INTEGRATING MACHINE LEARNING AND EDUCATIONAL ROBOTICS: THE FRANKIE PLATFORM FOR TEACHING ARTIFICIAL INTELLIGENCE IN HIGH SCHOOL

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ABSTRACT

This study explores an experiment conducted at a tuition-free school in Rio de Janeiro, Brazil, aimed at introducing high school students to Artificial Intelligence (AI) concepts through their mathematical foundations. Eleven students participated in workshops designed to connect mathematics and AI by engaging with a Weightless Neural Network (WNN) algorithm – WiSARD. The scripted activities focused on the mathematical calculations involved in the algorithm's training and classification phases, enhancing students' understanding of machine learning (ML). The results showed that students grasped both the functioning of the WiSARD algorithm and the mathematical principles behind it. Additionally, the activities fostered reflection on ethical concerns related to AI, emphasizing developer responsibility and the importance of protecting personal data.

KEY WORDS

artificial intelligence in education; neural network; educational robotics; technologies in education.

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Integrando Aprendizado de Máquina e Robótica Educacional: A Plataforma Frankie para o Ensino de Inteligência Artificial no Ensino Médio

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RESUMO

Este estudo explora um experimento realizado em uma escola gratuita no Rio de Janeiro, Brasil, com o objetivo de introduzir estudantes do ensino médio a conceitos de Inteligência Artificial (IA) através de seus fundamentos matemáticos. Onze estudantes participaram de oficinas projetadas para conectar matemática e IA utilizando o algoritmo de Rede Neural Sem Peso (WNN) - WiSARD. As atividades programadas focaram nos cálculos matemáticos envolvidos nas fases de treinamento e classificação do algoritmo, aprimorando a compreensão dos estudantes sobre aprendizado de máquina (ML). Os resultados mostraram que os estudantes entenderam tanto o funcionamento do algoritmo WiSARD quanto os princípios matemáticos subjacentes. Além disso, as atividades promoveram reflexões sobre preocupações éticas relacionadas à IA, enfatizando a responsabilidade do desenvolvedor e a importância da proteção de dados pessoais.

PALAVRAS-CHAVE

inteligência artificial na educação; redes neurais; robótica educativa; tecnologias na educação.

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Integrando Aprendizaje Automático y Robótica Educativa: La Plataforma Frankie para la Enseñanza de Inteligencia Artificial en la Educación Secundaria

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Resumen

Este estudio explora un experimento realizado en una escuela gratuita en Río de Janeiro, Brasil, con el objetivo de introducir a estudiantes de educación secundaria en conceptos de Inteligencia Artificial (IA) a través de sus fundamentos matemáticos. Once estudiantes participaron en talleres diseñados para conectar las matemáticas e IA mediante el uso del algoritmo de Red Neuronal Sin Peso (WNN) – WiSARD. Las actividades programadas se centraron en los cálculos matemáticos involucrados en las fases de entrenamiento y clasificación del algoritmo, mejorando la comprensión de los estudiantes sobre el aprendizaje automático (ML). Los resultados mostraron que los estudiantes comprendieron tanto el funcionamiento del algoritmo WiSARD como los principios matemáticos subyacentes. Además, las actividades fomentaron reflexiones sobre preocupaciones éticas relacionadas con la IA, enfatizando la responsabilidad del desarrollador y la importancia de la protección de los datos personales.

Palabras clave

inteligencia artificial en la educación; redes neuronales; robótica educativa; tecnologías en la educación.

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Integrating Machine Learning and Educational Robotics: The Frankie Platform for Teaching Artificial Intelligence in High School

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INTRODUCTION

Many people use devices with Artificial Intelligence (AI) without understanding how these technologies evolve through interaction with humans, their environment, and the data collected. This lack of awareness is common, with most users not realizing how these interactions improve intelligent systems. Basic education is critical in addressing this gap, offering an opportunity to introduce AI fundamentals. Programming, often taught through educational robotics, has become a key method for integrating computer science into elementary and high school education, serving as a pathway to AI literacy (Bellas & Sousa, 2023; Castro et al., 2018; Negrini et al., 2023; Ng et al., 2024).

This study explores the potential of educational robotics and artificial intelligence (AI) in teaching high school students introductory AI concepts. It is guided by the central research question:

How do the Weightless Neural Network (WNN) WiSARD, the Frankie Platform (Fostering Reasoning and Nurturing Knowledge through Informatics in Education) and the teaching strategies employed impact high school students' understanding of introductory AI concepts?

To address this question, the project designed a series of workshops that engaged students in diverse activities, including pencil-and-paper exercises, collaborative problem-solving using Google Colab[2], and hands-on interactions with Frankie, an educational robotic platform developed specifically for this research. These activities aimed to teach core concepts such as creating databases, training and classifying data, and testing the accuracy of pattern recognition systems.

The workshops were grounded in Vygotsky's theory of learning (2019), which emphasizes the importance of tools and social interactions in knowledge acquisition. Drawing on these principles, the study utilized peer collaboration, technological tools, and robotic interaction to support students in advancing from their current developmental level to their potential. These approaches were carefully integrated to create a robust and engaging learning experience.

Central to the project was the Frankie robot, which was designed to motivate students and foster teamwork. Frankie is equipped with cameras, ultrasonic sensors, motors, and mobility wheels, all powered by a Raspberry Pi microcomputer. The platform supports both electronic prototyping and Python programming, and it incorporates the WiSARD algorithm, a Weightless Neural Network (WNN) used for pattern recognition. By

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[2] https://colab.google/

simulating intelligent behaviour, Frankie provided students with real-world challenges that encouraged critical thinking and problem-solving.

This study also aimed to integrate AI into the high school curriculum through a multifaceted approach. The development of the Frankie platform and its associated activities introduced students to machine learning concepts in a hands-on manner. Workshops were designed to teach these concepts through scripted activities and interaction with the robotic prototype. The effectiveness of these workshops was evaluated to assess their impact on student learning and engagement.

The project aligns with the broader educational potential of robotics in computer science education, as highlighted by prior research (Altin & Pedaste, 2013). By combining unplugged exercises, collaborative coding tasks, and robotic interaction, the initiative sought to make AI concepts accessible, engaging, and relevant for high school students, thereby enhancing their understanding of this transformative technology.

RELEVANCE OF THE STUDY

The innovative aspect of this research lies in its fusion of educational robotics, pedagogical strategies, and simplified neural network modelling to create a unique, hands-on learning experience. Rather than relying on traditional, abstract approaches, this study leverages interactive robotics to make concepts like weighted connections, feedback loops, and learning algorithms more intuitive. Students program robots to perform tasks such as pattern recognition or decision-making, directly visualizing the principles of input, processing, and output. It is expected that this tangible interaction promotes active learning, fostering a deeper and more practical understanding of neural networks while integrating seamlessly with STEM education.

REVIEW OF THE LITERATURE

ROBOTICS IN EDUCATION

Educational robotics has gained significant attention as a practical and engaging tool for teaching artificial intelligence (AI). Platforms such as LEGO Mindstorms, Arduino, and VEX Robotics are commonly used to introduce students to Core AI principles, including machine learning, computer vision and natural language processing.

Research by Eguchi (2022, 2023) highlights how robotics fosters computational thinking and creativity while offering an intuitive understanding of complex systems. The author positions Educational Robotics (ER) as a pedagogical tool that transcends technical skills like programming and engineering, offering students opportunities to construct and control mechanical devices through computers. ER has been shown to motivate students, particularly by fostering an interdisciplinary learning environment where they can engage with scientific and mathematical concepts. This approach enhances interaction with their surroundings and has gained recognition for its role in teaching computer science.

Similarly, Su and Yang (2022) present some research with young learners exploring programming and AI integration, promoting experimentation and problem-solving. These projects demonstrate that robotics not only makes AI more accessible but also encourages active engagement through hands-on activities.

Beyond technical skills, educational robotics serves as a platform for interdisciplinary learning and ethical reflection. Projects like the Open Roberta Lab, which integrates AI concepts into robot design and programming, enable students to explore real-world applications while discussing AI's societal and ethical implications. This approach aligns with findings from Mubin et al. (2013), who emphasize the importance of robotics in developing critical thinking and preparing students for AI-driven futures. By bridging theoretical knowledge with practical application, robotics provides an innovative pathway for teaching AI, connecting computer science with other disciplines such as ethics, biology, and even the arts. As educators and researchers continue to refine these methods, educational robotics remains a powerful tool to inspire and equip the next generation of AI innovators.

In addition to academic benefits, ER contributes to the development of social skills, such as communication, empathy, and collaboration, which are essential in the 21st century (UNESCO, 2014, n.d.). These activities align with Vygotsky’s theories, promoting collaborative learning and dialogue. As ER becomes more integrated into school curricula, it supports project-based learning, where students interact socially and engage in peer learning, fostering the emergence of Vygotsky’s Zone of Proximal Development (Kozulin, 2004).

ROBOTICS AND AI EDUCATION

According to Grubišic and Crnokić (2024) educational robotics tools, such as programmable kits and AI-enabled robots, have demonstrated their capacity to simplify complex AI concepts for learners. For instance, these tools allow students to build and program robots, providing tangible results from their coding and algorithmic endeavours.

In higher education, robotics enhances collaborative and inquiry-based learning environments, bridging the gap between AI theory and practice (Phokoye et al., 2024). Researches presented here show the advantages of robotics in promoting engagement and motivation, especially when tackling advanced AI topics like neural networks and natural language processing. Additionally, robotics fosters interdisciplinary learning by integrating fields like mathematics, physics, and computer science into a unified educational experience.

Recent studies on literature reviews in educational robotics (Memarian & Doleck, 2024; Wang et al., 2024; Yim & Su, 2024) highlight a growing body of work focused on teaching artificial intelligence topics, particularly through tools like ChatGPT. However, these articles found a notable gap in research specifically addressing the learning of neural networks, especially the application of Weightless Neural Networks. This observation underscores the need for further exploration of these advanced AI concepts within educational robotics contexts.

In contrast, the Frankie Platform adopts a unique approach. It helps students grasp AI concepts through hands-on activities using the Python programming language and a Weightless Neural Network (Aleksander et al., 2009)

The activities proposed are grounded in different concepts from Mathematics and Physics giving to the students the opportunity to work in an interdisciplinary way.

WISARD WEIGHTLESS NEURAL NETWORK AND FRANKIE PLATFORM

WiSARD is a model of Machine Learning, specifically a type of WNN designed for pattern classification. It is based on Random Access Memory (RAM) and operates as a single-layer neural network (Carneiro et al., 2010). Its simplicity and efficiency come from requiring fewer operations during training and classification, making it lightweight and easy to execute (Aleksander et al., 2009).

WiSARD's operations are mainly based on binary logic, making it accessible for high school students who have basic knowledge of mathematical operations like percentages and binary image representation. Key skills required include pattern recognition, combinatorial thinking, and understanding random processes. The model comprises several important components:

- *Retina*: A matrix of binary pixels (m x p), where the image patterns are reshaped into a vector of k pixels.
- *Tuples*: Ordered sets of n bits, randomly selected from the image pixels.
- *Neuron*: Each neuron in the Weightless Discriminator Device (WDD) functions as a RAM unit, receiving n-bit tuples as input, and having 2^n memory locations.
- *Discriminator*: A single-layer network of N RAM neurons, each learning and recognizing subsets of a pattern linked to a specific class.
- *Adder*: This computes the similarity between the input and learned pattern, helping identify the correct class (Nurmaini et al., 2009).

WiSARD is a supervised neural network, meaning each training pattern is assigned to a specific class (Carneiro et al., 2010; Queiroz et al., 2021). During training, the Discriminator updates neurons based on the binary input pattern. Initially, each neuron's memory content is set to zero, and during training, the memory address—determined by the randomly chosen n bits from the pattern—is incremented.

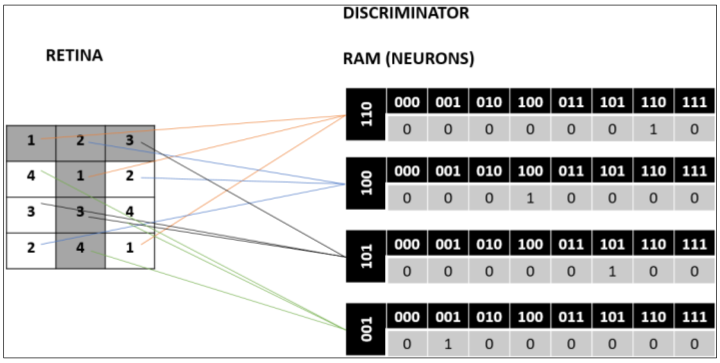
For example, in a case with a retina of 12 pixels and an input pattern of 3 bits, the Discriminator is made up of 4 neurons, each containing 2^3 memory addresses. Dark pixels on the retina are represented by 1, and light pixels by 0. When a tuple consisting of two dark pixels and one light pixel is processed, the memory address of the first neuron is updated from 0 to 1. This process continues for the other tuples, allowing the Discriminator to learn the pattern associated with a particular class.

WiSARD's ability to classify patterns with such simplicity, combined with its use of binary operations, makes it particularly useful in educational contexts, especially for introducing students to AI and machine learning concepts.

Figures 1 and 2 present two possible approaches for training the representation of the letter T in uppercase.

Figure 1

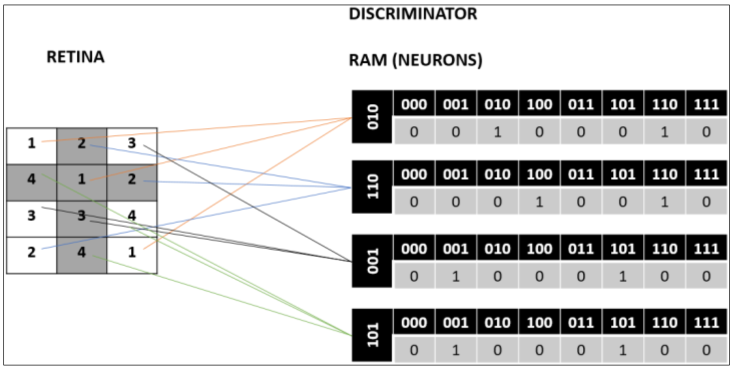
Discriminator of the "T" label with 8-bit memories - First training stage



Source: Authors.

Figure 2

Discriminator of the "T" label with 8-bit memories - Second training stage



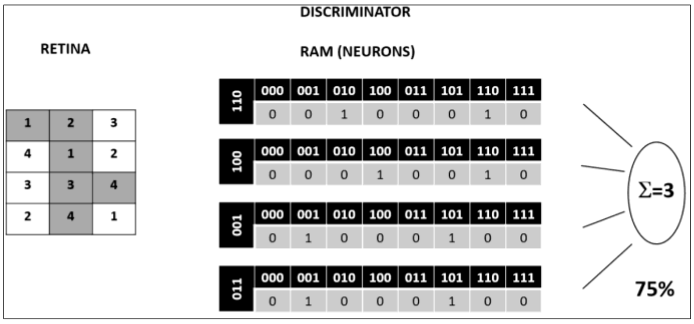
Source: Authors.

CLASSIFICATION PROCESS

In the classification phase (Figure 3), the neurons' addresses are derived from pixel tuples, following the same process used during training. The new label is input into the trained Discriminator, which uses a similarity measure to classify it. This measure is calculated by the Adder, which counts the number of neurons whose memory positions are addressed by the pixel tuples (Carneiro et al., 2010). The final value from the Adder represents the Discriminator's output.

Figure 3

Classification of the trained label in Figures 1 and 2 - 75% trust



Source: Authors.

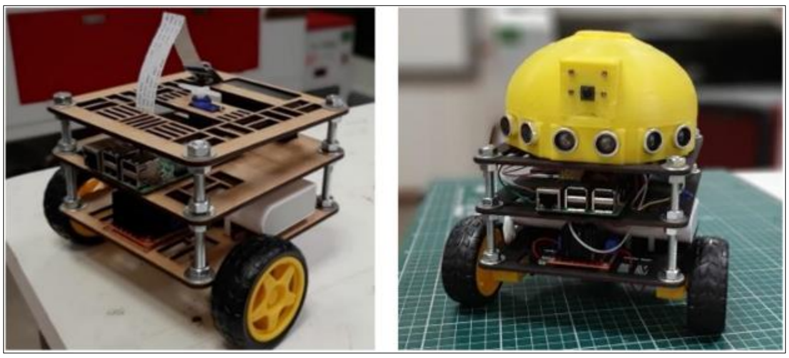
For each tuple, the neuron's memory content at the addressed location is evaluated. If the memory contains a 1, the neuron outputs 1; otherwise, it outputs 0. The classification confidence is determined by the ratio of the Adder's output to the total number of neurons. This ratio, referred to as "Trust," reflects the probability that the classified label matches the trained one.

FRANKIE PLATFORM: ROBOTIC DEVICE

The Frankie platform is an innovative example of integrating Educational Robotics (ER) with Artificial Intelligence (AI), assisting students connect theoretical concepts to real-world applications. ER allows students to experiment with real-life simulations, addressing contemporary challenges such as industry innovations and safe human-machine interactions. The Frankie robot achieves this through the use of Machine Learning algorithms, specifically WiSARD, alongside sensors and actuators, enabling interaction with its environment (Figure 4).

Figure 4

Frankie Robotic Device



Source: Authors.

Hardware Components - Frankie's hardware is designed to be easily replicable, with a total cost of around $125. The robot detects objects and classifies pre-trained images to autonomously make movement decisions. The robot is powered by a Raspberry Pi 3, a compact single-board computer with a 1.2GHz quad-core processor, 1GB of RAM, and 64-bit instruction support. The Raspberry Pi allows for real-time execution of Python scripts and connects to external peripherals like a monitor or keyboard via HDMI and USB ports.

Frankie Robotic Device Code - The Frankie robotic device is operated by a Raspberry Pi 3, a single-board minicomputer with a compact form factor, approximately the size of a credit card. It is equipped with a 1.2GHz quad-core processor, supports 64-bit instructions, and has 1GB of RAM. These specifications allow real-time execution of Python scripts, facilitating efficient computation and image processing. Peripheral devices such as a monitor, keyboard, and mouse can be connected to the Raspberry Pi via HDMI and USB ports.

The Raspberry Pi's GPIO ports are programmatically controlled through Python code, enabling interaction with both the device's actuators and sensors, as well as configuring parameters related to image classification. The system captures images using the device's camera, which are processed using the OpenCV library (Yang, 2023).

OpenCV provides functionality for converting captured images into input vectors for neural networks by transforming them into matrices with values between 0 and 255. These matrices are then converted into binary vectors using Python's flatten function.

Interaction with Students - The Frankie platform allows students to customize various aspects of the WiSARD Neural Network, including the number of tuple addresses, neurons in the Discriminator, and the resolution of the images for classification. Robotic parameters like motor speed and ultrasonic sensor distance can also be adjusted to optimize interactions between the robot and its environment.

Students access Frankie's control interface remotely via VNC Viewer, allowing them to adjust system settings on the Raspberry Pi. The terminal interface provides a range of customizable variables, enabling students to explore both robotics and AI in tandem.

The code allows configuration of key parameters like the optimal distance for object classification, motor speed, retina dimensions for image processing, the number of tuple elements (which define memory allocation for neurons), and the "Trust" variable, which indicates the classification confidence.

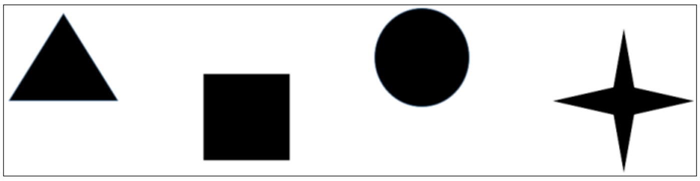
The main interactions with the platform are:

- The determination of the optimal distance between the image to be classified and the robotic device.
- The adjustment of engine speed and duration of movement.
- The specification of the dimensions of the retina, given its square configuration.
- The selection of the number of elements in the tuple, which dictates the number of memory addresses allocated to each neuron.
- The definition of "Trust," which quantifies the percentage of confidence that the classified label corresponds to the trained image.
- The parameters, configured by default in the code, facilitate the training of four distinct classes of labels. For example, Class 1 - triangle; Class 2 - square; Class 3 - circle; and Class 4 - star, as illustrated in Figure 5.

During workshop activities, students produced black images on white paper and had the opportunity to create additional images for the training phase, followed by subsequent classification tasks.

Upon classification, each image was associated with specific actions for the robotic device. For instance, as depicted in Figure 5, if the code identified an image as a triangle, the robot would advance forward. In contrast, if a square was classified, the robot would execute a right turn. Similarly, a classification of a circle would prompt the robot to turn left, while identifying a star would cause the robot to move backward.

Figure 5
WiSARD Trained Images



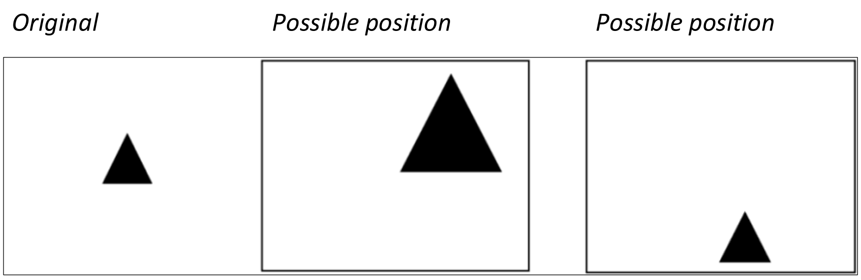
Source: Authors.

Students had the flexibility to modify the definitions of the trained labels and the corresponding actions of the robotic device based on the results of the label classification.

Additionally, the code was configured to display an error message if none of the predefined images were detected. Students could also set the accuracy threshold for image identification, allowing the robot to accept an image as a match if it meets the specified confidence level.

Challenges in Implementing the Code - One of the main challenges during the project was interpreting images captured by the webcam. The proximity of objects to the camera affected their size, meaning an object closer to the camera appeared larger than one further away. Additionally, different object positions led to varying interpretation results. For example, a single image in the camera frame could yield different outcomes depending on its distance and position (Figure 6).

Figure 6
Images- varying interpretation results

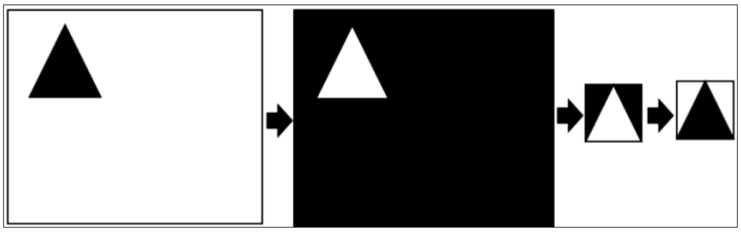


Source: Authors.

To address this challenge OpenCV library resources were utilized, particularly the findContours function, which detects white shapes on a black background. In the Frankie system, this function isolated geometric shapes from the binarized and inverted image captured by the robot. The cropped image was then resized to standard dimensions, ensuring uniformity regardless of the object's distance from the camera.

After resizing, the image was inverted again before being processed by the WiSARD algorithm. These steps allowed the code to consistently work with a standard-sized image, and positioning was stabilized by defining a square around the shape (Figure 7).

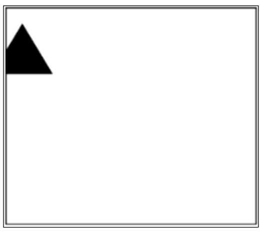
Figure 7
Treatment steps



Source: Authors.

However, two issues persisted. First, if the image was outside the camera frame, it could not be recognized (Figure 8). Second, low-contrast images posed challenges since they could be interpreted as white. The first issue can be resolved by training the WiSARD algorithm to recognize partial images, though this was not implemented. The second challenge, with light images, can be addressed through dynamic thresholding, adjusting the threshold during binarization to improve contrast detection.

Figure 8
Example of capturing the image outside the camera frame



Source: Authors.

Frankie Platform: Teaching and Learning Strategies - The workshops developed within the Frankie Platform were carefully designed to engage students as active participants in their learning process. The resources and activities integrated into the workshops were as follows:

- *Interactive Video Classes*: Video classes were employed as an educational tool across various contexts. To teach the Weightless Neural Network (WNN) WiSARD, an interactive video lesson was utilized through the Edpuzzle platform. Edpuzzle fosters active learning by allowing students to engage with content through interactions such as video segmentation, voice-recorded commentary, and embedded assessments, which can be accessed by educators to track student progress.
- *Unplugged Activities*: These were designed to introduce main concepts of the WiSARD WNN without requiring the use of computers. They allowed students to understand abstract concepts through hands-on activities.
- *Google Colab Collaboration Platform*: Google Colaboratory (Colab) is a cloud-based platform based on Jupyter Notebook, enabling collaborative teaching and research in Machine Learning. Similar to Google Docs, Colab allows users to share and co-edit notebooks, and supports Python 2 and 3. It also provides native libraries such as OpenCV for computer vision, as well as tools for Artificial Intelligence and Machine Learning like TensorFlow and Matplotlib.
- *Native Codes*: Python was the programming language used in the activities. No prior programming experience was required, as codes were provided via the workshop's website, http://bit.ly/FrankieLabZero. Three main "Native Codes" were utilized:
    - Native Code 1, developed by Lima Filho et al. (2020), available on GitHub, is a Python version of the WiSARD library used for training and classifying labels based on binary vectors.
    - Native Code 2 builds on the first code, adding functions for image processing and converting images into binary vectors using OpenCV.
    - Native Code 3 links Native Code 2 to the robotic components of the Frankie device, enabling its operation in the environment.
- *Frankie Robotic Prototype*: The Frankie robot was the central tool in the workshops. It enabled students to interact with a robot capable of learning to identify images using WiSARD and making decisions based on its learning. By transitioning from abstract concepts to tangible applications, students could observe the robot's behaviour in real-time, experiencing the outcomes of training success or failure, which could lead to incorrect classifications or unexpected actions by the robot.

Skills and *Competencies Covered in the Workshops* - The workshops aimed to equip students with the competencies necessary to configure the WiSARD WNN embedded in the Frankie Platform, particularly to optimize the Trust percentage when classifying images. The content covered in the workshops included the following key concepts:

- *Retina Definition*: Understanding the structure and purpose of the retina in WiSARD.
- *Pixel Count in the Retina*: Learning the importance of pixel numbers in image classification.
- *Binary Image Representation on the Retina*: How binary images are represented for processing.
- *Transformation of Binary Matrix into Input Vector*: Converting binary matrices into input vectors for classification.

- *Tuples as Ordered Sequences*: Understanding how retinal elements are organized into tuples.
- *Random Tuple Selection*: The randomness involved in selecting tuple elements.
- *Neurons as Random Access Memory (RAM)*: Understanding how neurons function within WiSARD.
- *Memory Locations*: The significance of memory locations in neurons.
- *Tuple Element Count and Memory Addresses*: Exploring the relationship between tuple elements and memory addresses.
- *Discriminator and Neuron Count (RAM Nodes)*: Understanding how discriminators classify patterns based on the number of RAM nodes.
- *WiSARD Training*: How the WiSARD neural network is trained to recognize patterns.
- *Classification and Generalization*: How classification and generalization are achieved through RAM nodes.
- *Trust in Classification*: Understanding and optimizing the Trust percentage during classification.

Each workshop had structured objectives, and activities were designed to meet these objectives through unplugged exercises, programming tasks using the Google Colab platform, and interactions with the Frankie robot. The integration of material resources, peer collaboration, and instructor mediation was intended to establish Zones of Proximal Development (ZPD) (Vygotsky, 2007), enabling students to reach their potential development level by the end of each workshop. Upon completing the five workshops, students' real development level would be reflected in their ability to configure the WiSARD WNN for image classification tasks with an optimal Trust percentage.

METHODS

This research adopts an exploratory descriptive approach focused on a single case study. The primary objective is to develop strategies for teaching Artificial Intelligence at the high school level by incorporating Machine Learning and Educational Robotics through exploratory workshops. These workshops utilized scripted activities and educational technologies. Due to the specific and focused nature of the research, it is classified as a case study.

A case study approach allows for both qualitative and quantitative analyses, making it suitable for examining a specific individual, group, or phenomenon. It is particularly useful for addressing "how" or "why" research questions related to contemporary themes, particularly in educational research (Cohen et al., 2018). In this study, a qualitative method was adopted, focusing on participant actions during activities within an interactive framework. Qualitative research seeks to deepen the understanding of social dynamics, aiming to explain and interpret social relationships rather than quantifying them (Cohen et al., 2018).

In the realm of educational technology research, Johnson (1995) asserts that qualitative methods are vital for understanding how educational tools are utilized in practice, rather than merely providing superficial examinations. These methods enable researchers to grasp the social, psychological, and environmental factors that influence the teaching and learning process.

EXPERIMENTAL PROCEDURES

To achieve the study's objectives, five workshops were developed, scheduled over consecutive weeks. Each workshop was structured around scripted activities designed to help students understand the functionality of the WiSARD Weightless Neural Network (WNN), focusing particularly on training and classifying tasks.

To support the workshops, a website was created containing all the scripted activities[3]. The researcher, who is also the author of this study, acted as the instructor and mediator throughout the sessions.

The teaching and learning strategies employed in each workshop were designed to establish Zones of Proximal Development (ZPD), a concept articulated by Vygotsky (2007). These strategies, including scripted activities, technological tools, peer interactions, and teacher mediation, were central to fostering student development. The workshops aimed to help students acquire knowledge they could achieve with appropriate guidance and support.

According to the theoretical framework underlying the workshops, students were expected to have an initial Real Development Level, which served as a foundation for building ZPDs. These ZPDs would facilitate the learning of essential Machine Learning concepts, particularly related to the WiSARD WNN. The Real Development Level encompassed the students' ability to independently perform basic mathematical operations, such as percentage calculations, recognize binary image representations, and demonstrate skills in pattern recognition, combinatorial thinking, and randomness.

SAMPLE

A total of 11 students, aged between 14 and 16, participated in the workshops. The group consisted of 3 girls and 8 boys, all enrolled in a tuition-free high school residency program in Rio de Janeiro. Of these students, 8 were in their first year, and 3 were in their second year of high school. None of the participants had prior knowledge of Machine Learning or experience with Python programming.

DATA COLLECTION

Fischer and Guzel (2022) emphasize that rigorous data collection procedures, including the use of tools such as recorded data, transcriptions, and carefully documented conditions, are crucial for maintaining the credibility and reliability of research. In this

[3] http://bit.ly/FrankieLabZero

qualitative study, data collection focused on observing and interpreting participant behaviour within context, identifying key themes for exploration (Patton, 1990).

Denzin and Lincoln (2011) say triangulation of information sources is essential when using multiple methods of data collection providing a multidimensional view of reality, allowing researchers to explore competing visions of a context through simultaneous rather than linear narratives.

In this study, four strategies were employed to link student attitudes, opinions, and learning outcomes, and these were later triangulated to present the results:

- *Scripted Activities*: The scripted activities included directed study exercises and learning assessments, administered in both written and digital formats through online platforms. In Workshops 1 and 2, students completed written exercises, which were collected for evaluation. In Workshop 2, students also engaged in online activities via the Google Colab platform, allowing the researcher to assess their performance. The scripted activities for Workshop 3 were conducted exclusively online, and in Workshops 4 and 5, students interacted with the robot to assess their ability to configure WiSARD WNN parameters. These activities also involved evaluating the robot's performance in image training and classification.
- *Field Diary*: As recommended by Lofland and Lofland (1984), the researcher compiled detailed field notes after each workshop to document the development of the activities. These reports captured observations regarding student behaviours, interactions, and responses during the activities, aiding in the analysis of the workshops.
- *Video Recording of the Workshops*: In addition to field notes, video recordings were used to capture the complexity of student actions. This strategy allowed for later review and provided further clarification of student behaviours during the activities.
- *Robot Code Parameter Configuration*: The Frankie Platform offered various programming tasks that involved interactions between the robotic device and its environment. For these introductory AI workshops, Native Code 3 was used to interact with the robot, allowing students to apply the Machine Learning concepts learned. The percentage of accuracy in label classification (Trust scores) reflected the students' understanding of WiSARD WNN configurations, which enabled the robot to make appropriate decisions when recognizing images.

ETHICAL PROCEDURES

The research was approved by the Brazilian Ethical Committee (CEP/CONEP- Plataforma Brasil) under number CAAE 28570820.5.0000.5257 on March 4, 2020.

WORKSHOPS: DETAILS, ANALYSIS AND RESULTS

WORKSHOPS DETAILS

The teaching and learning strategies implemented in each workshop were designed to foster the development of the Zone of Proximal Development (ZPD). This developmental process relied on the use of scripted activities, technological resources, and the interactions between peers and between students and the teacher-mediator. The main goal of the workshops was to support students in gaining knowledge they could attain with appropriate guidance and assistance.

The instructional strategies were supported by the Frankie Platform website. Workshop outcomes were analysed based on data collected from scripted activities, entries in the field diary, and video recordings of the sessions.

The course was structured into five thematic workshops, delivered over seven in-person sessions, each lasting 90 minutes, for a total of 10.5 hours of activities. The themes and the allocated time for each are as follows:

- Workshop 1: Introduction to the WiSARD Weightless Neural Network (WNN) through interactive video lessons and scripted activities (180 minutes).
- Workshop 2: Introductory activities with WNN WiSARD in Google Colab (90 minutes).
- Workshop 3: Activities using WNN WiSARD and the OpenCV library in Google Colab (90 minutes).
- Workshop 4: Interaction with the Frankie robotic device (90 minutes).
- Workshop 5: Training and classification tasks using the Frankie robotic device (180 minutes).

WORKSHOPS ANALYSIS AND RESULTS

Bogdan and Biklen (2006[1982]) describe qualitative data analysis as the process of organizing information into manageable units, synthesizing data, identifying patterns, and discovering significant findings. Using the data collected through the outlined methods, the researcher identified specific objectives for each workshop, facilitating the interpretation of student actions, the clarification of procedures, and the assessment of learning outcomes (Versuti et al., 2019).

To effectively convey the evaluation results, four performance levels were established, each associated with color-coded proficiency bands. These levels, as shown in Table 1, correspond to the average percentage of correct responses from students in each workshop:

Table 1

Levels of correct responses

Achieved Goals	Considered Proficiency
90% – 100%	Fully Achieved
80% – 90%	Achieved
50% – 80%	Partially Achieved
0% – 50%	Not Achieved

An objective was considered unmet if the average percentage of correct responses was below 50%. If the percentage was between 50% and 80%, the objective was classified as partially achieved, indicating that students demonstrated only a limited understanding of the content. If the percentage was above 80%, the objective was considered achieved, although additional support from the teacher-mediator might still be necessary for some tasks. A percentage exceeding 90% signified that the students had fully attained the objective, demonstrating a comprehensive understanding of the material.

The workshops aimed to introduce artificial intelligence (AI) concepts into basic education through the integration of Machine Learning and Educational Robotics. Each workshop included specific activities, observations on student behaviour, and an evaluation of their learning outcomes.

Workshop 1

Workshop 1 consisted of five exercises, delivered over two sessions, each lasting 90 minutes. The first exercise was an interactive video lesson on the Edpuzzle platform, specifically created to introduce students to the WNN WiSARD. The video lesson, accessible at https://edpuzzle.com/join/mevnubn, engaged students with queries related to the topic, allowing them to enhance their understanding through interactive content.

The second exercise reinforced the terminology of the WNN WiSARD components. Exercise 3 focused on selecting a training label, where students, working in pairs, could choose between the letters A and T, each representing different patterns. In Exercise 4, students engaged in the training process. Finally, Exercise 5 involved a classification task, where students evaluated the percentage of confidence in their image classification results.

Performance Analysis

During the training exercise, students successfully represented tuples in memory addresses. In the classification task, two students required assistance with associating retinal tuples with the labels used during training and classification. Additionally, some students faced challenges understanding two specific concepts: the relationship between generalization and the random selection of tuple elements, and the link between the number of tuple elements and the number of neurons. With the guidance of the teacher-mediator, these students overcame their difficulties and completed the exercises successfully.

Interestingly, six students proposed using a formula to calculate the number of neurons in the WNN WiSARD, despite this concept not being covered in the video lesson. By the end of Workshop 1, all students were able to participate in the unplugged training activities and label classification.

Table 2

Degree of proficiency students achieved concerning the objectives set for Workshop 1

Workshop 1 – Objectives	**Proficiency Level**
Comprehend the nomenclature of the fundamental components of the WNN WiSARD	Fully Achieved
Recognize the concept of a Retina and its composition of m × p binary pixels	Fully Achieved
Grasp the definition of a tuple and understand the rationale behind the random selection of its elements	Achieved
Infer how the random selection of tuple elements and their total number influence the WiSARD's generalization	Achieved
Understand the role of neurons in WiSARD's weightless neural network and how they function as random access memory	Achieved
Execute offline exercises involving label training and classification of new labels to assess classification accuracy	Achieved

The results from Workshop 1 demonstrate that the use of interactive video lessons, scripted activities, and teacher-mediator interventions effectively promoted the development of students' ZPD. Students were able to devise strategies to solve tasks they had previously struggled with independently, showing their potential for problem-solving.

The field diary entries, video recordings, and scripted activity results revealed that all students made significant progress in understanding key concepts related to WNN WiSARD. Their development was particularly evident in their ability to comprehend abstract mathematical concepts and apply them to AI-related tasks. Two students initially encountered difficulties in grasping the generalization process and the relationship between tuple elements and neurons, but with teacher guidance, they succeeded in completing the exercises.

Overall, the professor-researcher concluded that the objectives set for Workshop 1 were successfully achieved. The students demonstrated a strong grasp of the foundational concepts of the WiSARD Weightless Neural Network, setting the stage for more advanced topics in subsequent workshops.

Workshop 2

Workshop 2 facilitated students' acquisition of new knowledge by introducing the WiSARD Weightless Neural Network (WNN) in a collaborative programming environment, Google Colab. This marked a shift from unplugged activities in Workshop 1 to a digital platform, enabling students to programmatically replicate the training and classification exercises they had previously conducted manually using Native Code 1. Students entered vectors representing training and classification labels, reinforcing the foundational knowledge they had developed in the first workshop.

This transition helped to establish a new Zone of Proximal Development (ZPD) for students, allowing them to build on their prior understanding while using the available digital resources. The workshop consisted of eight exercises designed to deepen students' knowledge of the WNN WiSARD model.

In Exercise 1, students transformed a label (the letter "T" in a 3x4 Retina) into a matrix and then into a vector of binary elements. Exercise 2 introduced students to the Google Colab environment, where they accessed and engaged with Native Code 1. Exercise 3 involved the installation and importation of the WiSARD library within Google Colab. In Exercise 4, students transformed two additional labels (the letters A and F) into matrices and binary input vectors, processing this within Google Colab's cells. Exercise 5 required students to define the number of tuple elements to determine the number of neurons in the Discriminator.

In Exercise 6, students converted classification labels into binary vectors and incorporated them into the existing code. Exercise 7 involved training the labels from Exercise 4 using WiSARD and then classifying the labels from Exercise 6. Lastly, in Exercise 8, students assessed the trust value of the classifications produced by the system.

Performance Analysis

The exercises allowed students to realize that the random selection of tuple elements, previously performed manually in Workshop 1, was now automated by the implemented code. This marked an important step in the students' understanding of the programming process.

The code used to define the number of addresses for each neuron introduced students to the concept of using 24 elements in a tuple, which would generate one neuron with 224 addresses. Two students observed that generating only one neuron could reduce the system's generalization ability, highlighting their growing comprehension of neural network operations. Additionally, students learned that using a different divisor, such as 4, for the tuple elements would generate 6 neurons for the Discriminator, each containing 16 memory addresses. This demonstrated their capacity to apply learned concepts to new situations.

The WiSARD code efficiently classified the input vector, enabling students to observe how processes that required significant manual effort in Workshop 1 were now automated. By experimenting with tuples containing different numbers of elements, students verified the outcomes and consolidated their understanding.

All students successfully completed the initial scripted activity, which involved converting matrices of images, composed of black and white pixels, into binary vectors of zeros and ones. Four students initially experienced difficulties accessing the Google Colab platform, but with assistance from the instructor-mediator, these issues were quickly resolved. Every student transcribed the provided code into the Google Colab notebook, distributing it across ten cells to complete tasks ranging from library imports to training and classification processes.

Six students, who lacked prior experience with Python, encountered challenges related to code indentation, which caused interruptions in the workflow. However, the instructor-mediator’s interventions and peer support helped them resolve these issues and continue the activities successfully.

During the training and classification exercises, students modified the vectors and adjusted the number of tuple elements without difficulty. Associating labels with their corresponding vectors emerged as a crucial phase in the learning process, enhancing students’ ability to apply WiSARD within a programming environment.

By experimenting with different numbers of tuple elements, students directly connected the work they had done in Workshop 1 to the tasks in Workshop 2. They also adjusted the number of tuple elements and worked with labels, training, and test vectors directly in the code. As Workshop 2 did not provide a simplified interface, all these adjustments were made manually in the notebook cells, further strengthening students’ programming skills.

By the end of the workshop, students had demonstrated a strong familiarity with the programming environment and gained proficiency in using WiSARD within Python.

Table 3

Degree of proficiency achieved by students concerning the objectives of Workshop 2

Workshop 2 – Objectives	**Proficiency Level**
Create labels in Retinas, convert these labels into vectors of zeros and ones, and use them for training and classification in Python	Fully Achieved
Install and import the WiSARD library on Google Colab, following Python’s indentation rules, and share the notebook with a partner	Achieved
Understand the process of inserting training and classification vectors, associating labels with their vectors, and using the WiSARD library to classify them	Achieved
Modify the number of elements in the tuple and assess how this adjustment impacts the classification process	Fully Achieved

The results of Workshop 2 demonstrated significant student progress in understanding and applying WiSARD in a digital programming environment, marking an important milestone in their educational development.

Workshop 3

Workshop 3 aimed to deepen students' understanding of both theoretical concepts related to the WiSARD Weightless Neural Network (WNN) and their practical skills within the Python programming environment. In this session, students were introduced to the OpenCV computer vision library for the first time, which they imported and utilized. The workshop was composed of five exercises, requiring students to create a dataset by photographing images with their mobile phones, thereby interacting with OpenCV. This library automated the process that had been done manually in Workshop 2, specifically transforming images into binary input vectors for the WiSARD WNN. Students also learned how to link Google Drive to Google Colab, where the image database would be stored.

Exercise 1 involved creating a dataset. Students used A4 paper and black markers to draw triangles and squares, photographed these images, cropped them to a 1:1 ratio using their phone's cropping feature, and stored the images in a folder on Google Drive. They named the folders and files according to a predefined structure, preparing them for subsequent programming tasks.

In Exercise 2, students repeated steps from Workshop 2, such as installing and importing the WiSARD library, and configuring Google Colab to access the dataset stored in Google Drive.

Exercise 3 focused on the training process using the OpenCV library. Students processed their images using Native Code 2, converting them into binary vectors for input into WiSARD.

In Exercise 4, students conducted the first stage of classification, submitting new images to WiSARD for classification. The classification images were stored in a folder and accessed by the code.

Exercise 5 measured the trust value (confidence) of the classification using the code provided.

Performance Analysis

The workshop started with database expansion, where students added new labels to the training images folder. The images were uploaded to Google Drive for batch training, utilizing Python code that required importing both OpenCV and WiSARD libraries. Students reproduced two labels—triangles and squares—using black markers on white paper, created ten copies of each label, photographed them, cropped them to the dimensions required by the Python code, and added them to designated folders in Google Colab. The necessary code was made available on the Frankie Platform website, along with detailed instructions on the Colab page created for each student pair.

Although students primarily interacted with the code through transcription, as in Workshop 2, they encountered fewer issues related to Python indentation errors and demonstrated greater ability to identify and resolve such errors. Some challenges arose when modifying the code, but these were quickly addressed within the collaborative learning environment.

Building on the knowledge gained in Workshops 1 and 2, students adjusted WiSARD parameters to classify images and modified the number of neurons to optimize classification confidence. The increased confidence demonstrated in Workshop 3 marked the culmination of a transition from paper-based activities (Workshop 1) to Python programming in Google Colab (Workshop 2).

By the end of the session, students had developed an understanding of the machine learning process, which includes defining a database by class, creating the database, training, classification, and improving classification confidence. However, difficulties related to code interaction highlighted the need for a more user-friendly interface. This issue was addressed in subsequent workshops (Workshops 4 and 5) through the development of a simplified interface within the Raspberry Pi terminal.

After creating the image database for training, students proceeded to create an image for classification using the same process of drawing, photographing, and uploading to a designated folder. All participants successfully completed this task. They recognized that OpenCV automated the tasks they had previously performed manually in Workshops 1 and 2. Furthermore, students inferred that increasing the number of training images and adjusting the tuple size would improve classification confidence, demonstrating a strong grasp of the machine learning stages with WiSARD.

All participants successfully modified WiSARD parameters, optimizing the number of tuple elements to enhance classification accuracy. By this stage, students' proficiency in using WiSARD had progressed significantly, and they demonstrated readiness to apply this knowledge to interactions with the Frankie robotic device.

The results of Workshop 3 demonstrated significant progress in students' understanding and application of WiSARD within a computer vision and machine learning context, particularly through the automation of previous manual processes using OpenCV. This workshop marked an important step in their educational development as they prepared to integrate this knowledge with the use of the Frankie robotic device.

Table 4

Degree of proficiency achieved by students concerning the objectives of Workshop 3

Workshop 3 – Objectives	**Proficiency Level**
Import the OpenCV library into the Python environment in Google Colab. Create labels by drawing with black markers on white paper and scan them for use as training and classification data	Fully Achieved
Insert, expand, and access the database, understanding that these data are available for batch processing code	Achieved
Understand that the OpenCV library converts digitized images into binary vectors for training and classification, performed using the code provided	Fully Achieved
Perform training with newly created labels	Fully Achieved
Establish a correlation between classification confidence (Trust) and the number of neurons, retina size, and available data	Fully Achieved

Workshop 4

Workshop 4 introduced students to the Frankie robotic device and the Raspberry Pi platform, focusing on remote access and control. The Raspberry Pi, a single-board computer, serves as the robot's controller, and this workshop marked the students' first encounter with the Frankie Robot, the Raspberry Pi board, and the Raspbian operating system. Given that the Raspbian interface closely resembles Microsoft Windows, this session aimed to help students become familiar with the new environment while navigating minor differences between the two systems.

Exercise 1 focused on installing the VNC Viewer application on the students' laptops. This software enabled remote access to the Raspberry Pi, and consequently the Frankie Robot, by using its IP address. This setup gave students the possibility to perform tasks remotely, executing commands on the Raspberry Pi from their laptops.

Exercise 2 guided students through accessing the necessary folders and files to execute the codes for controlling the various components of the Frankie Robot, such as its motors, camera, sensors, and LCD. Students also learned basic Linux commands, including “dir” to list directory contents and “cd” to navigate between directories.

Additionally, students were taught that to execute Python scripts, identified by a ".py" extension, the command "python3" must be used before the file name.

Exercise 3 introduced Native Code 3, which allowed students to apply their theoretical knowledge from previous workshops, particularly in relation to the WiSARD Weightless Neural Network (WNN). This exercise involved configuring the WiSARD system to work with Frankie's sensors and actuators, enabling practical integration between the robot and the WiSARD system.

Performance Analysis

The default code provided for Workshop 4 allowed the robot to move in four directions: right, left, forward, and backward, with each direction corresponding to a specific label trained in the WiSARD system. While the primary goal was not to teach programming, students demonstrated increased comfort with Python due to their exposure to it in Workshop 2 through Google Colab.

Control actions for the Frankie robot, written in Python, were stored in a designated folder for students to execute. Some students modified the native programming code to expand Frankie's actions, showcasing their growing understanding and initiative in coding.

Native Code 3 enabled students to configure key WiSARD settings, such as the size of the Retina and the number of tuple elements, which directly influenced the number of discriminator neurons and optimized the classification trust level. These configurations were critical for controlling the robot's actuators and sensors, linking the theoretical knowledge of WiSARD from prior workshops to the practical operation of the robotic device.

Workshop 4 demonstrated that students had significantly advanced in their understanding since Workshops 1, 2, and 3. All participants successfully grasped the steps involved in configuring WiSARD parameters, particularly adjusting the dimensions of the Retina and tuple elements. This marked the first time students integrated the WiSARD system with a physical robotic device, further enhancing their learning experience.

Although students were initially unfamiliar with the Raspberry Pi and its remote access features, only two students experienced difficulties interacting with the robot. These issues were quickly resolved with assistance from the instructor, allowing all students to engage with the robot effectively. The opportunity to "teach" the robot created a strong sense of connection, fostering rapid learning and enthusiasm among the participants.

Students successfully performed their first interactions with Frankie by executing commands in the Raspbian terminal, which demonstrated the ability of robotic devices to improve student involvement in learning. Throughout the workshop, students configured the robot to train on pre-inserted labels, classify new images, and adjust settings for Frankie to interact with its environment through its sensors and actuators.

Additionally, students played an active role in improving the robot's physical design, suggesting enhancements to its structure and wheel axles. They also identified issues related to Frankie's movement, despite successful image classification, and these concerns were addressed in preparation for Workshop 5.

Workshop 4 highlighted the students' growing competence in both the technical and theoretical aspects of robotics and machine learning, as they successfully integrated their knowledge of WiSARD with the physical functionality of the Frankie robot.

Table 5

Degree of proficiency achieved by students concerning the objectives of Workshop 4

Workshop 4 - Objectives	Proficiency Level
Remotely access the Raspberry Pi using the VNC Viewer software	Achieved
Interact with the Raspbian operating system, mastering terminal commands to navigate directories and access the codes controlling Frankie's sensors and actuators	Fully Achieved
Configure both the robot's components and WiSARD image classification parameters by executing the code provided in the terminal interface	Fully Achieved

Workshop 5

This workshop consisted of two structured activities, each requiring multiple iterations throughout the training process to evaluate the classification performance and the trust percentage of the robotic system. The workshop was conducted over two 90-minute sessions.

Exercise 1 revisited tasks similar to those in Workshop 3, wherein students created a dataset of images and organized them into folders for subsequent access by the program. The focus remained on building an adequate image dataset that could be effectively used in classification tasks.

Exercise 2 centred on classification activities. Students were required to adjust the code or expand the dataset to increase the system's trust percentage in classifying images. This was an iterative process, encouraging students to refine their approach continuously until they achieved the desired classification accuracy. The exercise culminated in a practical field activity where students classified images along a designated path using the robot.

To complete these tasks, students needed to configure two sets of parameters: those related to the robot and those linked to the WiSARD artificial intelligence (AI) system. The robotic parameters involved determining the optimal distance between the robot and the image for camera capture, as well as adjusting the robot's movement speed to improve image framing. The WiSARD-related parameters included setting the Retina's dimensions (rows and columns of the matrix), choosing the number of tuple elements, determining the number of neurons in the Discriminator, and defining the desired trust level for classification.

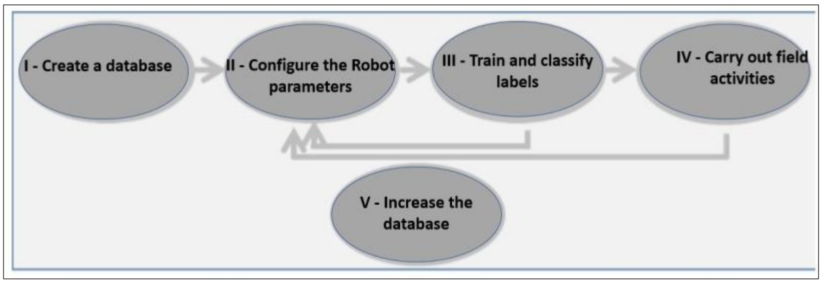
Performance Analysis

Students remotely accessed the Raspberry Pi's Raspbian operating system using the VNC Viewer software from their personal computers, interacting with the Frankie robot to test its sensors and actuators. They subsequently expanded the robot's image database. Initially, the students used the images they had created during Workshop 3 to insert new labels into the folders associated with the native programming. They later created additional images and added them in batches to the appropriate class folders. These steps prepared the robot to engage in practical tasks, including the field activities depicted in Figure 9.

While most students successfully increased the number of labels for each class, four students encountered difficulties storing the images in the appropriate folders with the correct dimensions. Despite completing similar tasks in Workshop 3, these students still required assistance from the instructor. Nevertheless, all participants successfully modified the code to adjust the number of training elements per class in the WiSARD system.

Figure 9

Workshop 5 - Field Activities



Additionally, students conducted trust evaluations on the robot's image classification capabilities, working to enhance both the trust level in image recognition and the robot's performance in practical tasks. These improvements were achieved by expanding the number of training labels and adjusting various WiSARD parameters.

Table 6

Degree of proficiency achieved by students concerning the objectives of Workshop 5

Workshop 5 - Objectives	**Proficiency Level**
Expand the WiSARD training database on the Frankie robotic device by adding new labels	Achieved
Modify code to adjust the number of training elements	Fully Achieved
Configure parameters in the terminal's interaction interface to enable the robot to engage in field activities and interact with images in its surroundings	Fully Achieved
Evaluate the trust level in image classification and demonstrate the ability to correlate improvements in trust with the expansion of the training database and adjustments to WiSARD parameters.	Fully Achieved

EVALUATION STUDENTS´ SELF-PERCEPTION

At the conclusion of the workshops, students were asked to complete an online Self-Perception Assessment questionnaire. This assessment aimed to capture students' personal reflections on the activities they had participated in. To measure their levels of agreement or disagreement with various workshop activities, a Likert scale questionnaire was employed, as detailed by Jamieson (2004). The Likert scale used featured five levels, as shown in Table 7.

The questionnaire included ten statements to evaluate students' perceptions:

Q1 - I found the WNN WiSARD concepts easy to understand.
Q2 - I understood the initial concepts of WNN WiSARD through the video lesson and unplugged activities.
Q3 - I had difficulty associating the labels representing vectors with zeros and ones.
Q4 - I understood that the OpenCV library in the code transforms the drawing into an input vector of zeros and ones.
Q5 - I was able to associate the activities from Workshops 1 and 2 with the automatic processes WiSARD performs in Python.
Q6 - Treating the image to be placed in the folder was difficult to carry out.
Q7 - Modifying the code to increase the number of trained images was a complicated process.
Q8 - The process of including images through folders was easy to understand.
Q9 - The Frankie Project is a valuable resource for introducing Artificial Intelligence concepts in high school, as it involves accessible basic mathematics concepts for teaching weightless neural networks.
Q10 - The Frankie robotic prototype helped me engage more deeply with the study of Artificial Intelligence.

Table 7
Likert Scale Used for Workshop Evaluation

1	2	3	4	5
Strongly disagree	Disagree	Indifferent (neutral)	Agree	Strongly agree

The results from the Likert scale questionnaire revealed that students generally found the WNN WiSARD concepts easy to understand, corroborating the teacher-mediator's observations during the workshops. Most students confirmed that the instructional methods—such as interactive video lessons and paper-based activities—were adequate for grasping the key concepts, as evidenced by their progress in the sessions.

While one student reported difficulty associating labels with vectors (Statement Q3), believing at first that labels could only be represented by matrices, this understanding improved as the workshop progressed. Nine students acknowledged that they understood how the OpenCV library converts images into binary vectors, facilitating their connection between these processes and the activities from Workshops 1 and 2.

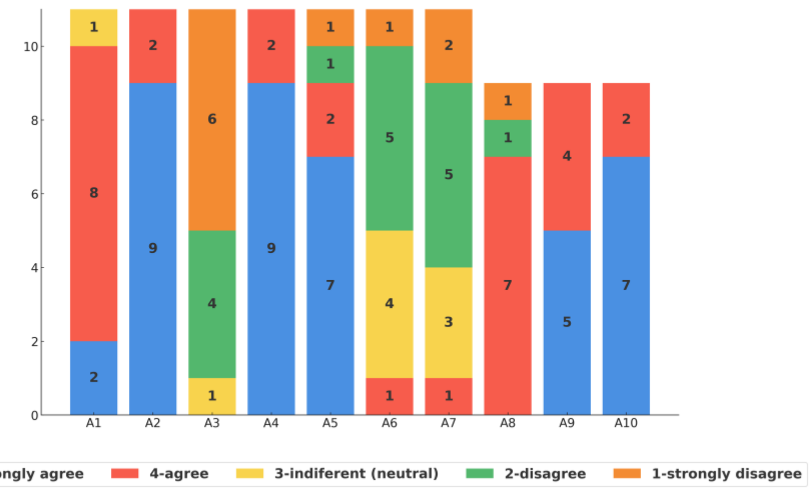
Although half of the students encountered some difficulty in creating and processing new labels for inclusion in the appropriate folders, the overall task was manageable. Some found the process took longer than expected, but most participants were able to modify the code effectively to expand the database. Throughout the sessions, students adapted quickly to working with Python (Figure 10).

The Frankie project was seen as a valuable opportunity to introduce machine learning concepts. Students found the Frankie robotic device to be a significant motivator, which deepened their engagement with artificial intelligence (AI) principles.

Figure 10

Response to the Questionnaire (Self-Perception Evaluation)

A1…A10 means answers to the 10 questions. The numbers inside the bars represent the total number of students who marked an option in the Linkert scale.



Source: Authors.

ETHICAL REFLECTIONS ON AI

By the end of the workshops, students not only demonstrated an understanding of AI's potential for pattern recognition and its role in modern production processes but also considered the ethical and social implications of AI technology. Their reflections, recorded by the teacher-mediator, raised important questions:

- "To what extent does society corrupt human beings? To what extent can AI be corrupted?"
- "If robots replace humans, will people become idle and gain more freedom?"
- "What about unemployment? Robots could perform manual labour while humans focus on research. However, in developing countries, unskilled youth may struggle to find opportunities. Social programs will be crucial for an AI-integrated society."
- "Society seems more concerned about robots than about people. We must consider the societal context when implementing AI. By 2050, how many people will be included in social contexts with AI?"
- "We need to think about humans who will no longer perform manual tasks."
- "Does complete intelligence require rationality?"
- "AI has become a part of our daily conversations, which was not the case before."

These reflections highlight the need for responsible and ethical implementation of AI technologies in society.

FINAL REMARKS

This case study aimed to address the following research question:

> *How does the WNN WiSARD, alongside the Frankie Platform and the employed teaching strategies, impact the understanding of introductory concepts of Artificial Intelligence in high school students?*

Regarding the overall objective of the research—to investigate the feasibility of teaching artificial intelligence (AI) concepts to high school students through the WiSARD system and educational robotics—the data collected demonstrate the potential for successfully engaging students in machine learning concepts. The 11 participating students completed five workshops, reaching the anticipated level of potential development by the final session.

One initial challenge faced by students was interacting with the Python programming language, which was essential for modifying and adjusting the code. However, this difficulty was viewed as a technical hurdle, and students gradually developed proficiency in the language throughout the workshops.

The instructional strategies employed were grounded in Vygotsky's learning theory, which guided the design of structured activities that encouraged student interaction and the use of technological educational tools. This study revealed that the strategies implemented effectively created Zones of Proximal Development (ZPD), facilitating students' understanding of AI concepts.

The skills outlined in the workshop syllabus were systematically developed during the sessions, enabling students to acquire the competency to configure WNN WiSARD parameters embedded in the robotic device.

The workshops underscored the importance of the robotic device as a central agent in fostering student engagement. The activities involving the robot were particularly engaging for students, as they could observe the outcomes of machine learning processes, including training and classification, through the robot's actions and responses.

Participants reported developing a sense of empathy toward the Frankie Robot, expressing that their desire for the robot to successfully recognize images and interact with the environment motivated them to strive for optimal classification results using WNN WiSARD.

In conclusion, the Frankie Platform, combined with the teaching strategies employed in this research, effectively facilitated the learning of AI concepts in high school students. Through the integration of machine learning, WNN WiSARD, and educational robotics, this study demonstrated a viable approach to introducing AI education at the high school level.

AUTHORS CONTRIBUTION

Conceptualization: C. S. Pimentel & F. F. Sampaio.; Methodology: C. S. Pimentel & F. F. Sampaio; Software: C. S. Pimentel; Validation: C. S. Pimentel & F. F. Sampaio; Formal Analysis: C. S. Pimentel & F. F. Sampaio; Investigation: C. S. Pimentel; Data Curator: C. S. Pimentel & F. F. Sampaio; Draft Preparation: C. S. Pimentel; Writing – Original: F. F. Sampaio & C. S. Pimentel; Review and Editing: F. F. Sampaio.

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