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ARTICLE

FOUNDATIONS FOR TEACHING ARTIFICIAL INTELLIGENCE WITH EXPLAINABLE NEURAL NETWORKS: A CONSTRUCTIONIST APPROACH MEDIATED BY THE OPEN ROBERTA LAB ROBOTIC SIMULATOR

Fundamentos para o Ensino de Inteligência Artificial com Redes Neurais Explicáveis: uma Abordagem Construcionista Mediada pelo Simulador Robótico *Open Roberta Lab*

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ABSTRACT | **Purpose:** To analyze the fundamentals for teaching Artificial Intelligence (AI) with Explainable Neural Networks (XAI), from a constructionist approach, investigating the Open Roberta Lab robotic simulator as a pedagogical mediator. **Research methods:** This study adopts a qualitative, theoretical-analytical approach, based on a literature review and the analysis of an educational artifact. The research was conducted in three stages: (i) theoretical review on AI in education, XAI, and constructionism; (ii) exploration of the Open Roberta Lab with examples involving neural networks; and (iii) analysis of the environment based on criteria such as artifact construction, interactivity, explainability, usability, and pedagogical mediation. **Results:** The findings indicate that the Open Roberta Lab robotic simulator has significant potential for AI education, particularly by promoting active learning, experimentation, and visualization of neural network processes. The integration of block-based programming, simulation, and XAI contributes to reducing the complexity of models and fostering a more critical and reflective understanding. **Discussion:** The study highlights the importance of articulating pedagogical and technological foundations in AI education, emphasizing the role of XAI in promoting AI literacy.

Furthermore, robotic simulators emerge as accessible alternatives for implementing constructionist practices, especially in contexts with limited infrastructure. **Originality and value:** As an original contribution, the study proposes a connection between constructionism, XAI (Interactive Application of Technology), and robotic simulation, offering theoretical support for the development of more accessible pedagogical practices.

Keywords | Artificial Intelligence, Explainable Neural Networks. Constructionism, Open Roberta Lab, Educational Robotics.

RESUMO | Objetivo: Analisar os fundamentos para o ensino de Inteligência Artificial (IA) com Redes Neurais Explicáveis (XAI), a partir de uma abordagem construcionista, investigando o simulador robótico *Open Roberta Lab* como mediador pedagógico. **Métodos de pesquisa:** Trata-se de uma pesquisa qualitativa, de natureza analítica, baseada em revisão de literatura e análise de um artefato educacional. O estudo foi desenvolvido em três etapas: (i) revisão teórica sobre IA na educação, XAI e construcionismo; (ii) exploração do Open Roberta Lab com exemplos envolvendo Redes Neurais; e (iii) análise do ambiente com base em critérios como construção de artefatos, interatividade, explicabilidade, usabilidade e mediação pedagógica. **Resultados:** Os resultados evidenciam que o simulador robótico *Open Roberta Lab* apresenta potencial significativo para o ensino de IA, ao favorecer a aprendizagem ativa, a experimentação e a visualização dos processos internos das redes neurais. A integração entre programação em blocos, simulação e XAI contribui para reduzir a complexidade dos modelos e promover uma compreensão mais crítica e reflexiva. **Discussão:** O estudo reforça a importância da articulação entre fundamentos pedagógicos e tecnológicos no ensino de IA destacando o papel das XAI na promoção do letramento em IA. Evidenciando que simuladores robóticos podem atuar como alternativas acessíveis para a implementação de práticas construcionistas, especialmente em contextos com limitações de infraestrutura. **Originalidade e valor:** Como contribuição original, o estudo propõe uma articulação entre construcionismo, XAI e simulação robótica, oferecendo subsídios teóricos para o desenvolvimento de práticas pedagógicas mais acessíveis.

Palavras-chave | Inteligência Artificial; Redes Neurais Explicáveis; Construcionismo; Open Roberta Lab; Robótica Educacional.

INTRODUCTION

The growing presence of Artificial Intelligence (AI) in contemporary society has fostered its integration across different educational levels, particularly in Basic Education, requiring the development of pedagogical approaches that promote not only the use of these technologies, but also their critical and reflective understanding (Holmes et al., 2019; Luckin et al., 2016). In this context, teaching AI becomes a complex challenge, as it involves abstract concepts, sophisticated computational models, and systems often characterized as "black boxes," making them difficult for students in early stages of learning to fully comprehend.

Among the core domains of AI, Artificial Neural Networks (ANNs) stand out due to their widespread application in contemporary technological systems. However, their interpretative opacity has motivated the emergence of Explainable Artificial Intelligence (XAI), which seeks to make the decision-making processes of these models more transparent and understandable (Adadi & Berrada, 2018). In educational settings, this characteristic opens relevant possibilities for teaching and learning, as it enables the approximation of complex concepts to students' realities, fostering the construction of meaningful knowledge about the functioning of intelligent systems.

Despite these advances, the literature still reveals a gap regarding the articulation between AI education, consolidated pedagogical approaches, and educational technologies that support active learning. In many cases, existing proposals focus primarily on introducing technical tools and concepts without sufficient theoretical grounding to sustain consistent pedagogical practices (Long & Magerko, 2020). Furthermore, studies addressing AI education in Brazilian Basic Education from a perspective that integrates explainability, knowledge construction, and accessible technological mediation remain limited.

In this scenario, constructionism, proposed by Seymour Papert, emerges as an important theoretical foundation for AI education. Grounded in the idea that learning occurs more effectively when individuals are engaged in the construction of meaningful artifacts, constructionism values experimentation, interaction, and problem-solving as central elements of the educational process (Papert, 1980). These characteristics make this approach particularly suitable for teaching complex concepts, such as those related to AI, since they enable the externalization of thinking and the concrete manipulation of abstract models.

Educational Robotics (ER) and computational simulation environments arise, in this context, as privileged means for operationalizing constructionist principles, allowing students to interact with programmable systems and dynamically observe the effects of their actions (Eguchi, 2014). Among these technologies, the Open Roberta Lab robotic simulator stands out for providing an accessible environment for the development of projects involving programming and AI concepts without requiring complex physical infrastructure (Alves & Trindade, 2025). Such environments can function as pedagogical mediators, enabling the active construction of knowledge and the understanding of the principles underlying intelligent systems.

Given this context, this study aims to analyze the foundations for an AI pedagogy based on XAI from a constructionist perspective, investigating the role of robotic simulators, such as Open Roberta Lab, as mediators in the teaching and learning process. Thus, the research seeks to contribute to the development of a theoretical framework that articulates pedagogical and technological foundations, providing support for more accessible, critical, and pedagogically grounded educational practices.

This article is organized as follows. Section 2 presents the theoretical framework, discussing the concepts of AI, XAI, constructionism, and technological mediation through robotic simulators. Section 3 discusses the articulation of these elements in the development of a pedagogical proposal for AI education. Finally, Section 4 presents the final considerations and implications of the study.

LITERATURE REVIEW

Understanding AI as a subject of teaching within Brazilian Basic Education requires the articulation of technological foundations and pedagogical perspectives capable of making its approach both accessible and meaningful. Historically, the origins of AI are closely associated with the advancements of Computer Science throughout the twentieth century, particularly through the foundational contributions of researchers such as Alan Turing, whose studies established theoretical bases for the development of systems capable of simulating aspects of human intelligence (Murer, 2025; Ferreira, 2025). Over the decades, the evolution of algorithms and computational power significantly expanded the possibilities for AI applications, consolidating AI as a central field within the contemporary technological landscape. However, its integration into educational contexts imposes challenges related to conceptual abstraction and model complexity, demanding pedagogical approaches that go beyond the mere transmission of technical content (Alves & Trindade, 2025).

In this context, ANNs stand out as one of the main paradigms of contemporary AI, being widely employed across different applications (Ferreira, 2026). Nevertheless, their frequently opaque nature, commonly characterized as a "black-box" behavior, makes it difficult to understand their internal processes, particularly in educational settings (Adadi & Berrada, 2018). In response to this limitation, XAI has emerged as an approach aimed at making model decision-making processes more transparent and interpretable. From a pedagogical perspective, this characteristic represents an important opportunity for AI education, as it allows students to understand not only the outcomes produced by intelligent systems, but also the underlying mechanisms that govern them, fostering the construction of more critical and reflective knowledge (Alves & Trindade, 2025).

For such content to be effectively appropriated by students, it becomes necessary to ground the teaching process in educational theories that value the active construction of knowledge. In this regard, constructionism, proposed by Seymour Papert, provides a consistent theoretical foundation by arguing that learning becomes more meaningful when individuals are engaged in the creation of artifacts that can be explored, tested, and shared (Trindade & Trindade, 2025). ER environments and computational simulators, such as Open Roberta Lab, emerge as important spaces for materializing these principles, enabling interaction with AI models in a concrete and accessible manner (Alves & Trindade, 2025). Therefore, this section seeks to establish the theoretical foundations that support an AI pedagogy grounded in the articulation between explainability, knowledge construction, and technological mediation.

Challenges and Possibilities of Artificial Intelligence in Education

The incorporation of AI into educational contexts has intensified over recent decades, following the rapid advancement of digital technologies and their growing presence in everyday life. In this scenario, AI is no longer viewed solely as a technical field within Computer Science, but also as an object of teaching and learning, particularly within Brazilian Basic Education, where there is an increasing emphasis on developing competencies related to computational thinking, problem-solving, and the critical understanding of technologies (Holmes et al., 2019). This shift in perspective implies recognizing that students' education should encompass not only the use of intelligent systems, but also an understanding of their operational principles and social implications.

However, teaching AI presents significant challenges, especially due to the abstract and complex nature of the concepts involved (Jacobina et al., 2026). Unlike more tangible computing topics, such as introductory programming, AI involves mathematical models, algorithmic structures, and machine learning processes that are often not directly observable. In this regard, machine learning systems, particularly neural networks, are frequently characterized by low interpretability, making it difficult to understand how decisions are generated within these models (Adadi & Berrada, 2018). These factors contribute to a perception of inaccessibility among both students and teachers, particularly in educational contexts marked by limitations in infrastructure and teacher training.

Another relevant aspect concerns the need to promote AI literacy, understood as the ability to comprehend, use, and critically reflect on AI-based systems (Long & Magerko, 2020). Such literacy extends beyond technical knowledge and also encompasses ethical, social, and cultural dimensions, considering the impacts of AI across different spheres of society. In this sense, international initiatives have sought to guide the integration of AI into education by emphasizing pedagogical approaches that encourage active student participation and contextualized learning experiences (Luckin et al., 2016). In the Brazilian context, documents such as the Brazilian Artificial Intelligence Plan (PBIA) reinforce the need to prepare citizens capable of critically understanding and interacting with AI technologies, thereby expanding discussions regarding their inclusion within educational curricula (Goulart et al., 2026).

In response to these challenges, pedagogical possibilities aimed at making AI education more accessible and meaningful have begun to emerge. Among these approaches, particular emphasis has been placed on experimentation, visualization, and interaction with computational models, allowing students to explore complex concepts through practical and contextualized experiences (Alves & Trindade, 2025). In this context, the use of educational tools and simulation environments has shown considerable potential by enabling the manipulation of variables, observation of behaviors, and formulation of hypotheses regarding the functioning of intelligent systems. Such strategies contribute to reducing the abstraction inherent in AI, promoting knowledge construction through action and reflection.

Therefore, understanding the challenges and possibilities of AI education requires recognizing the importance of integrating technological foundations with pedagogical approaches that foster active and meaningful learning. This integration paves the way for adopting theoretical perspectives that value knowledge construction through interaction with artifacts, as proposed by constructionism, as well as the use of technologies that mediate this process. In this regard, the following subsection deepens the discussion on XAI, highlighting its potential as a pedagogical strategy for AI education.

Explainable Neural Networks and Artificial Intelligence Education

ANNs constitute one of the main paradigms of contemporary AI, being widely employed in applications ranging from pattern recognition to recommendation systems and automated decision-making. Inspired by the functioning of the human brain, these networks are composed of interconnected units capable of learning from data by adjusting their internal parameters to solve complex problems (Ferreira, 2026). As discussed in the literature, the advancement of ANNs is directly associated with the increase in computational power and the availability of large volumes of data, factors that have driven the development of increasingly sophisticated and effective models. Nevertheless, despite their high performance, these structures present significant limitations when considered from an educational perspective (Alves & Trindade, 2025).

One of the main limitations of ANNs lies in their low interpretability, frequently described as the “black-box” problem, in which the internal decision-making processes of models are not easily understandable to human beings (Adadi & Berrada, 2018). This characteristic represents a significant obstacle for AI education, particularly within Brazilian Basic Education, where understanding concepts is just as important as obtaining results. The lack of transparency in these models hinders students' construction of meaning, resulting in superficial learning based solely on observing inputs and outputs without understanding the underlying mechanisms involved (Adablanu, 2024).

XAI emerges as a promising approach to mitigate these limitations by seeking to make model decision-making processes more transparent, interpretable, and understandable (Samek et al., 2017). In educational contexts, this characteristic assumes an even more relevant role, as it allows students to follow the internal functioning of models, understand how different variables influence outcomes, and develop a critical perspective regarding the behavior of intelligent systems. Thus, explainability should not be understood merely as a technical requirement, but rather as a fundamental pedagogical element for AI education.

In this sense, the use of explainable approaches fosters knowledge construction by enabling students to explore, test, and reflect upon machine learning processes. This possibility brings AI education closer to investigative practices, in which learners move beyond being passive users of technologies to become active agents in model construction and interpretation of results. Consequently, XAI contributes to reducing the level of abstraction associated with AI concepts, making them more accessible and aligned with teaching strategies that value experimentation and conceptual understanding (Alves & Trindade, 2025).

Therefore, the use of XAI in educational contexts supports the development of AI literacy by enabling students not only to understand how to use intelligent systems, but also how to interpret and critically question them. This dimension becomes particularly relevant given the growing presence of AI in decisions that affect social, economic, and cultural life, requiring citizens capable of understanding and evaluating the functioning of these technologies (Samek et al., 2017). In this regard, integrating explainability into AI education contributes to a more critical, ethical, and conscious educational formation.

Thus, XAI constitutes a central element in the development of pedagogical proposals for AI education by creating conditions in which complex concepts can be explored in a more transparent and meaningful way. However, for this potential to be effectively realized in educational settings, it is necessary to articulate such approaches with pedagogical theories that value the active construction of knowledge. In this sense, the next subsection discusses constructionism, highlighting its contributions to AI education mediated by technologies.

The integration of AI into educational contexts requires, in addition to technical and pedagogical foundations, a critical approach regarding its ethical implications (Suchara et al., 2025). AI-based systems, particularly those grounded in machine learning, are subject to algorithmic biases derived from the data used during training, potentially reproducing or amplifying social, cultural, and economic inequalities (Floridi et al., 2018; Holmes et al., 2019). In educational environments, these risks become even more sensitive, as they directly impact teaching, learning, and assessment processes. In this regard, promoting AI literacy should encompass not only the technical understanding of models, but also the ability to critically question their outcomes, limitations, and social impacts (Long & Magerko, 2020).

Within this scenario, explainability approaches such as XAI contribute to system transparency; however, they do not, by themselves, eliminate the ethical challenges associated with AI use. Model interpretations may be limited, oversimplified, or even lead to misleading understandings depending on how results are presented (Samek et al., 2017). Therefore, it becomes necessary to recognize that explainability must be accompanied by critical reflection concerning the reliability, accountability, and limitations of intelligent systems. In AI education, this implies developing pedagogical practices that not only make models understandable, but also encourage critical analysis of their ethical implications, promoting the education of students capable of acting consciously and responsibly within a society increasingly mediated by intelligent technologies.

Papert's Constructionism and Artifact-Mediated Learning

Constructionism, proposed by Seymour Papert, constitutes one of the main theoretical approaches for understanding learning mediated by digital technologies, especially within the context of Computer Science Education (Massa, de Oliveira & dos Santos, 2022). Derived from Piagetian constructivism, constructionism expands the notion of learning by emphasizing that knowledge is built more effectively when individuals are engaged in the creation of artifacts that can be explored, shared, and reflected upon (Souza, 2024). In this sense, learning is not limited to the assimilation of information, but rather involves an active process of construction in which the learner interacts dynamically and intentionally with the object of knowledge.

One of the central principles of constructionism is the idea that learning occurs more deeply when students participate in the construction of external objects that represent their thinking (Sousa, 2025; Wisnieski, 2022). These artifacts may take different forms, such as computer programs, digital models, robots, or simulations, functioning as mediators between abstract thinking and its concrete materialization. By externalizing their ideas, students have the opportunity to test hypotheses, identify errors, reformulate strategies, and develop a more solid understanding of the concepts involved (Papert, 1980). This perspective becomes particularly relevant in the teaching of complex subjects, such as those related to AI, which often require understanding processes that are not directly visible.

Within the context of AI education, constructionism provides a pedagogical foundation capable of addressing challenges associated with abstraction and the complexity of computational models. Rather than approaching AI solely through theoretical explanations, this perspective promotes learning through experimentation and interaction with systems that allow students to observe algorithms in operation (Alves & Trindade, 2025). In this regard, the construction and manipulation of models, even simplified ones, enable students to develop an understanding of how intelligent systems learn, make decisions, and respond to different inputs. This approach directly aligns with the need to foster AI literacy by allowing students to understand the principles underlying these technologies.

In this sense, constructionism demonstrates strong convergence with contemporary approaches in Computer Science Education, particularly with the development of computational thinking, which involves skills such as decomposition, abstraction, pattern recognition, and algorithm design (Vilanova, 2025). By engaging students in the creation of computational artifacts, this approach promotes not only the learning of specific concepts, but also the development of cognitive and metacognitive competencies essential for understanding and solving complex problems (Trindade & Trindade, 2025). Consequently, AI education mediated by constructionist principles contributes to the formation of individuals capable of critically interacting with digital technologies.

Another relevant aspect of constructionism is its recognition of error as an integral part of the learning process. Unlike traditional approaches, which often treat errors as indicators of failure, constructionism understands them as opportunities for reflection and reconstruction of knowledge (Palmeira & dos Santos, 2025). In the context of AI, this perspective is particularly relevant, since the process of training models involves iterative adjustments, experimentation, and continuous refinement. By experiencing these stages through artifact construction, students begin to understand machine learning as a dynamic process, developing a more realistic and critical perspective regarding intelligent systems.

Thus, constructionism constitutes an important and robust theoretical framework for AI education by offering principles that support active learning, meaningful knowledge construction, and mediation through technological artifacts. However, for these principles to be effectively incorporated into pedagogical practices, it is necessary to provide environments that enable the accessible creation, manipulation, and experimentation of computational models (Alves & Trindade, 2025). In this context, ER and simulation environments emerge as spaces that contribute to the materialization of these ideas, as discussed in the following subsection.

Educational Robotics and Simulation as Constructionist Environments

ER constitutes an important pedagogical approach within the field of Computer Science Education, particularly due to its potential to promote active learning through the construction and manipulation of technological artifacts (Alves & Trindade, 2025). Grounded in pedagogical perspectives aligned with constructionism, this approach enables students to develop knowledge through direct interaction with programmable systems, exploring concepts in a practical and contextualized manner. In this sense, ER extends beyond the mere use of technological devices, configuring itself as a learning environment in which making, experimenting, and reflecting become central elements of the educational process (Eguchi, 2014).

When integrated into AI education, ER assumes an even more significant role by enabling the materialization of abstract concepts through concrete interactions. This integration allows computational models to be observed in operation, bringing students closer to phenomena that would otherwise remain at a purely theoretical level (Alves & Trindade, 2025). Such articulation facilitates the understanding of processes such as perception, decision-making, and machine learning by making visible the effects of algorithmic actions within controlled environments. Consequently, ER functions as a mediator between the complexity of intelligent systems and the learner's experience (Alimisis, 2013).

However, the implementation of ER practices in school contexts faces challenges related to infrastructure, equipment costs, and teacher training (Santos, 2026). Many educational institutions, particularly in regions with limited resources, lack robotic kits or suitable environments for developing practical activities (Alves & Trindade, 2025). This reality may restrict students' access to more comprehensive constructionist experiences, limiting the pedagogical potential of ER as a teaching tool. Such limitations reinforce the need for alternatives capable of ensuring access to construction-based pedagogical practices without depending exclusively on physical resources (Benitti, 2012).

Within this scenario, computational simulation environments emerge as a viable and accessible solution, enabling the reproduction of robotic behaviors and experimentation with programmable systems without the need for physical devices. Robotic simulators allow students to interact with virtual models, test algorithms, and observe the results of their actions in real time, facilitating the understanding of complex concepts through experimentation (Alves & Trindade, 2025). Moreover, these environments offer greater flexibility by enabling activity repetition, parameter modification, and the exploration of different scenarios, aspects that contribute to a more investigative and reflective learning process (Holz & Trentin, 2025; Mikropoulos & Natsis, 2011).

From a constructionist perspective, simulators preserve the principle of artifact construction, even within digital environments, by enabling students to develop programs, create behaviors, and explore solutions to proposed problems (Biriba, 2023). The absence of a physical component does not prevent meaningful learning, provided that the environment offers interaction, autonomy, and opportunities for experimentation (de Oliveira et al., 2022). Thus, simulation environments can be understood as extensions of constructionist environments, expanding access to and possibilities for the use of ER.

In this regard, robotic simulators constitute highly relevant technological resources within the contemporary educational landscape. These environments allow students to design, program, and test robots without the need for physical equipment (Clemente, 2022). In this context, the *CoderZ*[1] simulator enables learners to experience practical activities similar to those provided by real robots. Consequently, access to ER education is expanded while reducing costs and overcoming structural limitations. Figure 1 presents the interface of the CoderZ simulator.

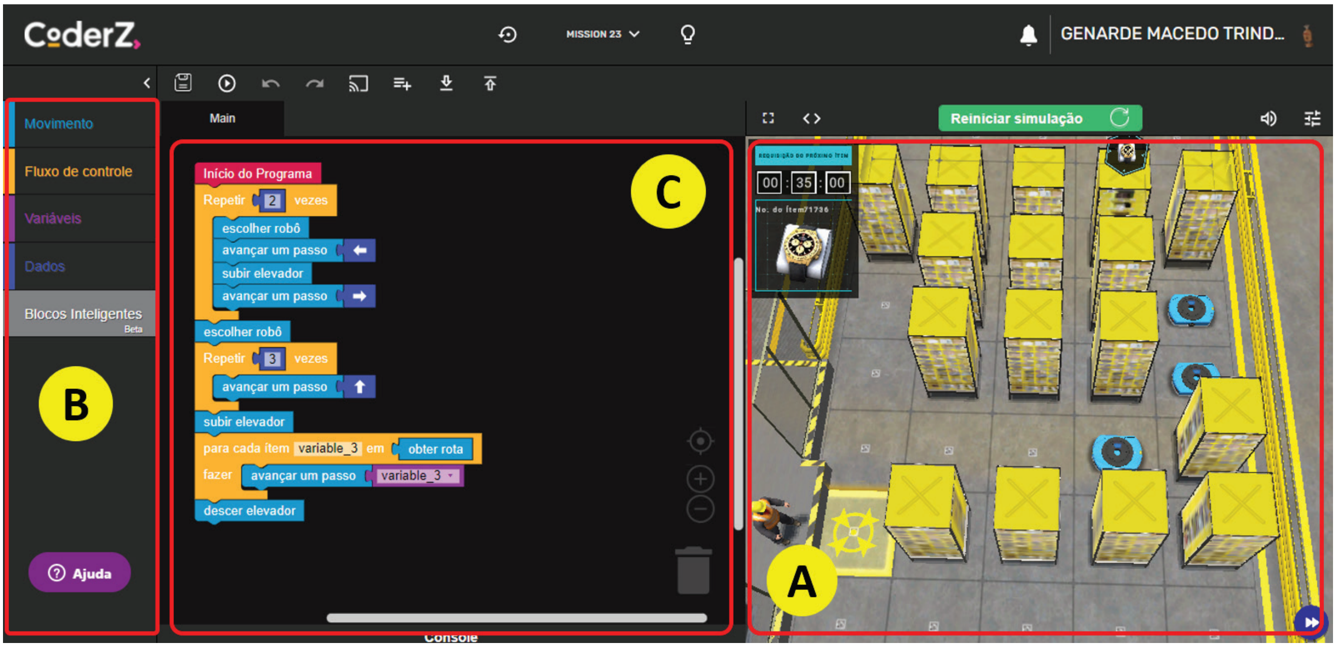

Figure 1. CoderZ simulator interface. Source: Trindade, de Souza and dos Santos (2022).

1 *CoderZ:* https://gocoderz.com/

Figure 1(A) illustrates the simulation area within CoderZ, which allows detailed observation of the components involved in the proposed challenge. The simulator also provides a two-dimensional visualization mode that can be selected by the user. Figure 1(B) presents the menu section in which programming blocks are organized into distinct categories, facilitating their identification and use. Finally, Figure 1(C) highlights the space dedicated to the development of programming logic, enabling users to structure solutions in a visual and interactive manner.

Therefore, ER and simulation environments constitute important tools for implementing pedagogical practices grounded in constructionism by promoting interaction between theory and practice, active knowledge construction, and the exploration of complex concepts in accessible ways. In the context of AI education, these environments become even more relevant by enabling the visualization and experimentation of computational models (Alves & Trindade, 2025). In this regard, the importance of specific tools integrating these characteristics becomes evident, particularly Open Roberta Lab, whose analysis is further explored in the following subsection.

Open Roberta Lab as a Mediating Artifact for AI Education

In 2014, the Fraunhofer Institute for Intelligent Analysis and Information Systems (Fraunhofer IAIS), located in Germany, with support from Google, launched the Open Roberta Lab robotic simulator with the aim of facilitating the teaching and learning of programming for people worldwide (Ruiz, Fernández & Carvajal, 2023). The platform uses the NEPO® graphical block-based programming language, a block programming language developed by Fraunhofer IAIS to provide intuitive programming for a wide variety of hardware systems. Inspired by the Scratch programming language, developed by the Massachusetts Institute of Technology, NEPO can be applied to a broad range of devices, from microcontroller boards to advanced humanoid robots. The language incorporates several features commonly found in traditional programming languages and continues to evolve under the development of Fraunhofer IAIS (Münsterberg et al., 2023). Figure 2 presents an example of block-based code and the corresponding robot simulation.

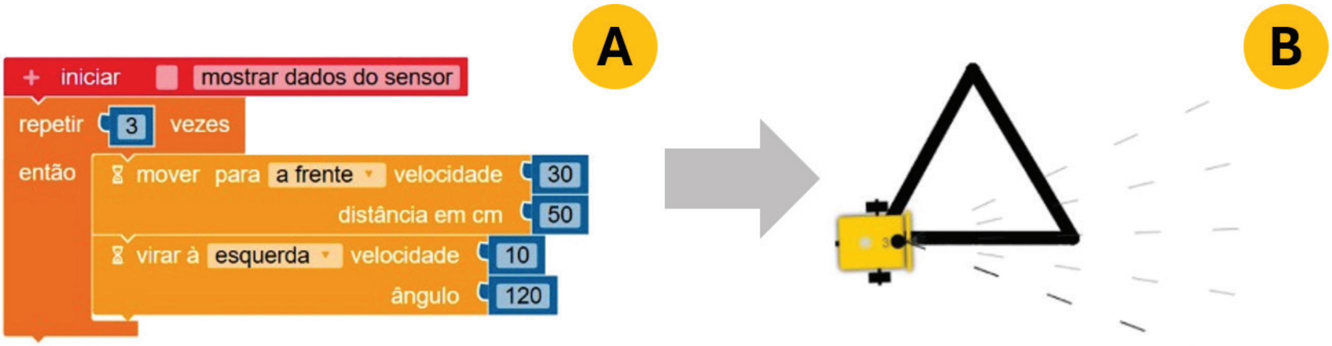

Figure 2. NEPO block-based code model and robot simulation. Source: Alves & Trindade (2025).

Figure 2(A) presents a block-based code used to program a robot through a sequence of repetitive actions, which is typical of educational programming environments such as Open

Roberta Lab. The main objective of this code is to make the robot execute a movement pattern a predetermined number of times. Figure 2(B), in turn, presents the robot simulation based on the developed code. It can be observed that the robot constructs a triangle by executing the forward movement three times, followed by a left turn of 120 degrees. This type of activity enables students to understand concepts related to repetition structures, motion control, and spatial orientation in robot programming.

One of the main distinguishing features of this simulator is its ability to reproduce the behavior of different robotic systems, allowing students and educators to develop and test algorithms even without direct access to physical robots. Among the main systems that Open Roberta Lab can simulate are: Calliope mini, Arduino, Micro:bit, mBot, Bionic Flower, BOB3, Bot'n Roll, Edison V2/V3, NAO, RCJ RescueOnlineSim, ROB3RTA, Robotino, senseBox, LEGO Spike Prime / Robot Inventor, Thymio, TxT Controller, WeDo, and LEGO Mindstorms. Table 1 presents and describes these systems according to the information available in Open Roberta Lab.

Table 1. Systems Simulated in Open Roberta Lab and Their Pedagogical Possibilities from a Constructionist Perspective. Source: Developed by the authors (2026).

Category	Simulated Systems	Constructionist Potential for Learning
Programmable Microcontrollers	Calliope mini, Arduino, micro:bit, senseBox	Introduction to computational logic and sensor control through the construction of interactive digital artifacts, promoting experimentation and active learning.
Physical Educational Robots	mBot, BOB3, Thymio, Bot'n Roll, Edison V2/V3, NAO, Robotino, RCJ Rescue Online Sim, Bionic Flower	Programming movement and interaction with the environment through the construction and manipulation of tangible artifacts, fostering learning through action, experimentation, and problem-solving.
Simulation and AI	ROB3RTA, RCJ Rescue Online Sim, módulos de rede neural, visão e som	Exploration of neural networks, decision-making, and Explainable AI through the construction and analysis of computational models, promoting understanding of the internal processes of intelligent systems.
Compatible LEGO Kits	LEGO Mindstorms (EV3, NXT), LEGO Spike Prime, Robot Inventor, LEGO WeDo, TxT Controller	Development of playful and authorial projects integrating physical and digital elements, stimulating knowledge construction through experimentation, reflection, and creativity.

Table 1 demonstrates that the pedagogical potential of the systems simulated in Open Roberta Lab extends beyond their instrumental use, configuring the platform as an environment aligned with constructionist principles for AI education. Regardless of category, the active construction of artifacts stands out as a central element, allowing students to experiment, test hypotheses, and reflect upon the results obtained. In the case of simulation and AI, this potential is further expanded by enabling the exploration of abstract concepts, such as neural networks and decision-making processes, through manipulable and interpretable models. In this context, the diversity of systems supports adaptation to different educational settings, reinforcing the accessible and inclusive nature of the approach.

Thus, the integration of ANNs into Open Roberta Lab aims to make fundamental concepts of this approach more understandable through a practical and accessible perspective. By using the simulation environment, the objective is to demonstrate how ANNs can be applied to robot control, enabling students to progressively understand how these models process inputs, adjust parameters, and generate outputs within dynamic contexts (Münsterberg et al., 2023). This approach supports learning by bringing abstract concepts closer to concrete experience, aligning with constructionist principles based on creation and experimentation. In this context, Figure 3 presents a programming example in which a robot is configured to maintain a fixed distance from a moving obstacle. Complementarily, Figure 4 illustrates the structure of the ANN implemented in Open Roberta Lab, highlighting how data are internally organized and processed.

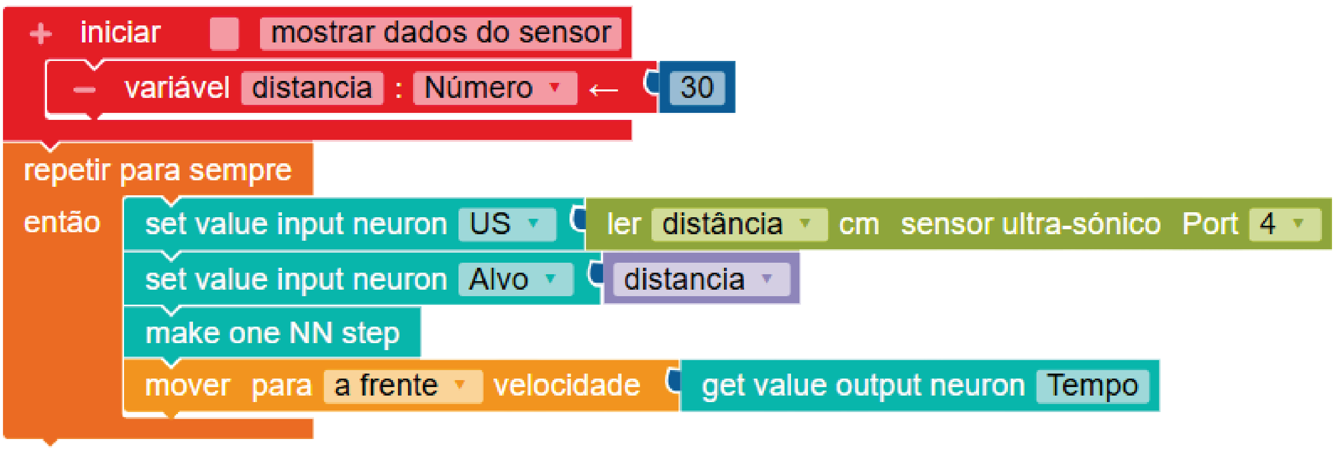

Figure 3. NEPOprog Program tab in Open Roberta Lab, developed by the authors (2026).

Figure 4. Neural Network Learn tab in Open Roberta Lab, developed by the authors (2026).

In Figure 3, the program enables the input neuron *US* to receive data from the robot's ultrasonic sensor. The variable *distance*, assigned the value 30, is connected to the input neuron *Target*. The execution of the command *make one NN step* processes the values of the input neurons through the neural network, resulting in the activation of the output neurons. The value generated by the output neuron *Time* is then used as a parameter to define the robot's movement speed. Figure 4, in turn, presents the interface of the *NEURAL NETWORK Learn* tab within the Open Roberta Lab platform, which is used for interactive and visual ANN training. In this environment, it is possible to configure and monitor the network learning process, including parameters such as learning rate, number of epochs, and error values during training.

In Figure 4, label (A) indicates the *learning rate*, defined as 0.0003, which is responsible for controlling adjustments to the network weights during training. Label (B) presents the control buttons that allow the user to start or pause the process. Label (C) corresponds to the *Epoch* field, which indicates the number of complete training cycles performed, while label (D) displays the *training loss*, a metric representing model error and guiding parameter adjustments. The reduction of this loss throughout the epochs indicates improvements in network performance. For better understanding, a tutorial demonstrating the process is available at: https://youtu.be/EBjnrR5blgk.

The ANNs implemented in Open Roberta Lab correspond to simplified supervised learning models in which network parameters are iteratively adjusted based on the minimization of an error function. The training process occurs through updates of synaptic weights, controlled by parameters such as the learning rate and the number of training cycles. Although the environment does not explicitly expose all mathematical details involved in the process, such as gradient-based optimization algorithms, it allows users to observe the effects of these updates through error reduction, providing an accessible representation of the network learning process. This simplified approach supports the initial understanding of fundamental ANN principles, even though it does not encompass the full complexity involved in more advanced AI models.

Thus, the ANNs implemented in Open Roberta Lab expand the pedagogical potential of the environment by enabling complex AI concepts to be explored in an interactive, visual, and progressive manner. By allowing students to build, train, and analyze neural models within a simulated environment, the platform supports the externalization of thinking and the understanding of the internal processes of intelligent systems, approaching the principles of explainability. From a constructionist perspective, this dynamic reinforces learning grounded in the creation of meaningful artifacts, experimentation, and reflection upon one's own actions (Papert, 1980). Consequently, the environment contributes not only to the technical understanding of AI, but also to the promotion of active learning, in which students assume a central role in the construction of knowledge.

Despite the demonstrated pedagogical potential, it is important to recognize the limitations of Open Roberta Lab as an environment for AI education. Since it is a simulator based on block programming and simplified neural network models, the platform may not fully represent the real complexity of systems used in contemporary AI applications. Although this simplification is pedagogically necessary, it may lead to a partial or overly reduced understanding of models, particularly regarding network architectures, data scale, and more complex training dynamics. In this sense, the abstraction promoted by the visual interface may limit students' understanding of deeper aspects related to algorithmic implementation and model performance. Therefore, the use of Open Roberta Lab should be understood as an introductory stage in AI education, requiring complementarity with other approaches and tools capable of expanding students' technical understanding and deepening their perspectives on intelligent systems.

METHODOLOGY

This study is characterized as qualitative and analytical in nature, focusing on the analysis of an educational artifact applied to AI education. The research does not involve direct application with participants; instead, it is grounded in the conceptual and pedagogical analysis of the Open Roberta Lab simulator, seeking to understand its potential as a mediating tool in the teaching and learning process of concepts related to XAI. According to Gil (2008), studies of this nature aim to deepen the understanding of educational phenomena through the interpretation of their constitutive elements, making them suitable for investigations that articulate theoretical and pedagogical dimensions.

In this sense, the analysis was conducted based on a structured theoretical-analytical protocol, in which the Open Roberta Lab simulator was systematically explored through the construction of usage scenarios involving block-based programming and XAI concepts. These scenarios were defined according to didactic situations representative of AI education, allowing observation of the environment's behavior according to the established criteria. This procedure ensured greater transparency and reproducibility of the analysis performed.

It is important to emphasize that, since this study consists of an analytical investigation based on simulated scenarios, the results do not allow for empirical generalizations, making further applied studies necessary for validation in real educational contexts. Nevertheless, the adopted procedure enables the replication of the analysis in other contexts or with different educational artifacts, thereby ensuring methodological consistency.

Methodological Procedures

The methodological procedures were organized into three main stages. Initially, a literature review was conducted focusing on three central axes: (i) AI in Education, aiming to understand the pedagogical challenges and possibilities related to the integration of AI into educational contexts; (ii) XAI, seeking to highlight strategies capable of facilitating the understanding of the internal processes of intelligent systems and reducing conceptual abstraction in teaching; and (iii) Constructionism, with emphasis on Seymour Papert's contributions, aiming to provide a theoretical foundation for pedagogical approaches grounded in the active construction of knowledge through artifacts.

In the second stage, the Open Roberta Lab environment was explored with emphasis on identifying its functionalities related to AI education, particularly those associated with neural network simulation and block-based programming development. During the exploration of the environment, scenarios involving motion control, sensor response, and neural network training were developed, allowing observation of the system's behavior under different configurations. These scenarios served as the basis for the application of the analytical criteria.

Subsequently, a qualitative analysis based on analytical categories (*content-oriented analysis*) was conducted on the simulator, seeking to establish relationships between its functionalities, the principles of constructionism, and the pedagogical demands of AI education, particularly regarding explainability and the reduction of conceptual abstraction.

Object of Analysis: Open Roberta Lab

The object of analysis in this study is the Open Roberta Lab robotic simulator, a block-based educational programming environment that enables the development and simulation of projects involving robotics and AI-related concepts. The choice of this environment is justified by its accessibility, the diversity of supported systems, and the integration of functionalities that enable the construction and visualization of computational models, including ANNs.

In this regard, the environment presents characteristics that make it particularly relevant for AI education within Brazilian Basic Education, such as its intuitive interface, the possibility of simulation without the need for physical hardware, and the availability of modules related to machine learning. These aspects allow Open Roberta Lab to be analyzed as a mediating artifact capable of operationalizing constructionist principles within educational contexts. Therefore, the unit of analysis in this study corresponds to the simulator's functionalities related to programming, robotic simulation, and ANN training, especially those that allow user interaction with parameters, model execution, and result visualization.

Analysis Criteria

The analysis of the simulator was guided by criteria grounded in the adopted theoretical framework, particularly constructionism and approaches to AI education. For each criterion, qualitative indicators were defined in order to observe how the environment's functionalities relate to the pedagogical principles discussed throughout the study. Thus, the evaluation was conducted from an interpretative perspective, considering observable evidence derived from the use of the simulator, without the application of quantitative metrics.

The following criteria were considered: (i) *Artifact Construction*, evaluated through the possibility for students to create and modify programs and models, highlighting the externalization of thought; (ii) *Interactivity and Experimentation*, analyzed through the environment's ability to support testing, parameter adjustment, and real-time observation of results; (iii) *Visualization and Explainability*, verified through support for representing and understanding the internal processes of ANNs; (iv) *Accessibility and Usability*, observed through the ease of use of the interface, the block-based programming language, and the possibility of use across different educational contexts; and (v) *Pedagogical Mediation*, analyzed according to the environment's potential to promote active learning, autonomy, and meaningful knowledge construction.

Thus, the criteria were operationalized through direct observation of the environment's functionalities within the defined scenarios and analyzed according to their presence, intensity, and mode of manifestation within the simulator. The intensity of each criterion was qualitatively assessed by considering the level of recurrence and centrality of the functionality within the environment. This operationalization enabled the articulation between the theoretical principles of constructionism and concrete evidence regarding the functioning of Open Roberta Lab, reducing the exclusively descriptive character of the analysis. Table 2 presents the analytical matrix used to evaluate Open Roberta Lab for AI education from a constructionist perspective.

Table 2. Analytical matrix for evaluating Open Roberta Lab in AI education from a constructionist perspective. Source: Developed by the authors (2026).

Criterion	Criterion	Criterion
Artifact Construction	Possibility for creating, modifying, and combining programs and models.	NEPO block-based programming; development of robotic projects; construction of ANN-based models.
Interactivity and Experimentation	Hypothesis testing, iterative adjustments, and real-time observation of results.	Robot simulation; immediate program execution; continuous adjustments to robot behavior.
Visualization and Explainability	Representation of internal processes and understanding of ANN functioning.	Neural network graphical interface; visualization of inputs, outputs, error (*training loss*), and training parameters.
Accessibility and Usability	Ease of use, intuitive language, and adaptability to different contexts.	Block-based interface; web-based environment without installation requirements; compatibility with multiple devices and educational levels.
Pedagogical Mediation	Promotion of active learning, autonomy, and meaningful knowledge construction.	Integration between programming, simulation, and AI; support for project-based learning and problem-solving.

Table 2 systematizes the analysis of Open Roberta Lab based on criteria aligned with constructionism and demonstrates that the environment presents strong coherence with principles of active learning mediated by artifacts. It can be observed that block-based programming and integration with simulation environments support the construction of digital artifacts, enabling students to externalize ideas and iteratively test solutions. The interactivity of the environment, combined with real-time execution, enhances experimentation and reflection upon results, while the ANN visualization resources contribute to reducing the abstraction of models and bringing them closer to an explainable perspective. Furthermore, the accessibility and usability of the simulator expand its applicability across different educational contexts, reinforcing its inclusive character. In this regard, the analyzed elements indicate that Open Roberta Lab functions as a consistent pedagogical mediator capable of articulating technological and constructionist foundations in AI education. Thus, the analytical matrix was applied to the defined scenarios, enabling the identification of analytical evidence derived from the simulated scenarios associated with each criterion.

RESULTS

The analysis of Open Roberta Lab, guided by the criteria established in the analytical matrix, revealed that the environment presents significant potential for AI education from a constructionist perspective. The results indicate that its functionalities support the active construction of knowledge, particularly by enabling students to develop, test, and modify digital artifacts iteratively, in alignment with constructionist principles (Papert, 1980).

Regarding artifact construction and interactivity, it was observed that the NEPO block-based programming language facilitates program development even for novice users, directing the focus of learning toward computational logic. Combined with real-time execution, this characteristic expands opportunities for experimentation and supports trial-and-error learning, considered essential for the development of computational thinking and the understanding of complex systems (Eguchi, 2014; Benitti, 2012). Furthermore, the iterative nature of the activities brings the learning process closer to the functioning of ANNs themselves.

With respect to visualization and explainability, the environment provides relevant support for understanding the internal processes of neural networks by allowing observation of parameters such as learning rate, epochs, and training loss. These resources contribute to reducing the "black-box" problem, making the models more transparent and promoting a more critical understanding of intelligent systems (Adadi & Berrada, 2018). Concerning accessibility and usability, Open Roberta Lab presents characteristics that facilitate its adoption across different educational contexts. As a web-based platform with an intuitive interface, the environment can be used by students with different levels of prior knowledge, contributing to the democratization of emerging technology education (Alves & Trindade, 2025).

Thus, regarding pedagogical mediation, the results indicate that Open Roberta Lab functions as an educational artifact capable of articulating theory and practice, promoting active and meaningful learning. The integration between programming, simulation, and AI concepts allows students not only to use intelligent systems, but also to understand their underlying operational principles. This characteristic reinforces the importance of environments that enable the construction and exploration of models, contributing to the development of AI literacy (Long & Magerko, 2020). Therefore, the findings demonstrate that Open Roberta Lab has strong potential as a pedagogical tool for AI education, particularly when articulated with a constructionist approach and the use of XAI. These results reinforce the need to integrate theoretical and technological foundations in the development of educational proposals capable of making AI education more accessible, understandable, and meaningful.

DISCUSSION

The results obtained from the analysis of the Open Roberta Lab simulator indicate that the environment is strongly aligned with constructionist principles and with contemporary demands in AI education. The possibility of constructing artifacts, combined with interactivity and experimentation, reinforces Seymour Papert's conception of active learning, in which knowledge is built more meaningfully when students are engaged in the creation and manipulation of objects that represent their thinking. In this sense, the simulator provides learning experiences that foster reflection, autonomy, and problem-solving.

Regarding AI education, particularly in the context of XAI, the findings demonstrate that the simulator contributes to reducing the abstraction of computational models, making their processes more accessible and understandable. This characteristic directly aligns with proposals for explainability discussed in the literature, which emphasize the need to make intelligent systems more transparent, especially in educational settings (Adadi & Berrada, 2018). By enabling the visualization of parameters and ANN behavior, the environment supports the understanding of AI internal mechanisms, contributing to the development of a more critical perspective regarding these technologies.

In this context, the integration between simulation and block-based programming highlights the potential of Open Roberta Lab as an inclusive educational tool capable of being implemented across different educational settings, including those with infrastructure limitations. This aspect is particularly relevant within the Brazilian context, where inequalities in access to technological resources still represent a significant challenge. Thus, the simulator emerges as a viable alternative for the democratization of AI education.

However, although the results indicate the pedagogical potential of Open Roberta Lab, it is important to emphasize that the conclusions of this study are grounded in a qualitative analysis based on analytical categories rather than empirical applications in real educational contexts. Therefore, future studies are needed to systematically investigate the use of the simulator in classroom environments, considering different student profiles, teaching strategies, and educational contexts. Such studies are essential for empirically validating the indications presented here, as well as for identifying possible limitations, implementation challenges, and effective impacts on learning outcomes. Additionally, future research may explore the application of Open Roberta Lab within structured didactic proposals, evaluating its contribution to the development of AI literacy, computational thinking, and the understanding of concepts related to XAI. Experimental or quasi-experimental studies, as well as qualitative investigations involving students and teachers, may provide more concrete evidence regarding the effectiveness of the environment.

CONCLUSION

This study aimed to analyze the foundations for an AI pedagogy grounded in XAI from a constructionist perspective, investigating the role of the Open Roberta Lab robotic simulator as a mediator in the teaching and learning process. Based on a qualitative analysis structured through analytical categories and supported by the articulation between AI, explainability, and constructionism, the study sought to understand how simulation environments can contribute to making AI education more accessible, meaningful, and aligned with contemporary demands in Computer Science Education.

The results indicate that Open Roberta Lab presents significant potential as a pedagogical resource, particularly by fostering active knowledge construction, experimentation, and the visualization of abstract AI-related concepts. The integration between block-based programming, robotic simulation, and XAI proved capable of reducing the complexity of computational models and promoting a more interactive and reflective learning process, in accordance with the constructionist principles proposed by Papert. In this regard, the environment contributes to the externalization of thinking, enabling students to progressively build, test, and understand the functioning of intelligent systems.

Thus, this study reinforces the importance of articulating pedagogical and technological foundations in the development of proposals for AI education, highlighting the role of XAI as a central element in promoting more transparent and critical learning experiences. In this sense, the findings demonstrate that simulators such as Open Roberta Lab can function as mediating tools, particularly in educational contexts characterized by infrastructure limitations, expanding access to constructionist practices and AI literacy.

However, it is important to emphasize that the findings of this study are based on a qualitative analysis structured through analytical categories and do not include empirical validation in real educational contexts. Therefore, future research should investigate the use of Open Roberta Lab in educational environments through experimental, quasi-experimental, or qualitative studies in order to critically analyze its impacts on learning, as well as its limitations and potentialities across different contexts.

Finally, it can be concluded that the Open Roberta Lab simulator, when articulated with a constructionist approach and the use of XAI, constitutes a promising alternative for AI education, contributing to the development of more accessible, investigative, and pedagogically meaningful practices aligned with the formation of critical individuals within contemporary society.

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