibilidad, aceptabilidad y asequibilidad de las tecnologías de la información, … el uso de la comunicación en el proceso educativo como derechos fundamentales y propiciar el vínculo de la enseñanza con las actividades productivas o sociales";

Lineamientos de REA (Recursos Educativos Abiertos):
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Es lo que se puede informar, auguramos éxitos en su trabajo de titulación.

Atentamente,

Documento firmado electrónicamente

Ana María Galarza Raad
SUBSECRETARIA DE FUNDAMENTOS EDUCATIVOS

Referencias:
- MINEDEC-SIITT-2025-0152-M

Anexos:
- 12131-12082025.pdf

Oficio Nro. MINEDEC-SFE-2026-00003-OF

Quito, D.M., 13 de enero de 2026

Copia:

Señor Magíster
Carlos Alberto Almeida Alvarado
Subsecretario de Investigación, Innovación y Transferencia de Tecnología

Isarelis Perez Ones
Directora de Investigación Científica

Señora Magíster
Luz del Carmen Silva Román
Directora Nacional de Currículo

Edgar Patricio Freire Caicedo
Analista de Currículo 1

ef/ls

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ANA MARIA GALARZA
RAAD
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