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# Studio e sviluppo di kit robotici per attività educative in classe

Design and implementation of robotics kits for introducing educational activities

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## Abstract

Educational Robotics (ER) represents a pivotal shift in modern pedagogy, with this thesis analyzing it, emphasizing challenges and highlighting the essential role of accompanying kits. The historical evolution of ER is explored within a broader context. Challenges include school accessibility and educator preparedness, addressed systematically with a focus on inclusivity. ER kits empower both students and educators. The thesis intersects with ANcybernetics, an academic spin-off linked to the Università Politecnica delle Marche (UNIVPM), contributing resources to enhance student learning. The structure of the thesis involves a sequential exploration of the ER field: a historical context and theoretical foundations in the literature review, research approach and introduction of Basic Kits in Methodology and Technology, and practical insights with Advanced Kits in Implementation and Validation. Findings and Guidelines encapsulate empirical results and recommendations. The conclusion synthesizes the journey, offering insights and future directions for ER. This thesis aims to contribute significantly to the field, addressing challenges, highlighting kit importance, and fostering effective integration in diverse educational settings.

## Summary (in Italian)

La Robotica Educativa (RE), punto d'incontro tra tecnologia e istruzione, promette esperienze di apprendimento trasformative. Questa tesi si addentra nel complesso scenario della RE, con particolare attenzione alle sfide che affronta e al ruolo cruciale dei kit a essa correlati. Nel contesto più ampio, contestualizziamo l'evoluzione della tecnologia nel campo della RE, mettendo in risalto la traiettoria storica e il ruolo fondamentale giocato da questi kit nel tradurre concetti teorici nella pratica.

Le sfide della RE, che vanno dalle questioni di accessibilità nelle scuole alla preparazione degli insegnanti, costituiscono uno sfondo critico. Affrontare queste sfide è l'obiettivo centrale di questa ricerca, che definisce chiari obiettivi per migliorare l'inclusività e l'efficacia del campo. La rilevanza dei kit di RE emerge come tema guida, fornendo strumenti tangibili sia agli studenti che agli educatori.

In questo contesto, è essenziale sottolineare l'implicazione diretta di ANcybernetics, uno spin-off accademico dell'Università Politecnica delle Marche (UNIVPM). Questo spin-off è dedicato alla creazione di kit educativi robotici e costituisce un elemento chiave nello sviluppo dell'ecosistema proposto della RE. La sua attività si intreccia con la ricerca svolta in questa tesi, contribuendo a sviluppare risorse pratiche e innovative per la formazione degli studenti.

La struttura della tesi è concepita come un percorso attraverso gli aspetti chiave per lo sviluppo di kit di RE. In primo luogo, la revisione della letteratura approfondisce il contesto storico e le fondamenta teoriche, preparando il terreno per una comprensione più approfondita del contesto e delle implicazioni dello strumento tecnologico in campo educativo. La sezione *Metodologia e Tecnologia* dettaglia l'approccio di ricerca, sottolineando i concetti fondamentali della robotica e i ruoli distinti dei vari kit della RE, con un particolare sguardo su uno specifico strumento didattico chiamato 'Basic Kit'.

La sezione *Implementazione e Validazione* descrive l'ulteriore sviluppo che ha portato alla vita la tipologia di strumenti chiamata 'Advanced Kit'. Inoltre, il capitolo offre approfondimenti pratici attraverso la presentazione di casi studio, mostrando l'impatto di questi kits, con una connessione diretta alle attività dello spin-off accademico. La sezione *Risultati e Linee Guida* presenta gli esiti della ricerca, offrendo suggerimenti pratici e raccomandazioni derivate dall'esplorazione articolata.

In particolare, i risultati della tesi evidenziano l'essenzialità di alcuni fattori per la riuscita di un'attività educativa svolta con kit robotici, tutti rinvenuti nelle esperienze di validazione trattate, tra questi :

- la valutazione dei feedback come strumento di correzione e miglioramento delle attività;

- La gamification delle attività come strumento di trasferimento di competenze;
- La capacità di attività manuali di facilitare l'apprendimento e rimarcare gli output dell'esperienza;
- La condivisione delle attività educative non solo tra pari, ma anche con un pubblico che va oltre l'età giovanile.

Il capitolo conclusivo sintetizza il percorso di ricerca, fornendo conclusioni esaustive e raccomandazioni per future direzioni.

Questa tesi mira a contribuire in modo sostanziale all'avanzamento della RE, riconoscendo le sfide che essa comporta e mettendo in luce il ruolo indispensabile dei kit nel colmare il divario tra teoria e applicazione. Attraverso un'approfondita esplorazione di questi elementi, la ricerca mira a fornire strategie e intuizioni operative per favorire un'integrazione più inclusiva ed efficace della RE in contesti educativi diversificati, con un particolare accenno alle iniziative dello spin-off accademico di UNIVPM, ANcybernetics, nel campo della creazione di kit educativi robotici.

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## Abbreviations

ER: Educational Robotics

RiE: Robotics in Education

RK: Robotics Kits

LabMACS: Laboratory of Modelling, Analysis and Control of Dynamical Systems

UNIVPM: Università Politecnica delle Marche

STEM: Science, Technology, Engineering, and Mathematics

STEAM: Science, Technology, Engineering, Art, and Mathematics

eSTrEM: environment, Science, Technology, robotics, Engineering, and Math

TMI cycle: "Think Make Improve" cycle

CAM: Collaborative Learning, Automation, and Marine Robotics

ML: Machine Learning

BOM: Bill of Materials

CE: Conformité Européene (European Conformity)

IoT: Internet of Things

IDE: Integrated Development Environment

ADC: Analog-to-Digital Converter

ESP32: Espressif Systems' System on Chip (SoC) with integrated Wi-Fi and Bluetooth capabilities

HAT: Hardware Attached on Top

IMU: Inertial Measurement Unit

IP68: Ingress Protection rating 68

RGB: Red, Green, Blue (LEDs)

RTC: Real-Time Clock

SG90: A type of micro servo motor

# CHAPTER 1. INTRODUCTION

ER (ER), situated at the intersection of technology and education, is a field that holds immense promises but is not without its challenges. This chapter will explore the intricate landscape of ER, delving into its nuanced aspects and emphasizing the significance of its kits. The introduction identifies challenges and outlines the broader context, research aims, and objectives, offering a comprehensive view of the thesis structure.

## 1.1 Contextualizing ER

ER represents a dynamic approach to learning, where technology becomes a conduit for engaging and interactive educational experiences. Integrating robotics into educational settings is a multifaceted journey, encompassing various challenges that demand our attention. It is crucial to appreciate the broader context in which ER operates.

The exploration begins with a delve into the contextual landscape of ER, examining its historical evolution and tracing the trajectory from its inception to its current state. Contextualizing ER through a literature review provides insights into the forces that have shaped its development and the educational philosophy underpinning its integration into classrooms.

The Robotics Kits (RK) designed to facilitate hands-on learning are central to the practical implementation of ER. These kits range from basic sets to advanced robotics tools, providing students with tangible resources to explore, experiment, and learn. Understanding the significance of these RK is fundamental to comprehending how ER translates theory into practice within the educational environment.

## 1.2 Challenges in ER

While ER offers innovative possibilities, it is not immune to challenges. This section navigates through these challenges, shedding light on the hurdles that educators, students, and policymakers face in embracing and optimizing the potential of this technology.

ER has a fragmented Implementation. Despite ER being a recognized approach, its application remains fragmented, often relegated to sporadic outreach program activities or infrequent classroom occurrences. This fragmentation is rooted in the absence of compelling evidence demonstrating the efficacy of learning through robotics (Alimisis 2013; Benitti 2012; Scaradozzi, Cesaretti et al., 2021).

ER encounters formidable barriers related to accessibility in schools. Issues such as resource availability, financial constraints, and the hesitancy of educational institutions to embrace new technologies collectively contribute to an accessibility gap. The limited availability of resources and the financial restrictions faced by many educational institutions create hurdles in adopting ER, restricting its reach and impact.

Teacher preparedness and training are fundamental in a technologically advanced subject like ER. The success of ER is intricately linked to the preparedness of educators to integrate these technologies into their teaching methodologies. Current challenges in teacher training must be addressed to enhance the skills and knowledge required for effective ER implementation.

Studies report challenges in implementing ER in early education, with teachers expressing apprehension and encountering technical hurdles in executing activities (Mangina et al., 2023). These challenges highlight the need for targeted strategies to facilitate ER integration in the early stages of education.

Despite demonstrated effectiveness in specific applications, ER lacks sufficient empirical evidence, particularly for students aged 11–12 (Mangina, Psyrra et al. 2023). The absence of robust research supporting ER effectiveness underscores the need for further investigation and validation. This research gap hinders the broader acceptance of ER as an impactful educational tool, necessitating rigorous studies to establish its efficacy and potential benefits in diverse educational contexts. Addressing this gap will strengthen the evidence base for ER and contribute to informed decision-making by educators and policymakers.

The rapid growth of the ER market has led to concerns about the reliability and educational content of tools. Issues such as poor motor calibration and robots violating social rules for technical reasons highlight the need for stringent quality control measures in ER tool development (Mangina, Psyrra et al. 2023).

The absence of organized guidelines for introducing ER into school curricula is a significant impediment. Each ER kit should ideally have a curated set of activities that elucidate its educational potential. As Costa, Screpanti et al. (2023) pointed out, the lack of such guidelines and limited practical knowledge among primary school teachers underscores the imperative to enhance teacher skills and comprehension in robotics.

Navigating these challenges is crucial for unlocking the full potential of ER and ensuring its effective and inclusive integration into educational systems.

## 1.3 Research Aims and Objectives: Navigating Solutions

This research sets clear aims and objectives in response to the identified challenges. These goals extend beyond mere recognition of issues; they encompass a commitment to actionable solutions that can positively impact the field of ER.

The primary aim is to contribute substantively to improving ER by addressing specific challenges. Reaching this objective involves developing strategies to enhance accessibility, refining teacher training programs, and promoting a more inclusive and equitable approach to integrating ER in diverse educational settings.

For this reason, the research is guided by specific objectives. They include thoroughly analyzing existing ER programs, designing and implementing targeted interventions, and evaluating the outcomes. Each purpose aligns with the broader goal of creating a more effective and inclusive ER framework.

Moreover, a distinct part of the thesis will explore marine robotics as an experimental exploration of incorporating natural life into ER. This innovative approach aims to bridge the gap between traditional ER and real-world applications, bringing the principles of marine life and underwater exploration into the educational sphere. Integrating marine robotics into ER adds a unique dimension to the learning experience and fosters a deeper connection between technology, environmental science, and robotics education. This experiment serves as a testament to the research's commitment to pushing the boundaries of ER and exploring novel avenues for its implementation in educational contexts.

### *1.3.1 A focus on environmental robotics and marine robotics*

ER is a powerful tool for teaching environmental robotics, encompassing robotic technology's design, development, and application for environmental monitoring, conservation, and management. A critical subset of environmental robotics is marine robotics, which focuses on the exploration and study of marine environments.

Traditionally, marine robotics activities have been confined to higher education programs, equipping students with essential skills for their future careers. However, recent literature on ER applied to marine environments suggests that it can be successfully integrated into primary, middle, and high school curricula (Costa, Screpanti et al. 2023). Marine robotics not only serves to engage students in blue careers but also provides an effective medium for ocean education, even for students with special

needs. Integrating marine robotics into schools offers numerous benefits, enriching students' learning experiences and fostering a deeper understanding of our oceans.

The OpenFISH.science project is a compelling example of the fusion of environmental robotics with ER, exemplifying its potential impact on primary school education. The project's creators embarked on an innovative journey to introduce eSTrEM concepts to young learners, emphasizing developing skills such as creativity, problem-solving, teamwork, and innovation capacity (Scaradozzi, Cesaretti et al. 2019).

OpenFISH.science's initial focus on environmental awareness, particularly in the marine field, is significant for engaging children in discussions about oceans and their inhabitants. The project leverages the expertise of its authors to develop and validate educational kits tailored to this field (Scaradozzi, Cesaretti et al. 2019). By integrating these innovative syllabi and technological devices into primary school education, OpenFISH.science broadens young minds and nurtures a generation of environmentally conscious and technologically adept students poised to address the complex challenges of our evolving world.

## 1.4 Overview of the Thesis Structure

This section provides a roadmap for the reader, guiding them through the organized structure of the thesis. Each chapter is positioned as a distinct step in the journey, contributing to a cohesive and comprehensive exploration of ER.

Chapter 2: Literature Review. The literature review delves into existing research and frameworks in ER. By synthesizing current knowledge, this chapter lays the groundwork for understanding the historical context, theoretical underpinnings, and key trends in the field.

Chapter 3: Methodology and Technology. This chapter outlines the research methodology employed, focusing on the materials, methods, and technologies used in the study. Additionally, it explores fundamental robotics concepts, emphasizing the role of various RK. Specifically, a focus is made on the Basic Kits, a branch of RK that share the same core technology and features.

Chapter 4: Implementation and Validation. These are crucial phases in the thesis that detail the practical application of the RK in the Advanced Kits, a further development of the Basic Kits, including case studies and experiences. It explores how the potential of this educational tools contribute to effective learning outcomes.

Chapter 5: Findings and Guidelines. Presenting the findings is a pivotal aspect of the research. This chapter reports on the outcomes and provides practical guidelines derived from the study about the validation experiences, offering insights into best practices for ER implementation.

Chapter 6: Conclusions and Recommendations. The final chapter synthesizes the research journey, offering conclusions based on the findings. It also presents recommendations for future directions, highlighting potential avenues for further research and improvement in ER and RK development.

In extending the introduction, the aim is to provide a more in-depth exploration of ER, its challenges, and the role of its kits. This expanded overview lays the foundation for a comprehensive and insightful exploration of the field throughout the thesis.

# CHAPTER 2. LITERATURE REVIEW

Chapter 2 overviews the existing knowledge, theories, and insights in ER. The goal is to distill the essence of scholarly contributions, research endeavors, and conceptual frameworks that have shaped the understanding of ER. The Chapter begins with an examination of the historical evolution of ER, tracing its roots and development over time.

As the exploration deepens, the focus shifts to the pedagogical underpinnings and theoretical frameworks that underlie the integration of robotics into education. Theoretical perspectives from educational psychology, cognitive science, and pedagogical theories provide a lens through which the cognitive and affective dimensions of student engagement with robotics are analyzed.

Furthermore, this chapter scrutinizes the empirical landscape, synthesizing findings from studies that have investigated the impact of ER on student learning outcomes, motivation, and skill development. By exploring the diversity of methodologies employed and the varied contexts in which research has been conducted, patterns are distilled and gaps identified that lay the groundwork for future empirical contributions.

## 2.1 Definition and Genesis of ER

The inception of ER (ER) marks a transformative convergence of educational philosophy and technological innovation. ER is not merely to teach programming or robotics but to use these tools to foster a deeper understanding of various subjects, including mathematics, science, and problem-solving skills.

Seymour Papert (Figure 1), a luminary in the field, played a pivotal role in shaping ER through his constructionist approach. Papert's work laid the foundation for using robotics as an educational tool, emphasizing the importance of hands-on, experiential learning. Papert's paradigm, articulated in 1980, reframed the role of computers from central learning entities to devices supporting the construction of knowledge. Scaradozzi, Screpanti et al. (2019) emphasize the significance of this approach, where technology becomes a catalyst for students to actively participate in creating, building, and sharing meaningful objects.

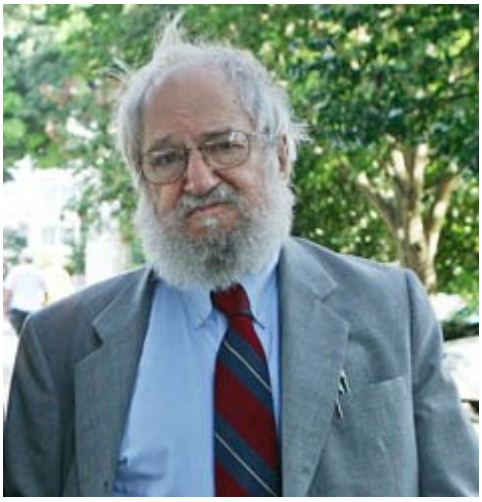


*Figure 1. Seymour Papert*

Expanding upon Papert's constructionist philosophy, Scaradozzi, Cesaretti et al. (2020) delve into specific educational processes within ER. They highlight the central role of students in creating personal and meaningful products, aligning with Papert's belief that knowledge is effectively "built" through such constructive activities. Scaradozzi, Cesaretti et al. (2020) also underscore the adoption of the "Think Make Improve" cycle, proposed by Sylvia Libow Martinez & Gary Stager (2013) in ER activities. This cyclic workflow corresponds to an iterative design process involving ideation, prototyping, testing, and refining cycles. In the context of ER, the TMI cycle is a structured approach where students first think about a problem or concept, then create a solution or project, and finally, through testing and reflection, seek ways to improve upon their initial design.

> *"ER aims at exploring Robotics fundamentals with and hands-on, playful approach, where students use robots for educational activities involving the construction and deconstruction of an artifact which can be programmed to accomplish a given task"* (Mangina, Psyrra et al. 2023).

Despite the clear theoretical foundationssuch as Papert's constructionism, there is an ongoing effort to incorporate ER into formal educational curricula. Scaradozzi, Screpanti et al. (2019) aptly capture this challenge, highlighting the need for continued advocacy, research, and curriculum development to facilitate the seamless integration of robotics into conventional education systems. As educators and researchers work towards aligning pedagogical theories with practical implementation strategies, the TMI cycle is regarded as a best practice during the hands-on ER activities. Notably, iterative learning methodologies play a crucial role in preparing students for future challenges.

### *2.1.1 Targets of ER*

The targets of ER extend to both the social and educational domains. Socially, ER aims to cultivate cooperation skills and engage learners in collaborative activities, recognizing the importance of these skills in contemporary society. Educationally, ER seeks to provide a hands-on and playful exploration of robotics fundamentals, promoting practical understanding through constructing and programming artifacts.

Moreover, the educational objectives of ER encompass broader societal and collaborative goals. Scaradozzi, Screpanti et al. (2019) emphasize the social purpose of ER, advocating for increased engagement of society, including learners across various educational levels, in cooperative activities. They contend that collaboration is fundamental to success in the contemporary world, and as such, collaborative skills should not only be cultivated but also assessed and evaluated. This perspective aligns with a broader societal need for individuals adept at working collaboratively (Figure 2), a skill set increasingly valued in various professional and personal contexts.

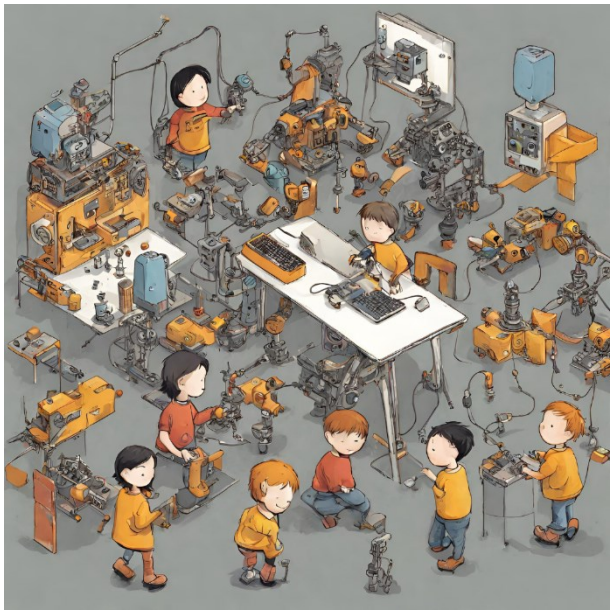


*Figure 2. Kids who play collaboratively with robots.*

Engaging in hands-on activities within ER serves as a catalyst for stimulating brain activity. As Screpanti, Scaradozzi et al. (2022) highlight, manipulating a robot's structure and observing its physical behavior trigger significant brain activities. These actions are intricately connected with cognitive processes such as lateralization, spatial management, and embodiment. The hands-on nature of ER provides learners with a tangible and interactive medium to explore theoretical concepts, fostering a dynamic environment that activates various cognitive functions. By physically interacting with robots,

students deepen their understanding of robotics and engage in a multidimensional learning experience that stimulates brain activity in areas crucial for spatial awareness, physical embodiment, and cognitive processing. This dynamic interaction underscores the effectiveness of hands-on ER in promoting holistic brain engagement and enhancing the learning experience (Screpanti, Scaradozzi et al. 2022).

The versatility of ER (ER) extends far beyond fundamental skills, serving as a powerful tool for introducing children to various application fields. For this reason, referring to the future application of ER, Scaradozzi, Screpanti et al. 2019, p. 6 state that:

> *"ER can be a powerful tool for teaching fundamental skills and introducing children to other important application fields: environmental awareness, human-robot interaction, elderly people assistance, agricultural, craftsmanship autonomous cleaning, flying robots for surveillance, and more."*

### *2.1.2 RiE and ER*

The field of robotics has made significant inroads into education, offering innovative approaches to enhance learning experiences. Two key terms often arise in this context: "Robotics in Education (RiE)" and "ER". While closely related, these terms carry nuanced distinctions that are vital for understanding the diverse applications of robotics within the educational landscape.

RiE is an interdisciplinary field that employs robots to facilitate and enhance the learning and teaching processes. Its primary goal is to foster students' problem-solving skills, critical thinking, creativity, and teamwork, as well as to provide practical exposure to technology and robotics. It often involves the use of robotic kits, coding, programming, and activities that bridge theoretical knowledge with real-world applications, encouraging students to explore, design, and develop solutions while making learning more interactive and enjoyable.

Instead, ER is a subfield of RiE (RiE), where robots are used as a tool to teach robotics and other subjects (Scaradozzi, Screpanti et al. 2019). ER is dedicated to utilizing robotics as a targeted educational tool. The aim is to enrich students' learning experience in specific subjects, particularly in STEAM. In ER, students use robotic platforms to achieve predefined educational outcomes. The emphasis is on introducing hands-on experiences that promote critical thinking, problem-solving, and collaboration. This approach positions ER as a dynamic and tailored educational methodology where robotics serves as a medium to achieve specific learning goals. As seen in the sections above, this thesis focuses mainly on ER.

### *2.1.3 The Importance of ER in School Curriculum*

Integrating ER (ER) into school curricula has gained significant recognition due to its potential to motivate students and enhance learning in STEM subjects. Researchers and educators have noted that early exposure to STEM subjects can significantly boost learning speed and offer valuable insights into technology fundamentals. Children gain technical skills and develop essential human and organizational values by introducing robotics as a curricular subject. This approach aligns to foster well-rounded individuals capable of navigating an increasingly technology-driven world (Scaradozzi, Screpanti et al. 2019).

Despite the recognition of ER's potential, it remains challenging to quantify its impact on school curricula. Understanding the influence of ER research projects on curriculum design is crucial for its successful integration into educational institutions. As reported by Scaradozzi, Screpanti et al. (2019), a clear understanding of its curriculum impact facilitates the replication of successful projects in other schools and institutions, allowing academic achievements to permeate daily educational practices.

Furthermore, emphasizing the impact on school curricula and learning environments underscores the feasibility of integrating ER into the educational system. Robotics should have a dedicated place within school hours, complete with its own lesson plans and assessment methods, or at the very least, be incorporated as closely related afternoon activities. Whether embedded in a comprehensive curriculum or offered within broader subjects, ER should be a fundamental component of the educational offering from an early stage, ensuring students benefit from its enriching potential (Scaradozzi, Screpanti, et al. 2019).

## 2.2. Processing Feedback on ER

This part of the thesis underscores the critical role of collecting and analyzing feedback in ER. Gathering information about the outcomes of these activities is a pivotal process that unfolds in two key phases: assessment and evaluation. Through assessment, we can gauge the immediate impact of ER activities on students, while evaluation delves deeper into these initiatives' long-term effects and effectiveness. This systematic feedback collection approach is essential for understanding the positive and negative outcomes and refining and optimizing ER experiences for enhanced learning and inclusivity.

### *2.2.1 Assessment*

The assessment of feedback during ER activities plays a crucial role in refining learning environments and our understanding of student learning processes. Measures of student behaviors offer valuable insights for designing adequate learning settings. By closely monitoring how students engage with robotics tasks, educators can identify areas for improvement and adapt the learning environment to better suit student needs, ultimately enhancing the learning experience (Scaradozzi, Screpanti et al. 2019).

Regarding the tools employed, Scaradozzi, Screpanti et al. (2019) highlight that surveys and questionnaires are instrumental in obtaining a thorough understanding of student attitudes and skills in ER. These tools facilitate data collection, enabling a triangulation process that offers a more rounded assessment of student perceptions and capabilities. Educators and researchers can acquire insights into diverse aspects of ER by employing this multifaceted approach to data gathering, ensuring a more comprehensive evaluation of its influence on students.

Furthermore, the timing of these measurements is a distinctive aspect of evaluation in ER. Evaluation can occur before, during, and after the activity, with each stage serving a unique purpose. By clearly defining the objectives of the assessment, researchers and educators can determine when and how to perform evaluations, tailoring the approach to best suit the specific goals of the ER activity and enabling more effective feedback and improvement mechanisms (Scaradozzi, Screpanti et al. 2019).

### *2.2.2 Evaluation Methods*

The evaluation of ER activities in schools encompasses a range of methods, including qualitative, quantitative, and mixed-methods approaches.

Qualitative methods in education involve the analysis of diverse sources such as essays, focus groups, projects, personal experiences, and more. These methods provide a deep and rich source of information about students' learning experiences and outcomes. However, Scaradozzi, Screpanti et al. (2019) explain that they may be challenging to implement in crowded classrooms and are susceptible to personal biases or external influences. In contrast, quantitative methods offer a more structured and replicable approach to assessment. Questionnaires, tests, and rubrics are commonly used quantitative tools to quantify the outcomes of ER activities.

While quantitative evaluation methods have advantages regarding replicability and ease of administration, they are often criticized as overly reductive in capturing the complexity of educational

experiences. In response to this limitation, education researchers have begun bridging the historical divide between qualitative and quantitative methods. The mixed-methods approach has emerged as a promising research method to address the multifaceted nature of educational contexts, including ER activities. Integrating qualitative and quantitative data offers a more comprehensive understanding of students' learning experiences and outcomes, making it particularly suitable for addressing complex educational challenges (Scaradozzi, Screpanti et al. 2019).

Modern evaluation techniques have evolved to harness the power of educational data mining and learning analytics, offering innovative ways to assess feedback from ER activities. As Scaradozzi, Cesaretti et al. (2021) highlighted, these methods involve automatic and systematic data collection and analysis from ER projects within real classroom environments, providing valuable insights for educators. Applying data mining techniques to the data collected during ER activities makes it possible to identify and model students' learning, particularly their programming skills and improvements over time.

For instance, Scaradozzi, Cesaretti et al. (2021) adapted devices for ER activities to capture and track students' programming sequences, enabling a detailed analysis of their problem-solving approaches and predicting their success in various exercises. ML is then employed to process this data, extracting performance indicators and forecasting the outcomes of these activities. This method has proven game-changing in helping educators and researchers comprehended the diverse problem-solving strategies employed by students, including approaches such as "tinkering with refining," "mathematical/planning," and "tinkering with significantly High Changes" (Scaradozzi, Cesaretti et al. 2021). These modern evaluation techniques offer a deeper understanding of students' learning processes and inform instructional practices in ER.

These innovative evaluation methods offer significant benefits in ER. For example, as cited in Screpanti, Scaradozzi et al. 2022, students engage with the building blocks of a simple object without being burdened by assessment-related anxieties, allowing for a more relaxed and productive learning environment. Simultaneously, intelligent objects continuously monitor and update their trajectories, predicting potential outcomes. These real-time updates can inform teachers about students' progress and, in the future, may even provide students with feedback and guidance toward achieving their learning goals. This dynamic feedback loop enhances the overall ER experience, facilitating effective learning and skill development.

## 2.3 Working on Robotics for Schools

In recent years, the integration of robotics in school curricula has emerged as a transformative educational paradigm, offering students a dynamic and engaging way to explore fundamental concepts. Central to this educational revolution is RK, purposefully designed tools that encapsulate the essence of hands-on, project-based learning. These kits provide students with the tangible building blocks to construct, program, and interact with robots, transforming abstract theoretical concepts into real-world applications.

RK constitute a comprehensive set of physical components, encompassing mechanical parts, electronic elements, sensors, and programmable controllers. These kits are meticulously designed to be assembled and programmed by users, offering a hands-on exploration of robotics principles. Beyond a mere collection of components, RK is an invaluable educational instrument, providing a tangible and interactive platform for individuals to delve into engineering, programming, and technology.

The purpose of a robotics kit transcends its physical components, embodying a multifaceted role within the educational landscape. Primarily, it functions as an educational catalyst, facilitating a dynamic and experiential learning approach in STEM disciplines. As users engage in the assembly and programming of a robot, they gain insights into theoretical concepts, fostering a deeper understanding of the intricacies of robotics.

Furthermore, RK have a crucible for skill development. By tackling the challenges posed by assembling and programming a robot, users hone critical skills such as problem-solving, creativity, and teamwork. The programmable controllers integrated into these kits introduce individuals to coding and provide a practical avenue for hands-on programming practice.

RK are a conduit for practically applying fundamental robotics concepts and encouraging skill development. Users grapple with sensor integration, actuation, and automation, gaining a nuanced understanding of how robots sense and interact with their environment. This practical introduction to robotics concepts lays the foundation for a holistic comprehension of the field.

Ultimately, RK play a pivotal role in inspiring innovation and creativity. Users are encouraged to experiment with different configurations, pushing the boundaries of design possibilities. This aspect of exploration nurtures a spirit of creativity and innovation, laying the groundwork for the emergence of future engineers, programmers, and technology enthusiasts.

### *2.3.1 Classification*

In examining ER tools available in the literature, the classification criteria are fundamental to understanding the diverse landscape of these educational resources. The methods employed for inclusion encompass tools designed purposefully for education or those that have been applied in educational contexts with documented activities in scientific papers.

The taxonomy of ER tools, as outlined by Scaradozzi, Screpanti et al. 2019, is a nuanced classification system that considers various dimensions to provide a comprehensive understanding of these educational resources.

One key dimension is the ‘Age’ dimension, a categorization that ensures the alignment of ER tools with the cognitive capacities and learning requirements of distinct age groups. This tailored approach acknowledges the diverse developmental stages of students.

The ‘Programming Language’ dimension encompasses the choice between block-based environments, like Scratch, which promotes visual programming techniques, and text-based programming languages. This consideration reflects the diverse pedagogical approaches employed in ER.

Another critical facet is the ‘Assembly Feature’ of RK. Some kits are deemed "ready to use," with pre-assembled robots, while others are designated "to build," allowing students to construct the robot themselves. The emphasis on building aligns with a constructionist philosophy, promoting hands-on creation and a deeper understanding of core robotics concepts.

The significance of the ‘Building Process’ is underscored in the classification, emphasizing that kits allowing students to manipulate basic robot elements, design experimental mechanisms, and create personalized entities foster a profound comprehension of ER concepts. This concept aligns with the constructive learning philosophy proposed by Papert.

Additionally, ER tools are categorized based on their ‘Operating Environment’, encompassing traditional settings such as the floor or school desk (earth robot) and extending to contemporary environments like the air (drones) and water (marine vehicles). This diversification reflects the expanding scope of ER applications and learning contexts.

In essence, this classification serves as a comprehensive framework, enabling educators and researchers to make informed decisions regarding selecting and implementing ER tools. It acknowledges the multifaceted nature of ER and its potential to cater to diverse educational needs and philosophies.

### *2.3.2 RK examples in literature*

As students progress from primary to secondary school, RK evolve to suit their changing needs, skills, and interests. These kits adapt to accommodate the shifting requirements of students as they mature in their learning journey. Table 1 explores the differences between primary and secondary school kits, emphasizing their impact on practical, creative, and enjoyable aspects of robot-focused learning. The table represents a summary of the findings mentioned in the previous section.

*Table 1. Differences between primary and secondary school RK.*

| **Aspect** | **Primary School Kits** | **Secondary School Kits** |
|---|---|---|
| **Complexity of Concepts** | They are designed for younger students. Introduces fundamental concepts. Emphasizes basic programming and hands-on assembly of straightforward structures. | Geared towards older students. Delves into more complex concepts involving advanced programming languages and intricate engineering designs. |
| **Programming Languages** | Emphasizes visual coding languages (e.g., Scratch). Provides an intuitive understanding of programming logic. | Introduces a broader range of programming languages, including text-based languages like Python or Java. |
| **Assembly and Design** | Focuses on simplicity and ease of assembly. Components are larger. Emphasis on basic mechanical structures. It may include pre-assembled components. | Provides more intricate components and structures. Challenges students with detailed assembly processes. It may involve advanced materials like gears and motors. |
| **Educational Objectives** | Cultivates curiosity, creativity, and a foundational understanding of STEM concepts. Fosters a positive attitude towards technology and problem-solving. | Aligns with higher-grade educational objectives. Prepares students for advanced STEM studies and potential career paths. |
| **Integration with STEM** | Integrates seamlessly with general STEM education. Emphasizes broad concepts spanning multiple disciplines. | Integrates more deeply with specific STEM subjects. Allows exploration of specialized areas like physics, computer science, or engineering. |
| **Scope of Projects** | Focuses on simpler projects (e.g., basic line-following robots). Emphasis on exploration and play. | Provides a broader scope for projects, encouraging the tackling of more intricate challenges like robotic arms or autonomous vehicles. |

At every school level, using RK is a dynamic journey. Students engage in activities focused on planning and constructing robots using various materials. Scaradozzi, Screpanti et al. (2019) propose an approach composed of different kits for different school levels that will be analyzed in this section. The proposal includes the initial two years of LEGO WeDo to set the foundation, followed by the progression to LEGO NXT/EV3 or SAM Labs in the subsequent classes. The journey culminated in the last year with the utilization of custom hardware like the OpenFISH.science kit, complemented by the advanced programming language LabVIEW.

This carefully designed trajectory enhances logical thinking, encouraging students to discriminate and classify materials. Simultaneously, it nurtures creativity in handling diverse materials, empowering students to build objects while applying their acquired skills. The approach reflects a commitment to providing a well-rounded and progressively challenging robotics education experience at every educational stage.

***LEGO WeDo***

LEGO WeDo is an ER platform designed for elementary school students. It features a set of LEGO bricks, sensors, and motors that enable students to build and program various models (Figure 3). The user-friendly software uses a drag-and-drop interface, making it accessible to young learners. LEGO WeDo focuses on STEM education, encouraging students to explore scientific concepts and develop basic programming skills.

In early-stage learning, where fostering a love for discovery and laying the foundation for essential skills is paramount, LEGO WeDo emerges as a strategic choice (Scaradozzi et al., 2019). Solutions catering to this age group require a playful approach, engaging students in math, science, and language skills exploration. For young learners, the preference is for robots that students assemble, providing an opportunity to delve into mechatronic components, their functionality, and their structure (Scaradozzi, Screpanti et al. 2019).

During the initial year, activities with LEGO WeDo involved designing simple static "robots" or entities, utilizing both LEGO WeDo components and recycled materials. These activities extend beyond mere construction, incorporating measurements, mapping, and the understanding of verification concepts. An intriguing example is the creation of an alligator robot, providing an avenue for introducing environmental considerations (Scaradozzi, Screpanti et al. 2019). Thus, LEGO WeDo not only triggers natural curiosity but also serves as a tool for developing vital communication, creativity, collaboration, and critical thinking skills in an enjoyable and exciting manner.




*Figure 3. Lego WeDo kit.*

***LEGO NXT/EV3***

Compared to LEGO WeDo, the LEGO MINDSTORMS Education EV3 represents a more advanced and versatile ER platform. While LEGO WeDo is tailored for early-stage learners, focusing on fundamental STEM concepts through simpler constructions and programming, the EV3 caters to a more sophisticated educational level (Figure 4).

The LEGO MINDSTORMS Education EV3, a cornerstone in ER, empowers users to delve into robotics through hands-on creation, programming, and testing of customizable robots. This comprehensive set includes motors, sensors, gears, wheels, axles, and various technical components. At its core is the LEGO Brick EV3, a compact yet powerful device facilitating motor control, sensor feedback, and many other functions. With front and back inputs for external devices and motors, the LEGO Brick connects to a PC via Bluetooth, Wi-Fi, or cable, offering a versatile interface for programming and exploration.

Scaradozzi, Screpanti et al. (2019) states that as students progress to the 3rd and 4th classes, pivotal years in the STEAM curriculum, LEGO NXT/EV3 systems emerge as instrumental tools for advancing competencies in coding and mechatronics. These years provide a crucial foundation for students to read, write, and engage in activities that foster the development of autonomous robots capable of communication and reaction based on structured programs. The LEGO kits, coupled with their supporting Integrated Development Environment (IDE), streamline the processes of building,

programming, and commanding robots, making the learning experience both smarter and faster. Notably, the system's integration with LabVIEW from National Instruments enables rapid prototyping of new software blocks, offering educators a valuable tool to create personalized educational kits.




*Figure 4. LEGO® MINDSTORMS® EV3.*

***SAM Labs***

SAM Labs emerges as an innovative platform for introducing the Internet of Things and the fundamentals of multi-agent systems (Scaradozzi, Screpanti et al. 2019). Unlike traditional brick-based systems, SAM Labs offers a unique programming approach, allowing students to design, write, and debug programs using a set of interactive blocks. These blocks enable the application of sequencing, selection, and iteration, fostering logical reasoning in algorithmic design (Figure 5). Students engage in writing algorithms that incorporate variables, inputs, and outputs, gaining practical insights into controlling and simulating physical systems.

SAM Labs presents an alternative to LEGO systems, making it suitable for use starting from the 3rd class, integrating STEM and IoT curriculum elements (Scaradozzi, Screpanti et al. 2019). SAM Labs stands out for its capability to awaken, connect in a network, and operate in a distributed manner. This unique feature makes SAM Labs an effective instrument for teaching concepts such as sensory networks, distributed actuation, and centralized and distributed control systems. Through SAM Labs, students can delve into a hands-on exploration of IoT principles, providing a dynamic and interactive learning experience in ER (Scaradozzi, Screpanti et al. 2019).




*Figure 5. SAM Labs STEAM Course Kit - Team size.*

***OpenFISH.science toolkit***

The OpenFISH.science toolkit, as proposed by Scaradozzi, Screpanti et al. (2019), offers students a creative avenue to design bioinspired robots shaped like animals, mainly fish. Beyond sparking creativity, this toolkit serves as an educational instrument, teaching various facets of the marine environment while fostering awareness about the sea and its associated challenges.

The OpenFISH.science kit boasts a modular architecture resembling the anatomy of a real fish. Comprising several blocks, this kit integrates different hardware and software components specifically tailored for children. Notably, it allows for automatically collecting real-time data from children's activities, facilitating measurement and analysis. The mechatronic architecture of the robot is designed to be enhanced by students who can add sensors and actuators, enabling the robot to better "sense" and "interact" within the marine environment.

A significant aspect of the OpenFISH.science kit is its 3D-printed structure, with a motorized caudal fin. Engineered to meet an IP68 rating, the kit is programmable for underwater movement, offering a unique opportunity for students to engage in hands-on learning and experimentation within the marine sciences (Scaradozzi, Screpanti et al. 2019).

### *2.3.3 Other RK in the market*

The market for robotics tools is experiencing robust growth, providing a wide array of options for educational institutions. Notably, Mangina, Psyrra et al. (2023) underscore the prominent role played by well-established educational material manufacturers in the utilization of robotic tools. Examples of these tools include Bee-bot (Figure 6), NAO, Dash Robot, and the Arduino MEGA development board, each offering distinct features and educational objectives. This diverse landscape of available RK caters to various educational needs and preferences.



*Figure 6. Bee Bot kit for the classroom, a Programmable educational robot.*

Notably, the reviewed RK in this context adhere to a conventional conception of robotics, reiterating concepts explored extensively in the field. In contrast to this traditional approach, the contemporary landscape of robotics in schools is witnessing the infusion of new technologies and approaches. An exemplar of this innovative and versatile robotic kit concept is embodied in the M5StickC Plus microcontroller ecosystem (Figure 7). This component aligns with the philosophy of the manufacturing company M5Stack, as elucidated in Chapter 3. The introduction of such cutting-edge technologies signifies a dynamic shift in the ER landscape, paving the way for novel and engaging learning experiences in primary education.

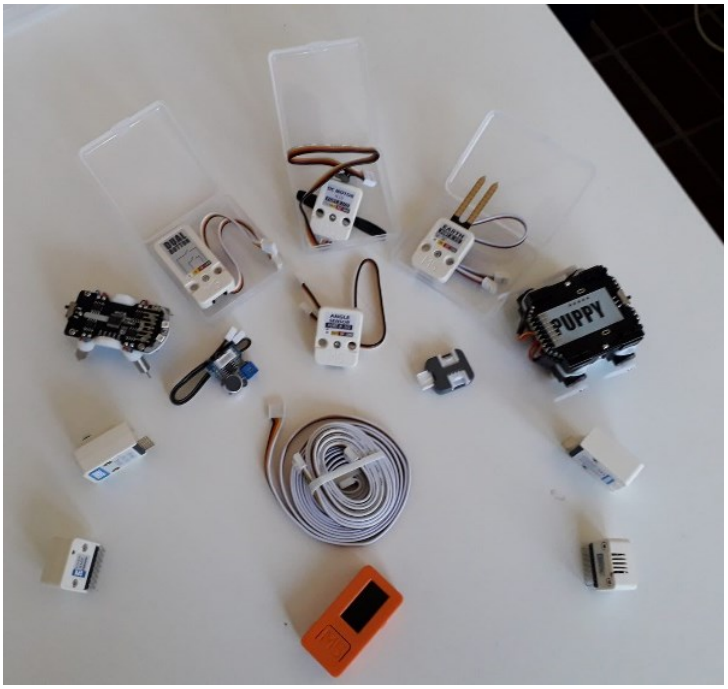



*Figure 7. Pieces of an M5StickC Plus ecosystem.*

# CHAPTER 3. METHODOLOGY AND TECHNOLOGY

Chapter 3, titled "Methodology and Technology," is organized into distinct sections that guide the reader through a comprehensive overview of the strategies and tools utilized to investigate the impact of RK in ER activities.

Regarding the latter part, the chapter analyzes the critical components for designing and providing effective RK, highlighting the essential considerations underpinning their educational impact. Subsequently, the exploration continues into the core hardware and software technologies shared by the kits under discussion, providing a crucial link between the Basic Kits and their implementation, which will be further elaborated in Chapter 4.

Within the chapter's final sections, two fundamental categories of Basic Kits are introduced. The first exemplifies adaptability in the context of a European Project, showcasing the broader-scale implementation of robotic kits. The second is tailored specifically for a secondary school environment, presenting a focused and measured approach to robotics education.

## 3.1 Research Design

The success of any research endeavor is intricately linked to the design and planning that precede it. In this section, we navigate through the methodological decisions and the underlying motivations that guided the selection of these specific case studies. Understanding the why and how of the chosen research design is crucial to ensure the robustness and validity of the forthcoming findings and to provide a transparent view of the research process. This section sets the stage for an in-depth exploration of the Implementation and Validation experiences, shedding light on the deliberate choices that have shaped the research journey.

### *3.1.1 Case study methodology*

The case studies selected for this research present a comprehensive spectrum of educational tool development, ranging from Basic Kits to Advanced Kits. These case studies encapsulate the evolution of ER, highlighting the varied uses and applications of RK within the educational context.

When focusing on the validation experiences, a deliberate approach was taken to encompass various contexts. Rather than drawing comparisons among various case studies, the goal was to offer an objective and absolute evaluation of the integration of RK in educational settings. The

selected case studies represent distinct and specific scenarios, providing a well-rounded perspective on the impact and effectiveness of these kits in vastly different educational environments.

The common thread running through these case studies is the unwavering presence of the central participants: primary and secondary school students. Their role as the protagonists of ER activities ensures that the results obtained are closely tied to the impact and effectiveness of these kits in diverse educational settings.

### *3.1.2 Data processing methods*

The execution and evaluation of these experiences hinged on the systematic collection and analysis of feedback data, enabling us to achieve several vital objectives. Primarily, these data provided insights into the suitability of the proposed RK regarding their educational potential. Secondly, they offered a means to gauge the quality of these RK. Additionally, they allowed us to uncover both the positive and negative facets of the validation experiences.

Questionnaires served as the primary instruments for data collection. In the initial experience, they were extensively utilized to extract a wealth of precise and comprehensive information. In subsequent experiences, questionnaires were employed to gauge the students' satisfaction levels, which were then complemented with direct feedback from the organizers.

A mixed methods approach was adopted to ensure a well-rounded datasetas previously discussed in Chapter 2 and cited by  Scaradozzi, Screpanti et al. (2019). This approach incorporated both quantitative and qualitative methods to comprehensively evaluate the impact of these RK and the validation experiences.

### *3.1.3 Validation methods of RK*

To achieve the goals set out in Chapter 2, well-designed robotic kits are essential in ER. They go beyond tools, acting as the linchpin bridging theoretical learning objectives to practical, hands-on experiences. As noted by Scaradozzi, Screpanti et al. (2019), the incorporation of robotics complements and empowers the didactical approach in ER. Students' technical understanding of the objects they manipulate is vital to their educational journey. This subsection explores the methods through which well-designed RK proves effective in classes, recognizing them as essential instruments for realizing the educational targets outlined in Chapter 2.

In ER, RK design and composition are pivotal in their effectiveness within a school environment. To be included in this thesis's implementation and validation phase, the RK treated here must encompass

several key aspects to ensure a comprehensive and enriching learning experience for students. These include:

- Electronic Foundation: RK rely on electricity and electronic components, forming a tangible link between technology and education.
- Analogous to Nature: Effective kits mirror elements from the natural world or familiar human structures, enhancing students' ability to relate to and comprehend complex concepts.
- Component Diversity: The inclusion of a diverse array of components like actuators and sensors enables students to experiment with various elements, fostering exploration, problem-solving, and skill development.
- Freedom to Create: Kits should grant students the freedom to construct complex systems as they see fit, fostering creativity and critical thinking.

However, it's essential to note that not all RK encompass these aspects. Some ER activities may focus solely on assembling a robot through step-by-step instructions, neglecting the critical construction aspect, which limits students' potential for developing essential 21st-century skills (Scaradozzi, Screpanti et al. 2019). Including these vital aspects in RK is crucial for optimizing the quality of learning experiences in ER.

## 3.2 Technical choices

The choice of hardware and software technology for creating RK plays a pivotal role in shaping the educational experience of students and teachers alike. In alignment with the outlined specifics that emphasize versatility, flexibility, and ease of use, the designers of these RK have made a deliberate decision. They aim to provide students with a learning environment that is not only engaging but also accessible. To achieve this, the M5StickC Plus microcontroller, manufactured by M5Stack, has been selected as the foundational component for the basic kit, embodying these principles. This compact yet powerful device is the cornerstone of the kit's hardware, enabling students to embark on their ER journey with an intuitive and adaptable tool. The choice of the M5StickC Plus reflects the commitment to ensuring that pupils, along with their teachers, can seamlessly embrace ER, fostering a conducive and empowering learning environment.

For these reasons, the following segments of this section will delve into the remarkable company behind the M5StickC Plus microcontroller and provide a detailed introduction to its features and practical applications in our educational kits.

***M5Stack***

M5Stack emerges as an ideal choice for the foundation of our RK, owing to its remarkable attributes and unwavering commitment to innovation. As a manufacturer and provider of IoT devices built upon the robust ESP32 platform, a significant advancement from the ESP8266, M5Stack brings a wealth of capabilities to the table. Their devices are characterized by modularity, stackability, and compatibility with a wide array of sensors and actuators, allowing for unparalleled flexibility and adaptability in our educational kits. Furthermore, M5Stack's dedication to user-friendly development is epitomized by UIFlow, a visual platform simplifying the creation of IoT applications.

What sets M5Stack apart is its diverse reach across various industries, including agriculture, commerce, environment, and meteorology, offering tailored solutions for data collection, analysis, and process optimization. In addition to its technical prowess, M5Stack embraces openness in every facet of its operation. The company wholeheartedly supports open-source standards, open APIs, and various forms of collaboration, aligning seamlessly with our commitment to providing a versatile, accessible, and innovative platform for ER. These compelling qualities make M5Stack a fitting partner for our educational endeavors, ensuring that students and teachers can access cutting-edge technology that inspires exploration and learning.

### *3.2.1 The hardware: M5StickC Plus ecosystem*

The keystone of our basic RK is the M5StickC Plus, a versatile and user-friendly open-source IoT development board. Powered by the ESP32-PICO-D4 with built-in Wi-Fi capabilities, this device represents an evolutionary step forward from the original M5StickC, boasting a larger 1.14-inch 135*240 colorful TFT LCD screen. The M5StickC Plus (Figure 8) offers a wealth of integrated hardware resources, including features like infrared, RTC, microphone, LED, IMU, buttons, and PMU, ensuring that students have a diverse array of tools at their disposal. Moreover, its compatibility with multiple development platforms, including UIFlow, MicroPython, Arduino, and .NET nanoFramework, empowers students to explore and create easily. The device's compact 15g body, complete with a 120mAh battery rechargeable via a USB Type-C port, enhances its portability and convenience. This remarkable device finds application in various domains, from an Internet of Things terminal controller to wearable devices, STEM education tools, and DIY creations, making it an ideal choice as the central component of our basic RK.




*Figure 8. M5StickC Plus.*

The M5StickC PLUS comes from years of research and development: it is a direct evolution of the M5StickC device; in fact, the former has a slightly larger screen, a larger battery, and a buzzer included. Both devices are compatible with the UIFlow programming.

While the M5StickC Plus is the central element of our basic RK, its true potential is fully realized when integrated into a larger ecosystem of compatible add-ons. At the heart of this ecosystem lies the M5Stack's extensive e-commerce site, which offers many add-ons designed to meet a broad spectrum of needs. These add-ons encompass an impressive range of sensors and actuators, providing the building blocks for virtually limitless possibilities in ER. One key feature of these add-ons is that they are plug-and-play: they're intended to work perfectly when first used or connected without reconfiguration or adjustment by the user.

These add-ons can be categorized into two types based on their mounting mechanisms on the microcontroller: the "HATs" and the "Units." The flexibility and compatibility of these components allow them to be seamlessly combined and mounted in various configurations, facilitating the creation of complex electronic systems. This modularity empowers students to explore and experiment with different combinations, fostering a deeper understanding of electronics, programming, and robotics. The rich diversity of add-ons, coupled with the ability to interconnect them in myriad ways, ensures that our RK are not standalone tools but rather part of a dynamic, adaptable ecosystem that encourages creativity and innovation in the classroom.

### *3.2.2 The software: UIFlow IDE*

The UIFlow Integrated Development Environment (IDE) is a pivotal software component within our RK. Purposefully designed for M5Stack devices, it plays a vital role in imparting instructions to the M5StickC Plus based on the programs created by students. This IDE leverages Blockly, a widely acclaimed graphical programming language in the educational realm, providing an accessible interface for students to design and implement their projects. UIFlow further enhances its versatility by supporting MicroPython coding, an implementation of Python 3 tailored for microcontrollers and embedded systems. This comprehensive platform simplifies the development of projects that involve robust real-world interactions, making it an ideal choice for individuals venturing into the realms of automation and programming. UIFlow's flexibility extends to its usability, offering both online and downloadable versions, ensuring students have convenient access to this empowering tool for their ER endeavors.

Within the UIFlow IDE interface (Figure 9), users encounter a user-friendly and versatile platform for programming the M5StickC. This interface offers two distinct avenues for code implementation, providing students flexibility in their learning journey. They can choose to utilize Blockly, a graphical programming approach, leveraging prebuilt blocks to execute specific functions, such as toggling the M5StickC's LED on or off. Alternatively, students can opt for Python to craft more customized scripts. Critical commands at the interface's bottom enable users to connect the M5StickC to the IDE, select the appropriate API key, and save or load content onto the device. Connectivity options encompass USB and Wi-Fi. Once connected, the UIFlow IDE empowers students to program every aspect of the M5StickC, including its display, allowing them to incorporate titles, labels, images, and other elements to tailor the device's behavior precisely as they envision it. This intuitive interface serves as a springboard for creativity and hands-on learning in ER.

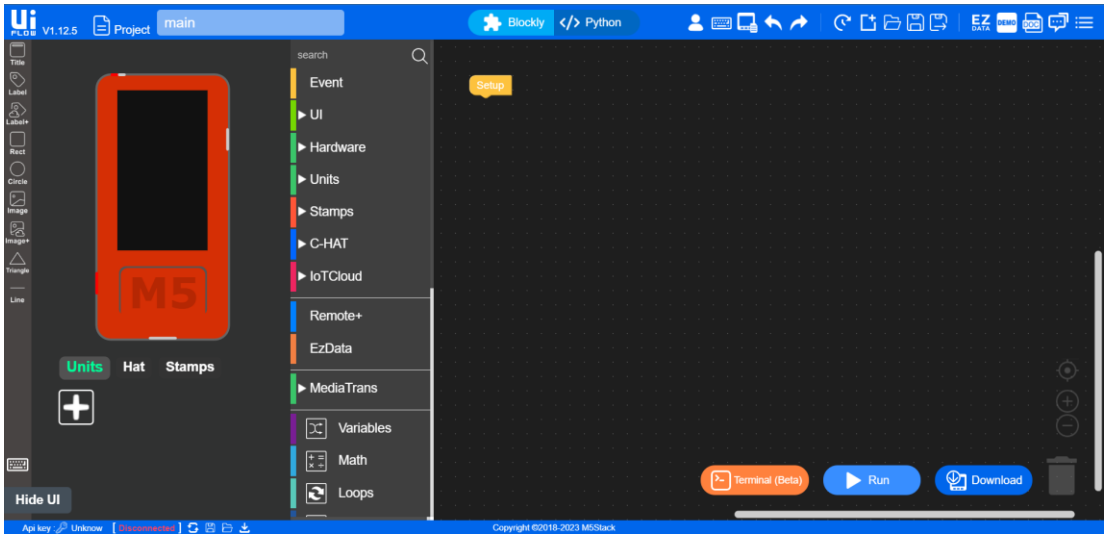



*Figure 9. theUIFlow IDE.*

An essential feature of UIFlow is the UIFlow Block Maker, a powerful tool within the IDE that enables users to create custom blocks using Python code. This innovative functionality facilitates the implementation of functions in Blockly, bridging the gap between graphical and text-based programming. These custom blocks can be effortlessly downloaded and utilized with the M5StickC Plus, streamlining the coding process for students, particularly those new to programming. This feature greatly simplifies the utilization of our kits, especially in their implementation versions, fostering a more accessible and engaging learning experience in ER.

## 3.4 The Basic Kits

This section on unveils a distinctive concept of kits meticulously crafted by the researchers of the Laboratory of Modelling, Analysis and Control of Dynamical Systems (LabMACS) in the Department of Information Engineering at Università Politecnica delle Marche (UNIVPM).

LabMACS is situated within the Department of Information Engineering at the UNIVPM in Ancona, Italy. This research facility specializes in the exploration of mechatronic systems and digitalization. Within its premises, LabMACS houses an array of technologies and robots dedicated to submarine systems research and ER. Notably, the laboratory actively engages in orientation initiatives, drawing upon its involvement in national and international projects that encompass students across all academic levels. Among its noteworthy assets are marine and submarine robots, state-of-the-art three-dimensional navigation equipment for archaeological sites and protected marine areas, as well as biomorphic robots mimicking fish and humanoids with bipedal locomotion capabilities.

As detailed in the following sections, these Basic Kits embody two fundamental principles: expandability and user-friendliness. They have been thoughtfully designed to cater to a wide range of learners, irrespective of their technological expertise, ensuring that the world of ER becomes accessible and engaging for all.

### *3.4.1 RoboFISH Basic Toolkit*

The RoboFISH Basic Toolkit represents a remarkable educational innovation that emerged within the framework of the European Project known as RoboPisces. This collaborative endeavor unites academic institutions with primary education schools, aiming to impart digital skills and STEAM

knowledge through the medium of ER. At its core, the project seeks to bring the exciting world of robotics into the classroom, inspiring students to explore their creativity and technical abilities.

Specifically, the RoboFISH Basic Toolkit was conceived as a pivotal component of the RoboPisces initiative, designed to facilitate the adoption of technology in educational activities within primary schools. This toolkit plays a vital role in introducing the initial ten topics from the FISH curriculum (a specific course involving activities with the kit), serving as an accessible gateway to the world of robotics and technology for both students and teachers alike. Comprising a microcontroller, the M5StickC (the earlier iteration of the M5StickC Plus), and a carefully curated selection of plug-and-play add-ons, including sensors and actuators, this kit empowers educators and learners to embark on a journey of exploration and discovery.

More specifically, the course was intended to guide students and teachers through the interaction between the kit and the environment as humans do daily. For example, the course focused on our capacity to sense things and act to modify the surrounding environment. In the same way, the kit can be built to sense and interact with the world. For this reason, it is noticeable how the kit includes different types of sensors and actuators.

The development of the RoboFISH Basic Toolkit followed a meticulously designed methodology aimed at enhancing the teaching of Robotics and STEAM subjects with a particular emphasis on fostering environmental awareness. By integrating innovative technology with pedagogical expertise, this kit not only simplifies the complexities of robotics but also inspires a new generation of students to become stewards of the environment through hands-on, engaging, and environmentally-conscious educational experiences.

***Kit's structure***

Table 2 analyses the structure of the kit to better understand the didactic potential.

*Table 2. BOM RoboFISH Basic Toolkit.*

| **Component** | | **Function** |
|---|---|---|
| Central Unit "M5StickC" |  *Figure 10* | The programmable unit serves as the intermediary, receiving data from sensors and transmitting instructions to actuators. This unit can be programmed through the UIFlow IDE, offering a programming environment reminiscent of Scratch or through Python coding. |

| | | |
|---|---|---|
| ENV sensor | <br>*Figure 11* | This environment monitor sensor detects temperature, humidity, and atmospheric pressure using multiple sensors. These sensors communicate over I2C. It ensures accurate temperature and humidity readings with low power consumption. The barometric pressure sensor is ideal for mobile applications. |
| Speaker Hat | <br>*Figure 12* | The Speaker HAT, designed to work with M5StickC, is a speaker with an integrated amplifier. This amplifier provides clear sound with a power output of 3 watts. It's designed to reduce noise and interference, ensuring high-quality audio playback while keeping things simple and easy to use. |
| Sensor Button | <br>*Figure 13* | "Dual Button" – a two-button module in different colors. Both buttons work based on the same principle: their status is detected by checking the electrical level on the input pin (high or low). It easily connects to the M5StickC through the GROVE interface with dedicated UIFlow IDE blocks. Plus, it's Lego-compatible for versatile mounting. |
| Sensor Joystick Hat | <br>*Figure 14* | The Joystick HAT, tailored for M5StickC, boasts a compact design with an embedded microprocessor for I2C communication. This mini joystick module allows full angular movement and center pressing, delivering angular data alongside digital button signals. Its 'HAT' plug-in design ensures a secure and streamlined connection, enhancing the overall user interface experience. |
| Sensor Moisture | <br>*Figure 15* | The EARTH unit serves as a Soil Moisture Sensor, measuring soil moisture levels. It features two large pads functioning as probes, acting as a variable resistor. More moisture leads to better conductivity, resulting in lower resistance and higher SIG output. This unit supports both Analog and Digital output, with an ADC interface for soil moisture reading. It offers an adjustable measurement range with a built-in potentiometer. |

| | | |
|---|---|---|
| | | The GROVE-compatible unit works with UIFlow IDE and features two Lego-compatible holes for easy integration. |
| Sensor Angle | <br>*Figure 16* | ANGLE is a rotary switch Unit housing a 10K Ohm potentiometer. It enables continuous signal rotary control, ideal for adjusting volume, brightness, or motor speed. Potentiometers feature three terminals: two connected to a resistive element and one to an adjustable wiper, determining the output voltage based on the wiper position. |
| Actuator MiniFan | <br>*Figure 17* | The Vibration Motor Unit is an ADC motor without gears linked to a 60mm mini fan paddle. Powered by 5V DC, it offers a single-direction rotation at a speed of 8800 RPM. Featuring a GROVE interface, it seamlessly integrates with the UIFlow IDE and includes two Lego-compatible holes. |
| Actuator Servo | <br>*Figure 18* | SERVO HAT is a servo motor module featuring the "ES9251II" digital servo, offering a 145°±10° range of motion controlled by PWM signals. The signal pin connects to G26 on M5StickC. |
| Actuator BugC | <br>*Figure 19* | It is a little robot resembling a Bug.<br>It has 4 Geared motors (1 each leg), 2 RGB LEDs onboard, and is equipped with a battery holder. It allows flexible movement in all directions. |
| Actuator PuppyC | <br>*Figure 20* | PuppyC is a programmable four-legged robot base designed for M5StickC, with 4 micro servos, a battery holder, and a switch. It communicates via I2C with M5StickC for controlled movement. While it moves slowly, it's highly maneuverable and suitable for different surfaces. You can program it using UIFlow IDE and attach it as an accessory to M5StickC. |

| | | |
|---|---|---|
| Loudness sensor | <br>*Figure 21* | The Grove - Loudness Sensor measures the loudness of sounds in the environment using a built-in microphone and amplifier. It produces a value that depends on how loud the sound is. It's designed to reduce unwanted noise and allows its sensitivity to be adjustes. You can program it using UIFlow IDE and connect it to the M5StickC grove port for easy use. |

### *3.4.2 L.S.S. "Volterra" Basic Kit*

This kit emerged from a collaborative effort between the LabMACS at UNIVPM and the forward-thinking Liceo Scientifico Statale 'Vito Volterra'" secondary school in Fabriano. This partnership was forged with a shared vision of innovative teaching methods and a commitment to engaging students more actively in their learning journey.

The genesis of this kit was driven by the school's desire for a versatile tool capable of fostering student engagement while imparting crucial technological skills. Recognizing the school's focus on STEAM subjects within its curriculum, the kit was carefully crafted and customized to meet the needs of medium to high-skilled pupils, ensuring its alignment with the school's educational objectives and enhancing its overall effectiveness as an educational resource. Furthermore, through these kits, the school could also initiate workshops and specialized courses for educators nationwide, aiming to maximize the reach and impact of these educational tools.

The kit follows a structure akin to the BoroFISH Basic Toolkit, featuring the M5StickC Plus as its central component. However, what sets this kit apart is its carefully selected array of add-ons, each chosen for its significant didactic potential. These add-ons encompass various physical principles, making them excellent tools for introducing key concepts during lessons. Through hands-on exploration, students understand the functionality of these add-ons and gain proficiency in their use.

Moreover, some components serve a dual purpose by enabling the creation of complex systems that interact with the environment, aiming to raise students' awareness. For instance, the Watering Unit, an integral part of the kit, allows students to actively participate in nurturing the school's plants. By designing systems with real-world applications, this kit imparts technical skills and fosters a sense of responsibility and environmental consciousness among students, making it a versatile and impactful educational resource.

***Kit's structure***

Table 3 describes the components of this kit.

*Table 3. BOM of L.S.S. "Volterra" Basic Kit*

| **Component** | | **Function** |
|---|---|---|
| Central Unit "M5StickC Plus" |  *Figure 22* | The programmable unit serves as the intermediary, receiving data from sensors and transmitting instructions to actuators. This unit can be programmed through the UIFlow IDE, offering a programming environment reminiscent of Scratch or through Python coding. |
| Sensor Button | | "Dual Button" – a two-button module in different colors. Both buttons work based on the same principle: their status is detected by checking the electrical level on the input pin (high or low). It easily connects to the M5StickC through the GROVE interface with dedicated UIFlow IDE blocks. Plus, it's Lego-compatible for versatile mounting. |
| Sensor Moisture | | The EARTH unit acts as a Soil Moisture Sensor, using two large probes as a variable resistor to measure moisture levels. It offers Analog and Digital output, adjustable range, and GROVE compatibility for easy use with UIFlow IDE and Lego integration. |
| 8-Channel Servo Driver Hat |  *Figure 23* | The **8-Channel Servo Driver Hat** is an 8-channel servo driver module designed for use with the M5StickC/C Plus series. It uses a main controller and drives servos using PWM signals via I2C communication. The module includes an embedded power management circuit to programmatically control the servo ON/OFF state. When powered by a rechargeable 16340 lithium battery (700mAh capacity), it can support a maximum load of 1.3A. This module is ideal for robotic and DIY projects. |

| | | |
|---|---|---|
| Micro Servo | <br>*Figure 24* | The Micro Servo SG90 is a small and lightweight motor that is commonly used in robotics and automation projects. It can rotate approximately 180 degrees and works just like the standard kinds but smaller. It is easy to use and control with a microcontroller like M5StickC Plus |
| Watering Unit with Moisture Sensor and Pump | <br>*Figure 25* | The Watering Unit, equipped with a Moisture Sensor and Pump, is a versatile device for monitoring and controlling soil moisture levels, simplifying intelligent plant cultivation. |

## CHAPTER 4. IMPLEMENTATION AND VALIDATION

In the ever-evolving landscape of ER, the journey from Basic Kits to Advanced Kits marks a pivotal shift. These latter tools, developed with empowered features, transcend the conventional boundaries of robotics education. This chapter delves into the development process that culminated in the creation of these innovative educational tools. At the heart of this chapter are two case studies showcasing advanced kits designed and manufactured by ANcybernetics, a spin-off from UNIVPM: the "PaperFISH kit" and "Guizzo."

The "PaperFISH kit" and "Guizzo" represent the forefront of ER, offering exciting opportunities for students and educators alike. These advanced kits go beyond the rudimentary concepts and provide a platform for creativity, problem-solving, and innovation. They are equipped with cutting-edge technology, encouraging students to explore, experiment, and push the boundaries of what they can achieve.

Following the exploration of these Advanced Kits, the chapter takes a deeper dive into the practical application and validation of these tools. Four distinct validation cases are analyzed, each set in a different context, with pupils of different ages and cultures: a summer camp, a robotics competition, a workshop, and a public event. These cases shed light on the diverse possibilities and the tangible impact that the deployment of advanced kits can bring in various educational settings.

Embarking on a journey through the world of advanced ER reveals the transformative potential of these tools and their ability to inspire, educate, and empower the next generation of innovators and problem solvers. This chapter stands as a testament to the dynamic nature of robotics education, where innovation knows no bounds, and learning takes on a whole new dimension.

## 4.1 Implementation of Basic Kit: Advanced Kits

Exploring the concept of the Basic Kits has led to the development of advanced versions, elevating the educational content by integrating components and expanding capabilities. Advanced kits are distinguished by their high technological complexity, tailored to specific contexts and educational outcomes. This approach aims to equip students with specialized skills, such as underwater robot control, and delve into particular themes like marine biology and environmental awareness. Notable distinctions between basic and Advanced Kits encompass:

- Physical Structure: Basic Kits lack a stable, mountable structure, resulting in a more formless assembly. Conversely, Advanced Kits predominantly feature components integrated into an adjustable chassis, offering students greater customization and creative possibilities.
- Mechanical Adjustment: Advanced Kits' structured design allows for mechanical modifications, fostering creativity, customization, and expanded educational opportunities.
- Limited Expansion: To ensure robustness, seamless integration, and reliability, Advanced Kits are composed of electronically modified add-ons. While this limits the ability to incorporate any M5Stack add-on available in the market, it concentrates on specific robot behaviors, facilitating focused classroom concepts.

Despite these differences, the technology employed in advanced kits remains consistent with that of Basic Kits. This deliberate continuity ensures a smooth transition between tools, preventing any disruptions to the learning process. Teachers and students can seamlessly progress from one kit to another, maintaining an efficient and uninterrupted educational journey.

Both Basic and Avanced Kits share a fundamental objective: to be programmed by students, enabling movement on land or in water through actuators and collecting environmental data via sensors. These functionalities, seamlessly integrated into hypothetical school curricula, play a crucial role in maximizing the learning potential of the lessons. The adaptability of these kits aligns with the curriculum, providing a platform for students to explore and apply programming concepts in real-world scenarios. This integration ensures a cohesive and effective educational journey, allowing teachers and students to transition smoothly between different kit levels while maintaining a continuous and uninterrupted learning experience.

## 4.2 Two case studies by ANcybernetics

The following case studies spotlight two distinct Advanced Kits, both conceived and crafted by ANcybernetics, a burgeoning enterprise inspired by the foundational Basic Kits developed by the expertise and knowledge of researchers at the LabMACS of UNIVPM.

Established in 2021 as a spinoff of UNIVPM, ANcybernetics specializes in educational underwater robotics, bridging the realms of nature and technology to create added educational value for the next generation. Beyond academic expertise, one minor business is to provide consultancy for tailored marine solutions to external companies. Our primary focus revolves around the development of bio-inspired mechatronic kits designed to offer more effective and comprehensive STEAM education within schools. These kits, closely resembling aquatic creatures, facilitate the teaching of challenging subjects ranging from robotics to marine biology. Furthermore, our devices offer diverse educational activities, including 3D printing and coding, fostering the development of essential soft skills such as teamwork and environmental consciousness. This dual benefit enhances students' learning experience and empowers educators with innovative skills to enrich classroom instruction.

The case studies described below coincide with the main offer of ANcybernetics, consisting of two educational devices: PaperFISH kit and Guizzo.

### *4.2.1 Paperfish Kit*

The "PaperFISH kit" represents an innovative educational tool thoughtfully crafted by ANcybernetics to introduce STEAM subjects to teachers and students, with a focus on primary school education. This comprehensive kit includes pre-cut colored cardboards, structurally essential 3D-printed components, the M5StickC controller, a selection of M5Stack add-ons, and three servo motors. The initial step for students involves building the robot, which incorporates some of the add-ons. Additionally, several add-ons are intentionally left as optional components, which students can explore during their educational journey with the kit.

The built robot features three fundamental components:

- The body houses the electronic components and boasts a detachable upper section, revealing the M5StickC controller.
- The caudal fin, connected to the body through a servomotor with a 3D-printed part that culminates in an interchangeable cardboard section, allowing students to modify its shape.

- The lateral fins, affixed to the body using two servomotors, possess mobile elements to enable rotation, providing a practical illustration of fluid dynamics concepts.

The "PaperFISH kit" distinguishes itself through several key attributes. One is affordability since the kit offers a cost-effective solution, enabling schools to obtain multiple kits for enhanced accessibility, and the affordability ensures greater feasibility for implementing activities on a larger scale. The second is the similarities with the basic kit format so to help teachers seamlessly adapt to this new tool while retaining the familiarity of traditional educational formats.

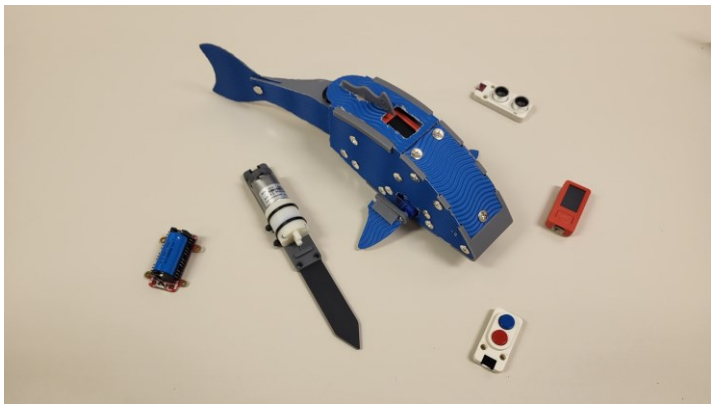


*Figure 26. PaperFISH kit blue (Silvestrini, 2023).*

The two innovative aspects of this kit are the possibility of hands-on construction. The kit fosters a hands-on learning approach, allowing students to actively participate in building the PaperFISH, thereby facilitating self-expression and skill development. Moreover, beyond the educational aspects, the building component of the kit empowers students and educators to address environmental concerns in the classroom. For instance, students can personalize certain kit elements by replacing fins with recycled materials, emphasizing the importance of environmental sustainability in their learning journey.

The specific add-ons included in the kit are described in Table 4 below:

*Table 4. BOM of Paperfish Kit.*

| **Component** | | **Optional for PaperFISH** | **Function** |
|---|---|---|---|
| Central Unit “M5StickC Plus” | | No | The programmable unit serves as the intermediary, receiving data from sensors and transmitting instructions to actuators. This unit |

| | | | |
|---|---|---|---|
| | | | can be programmed through the UIFlow IDE, offering a programming environment reminiscent of Scratch or through Python coding. |
| Sensor Button | | Yes | "Dual Button" – a two-button module in different colors. Both buttons work based on the same principle: their status is detected by checking the electrical level on the input pin (high or low). It easily connects to the M5StickC through the GROVE interface with dedicated UIFlow IDE blocks. Plus, it's Lego-compatible for versatile mounting. |
| Channel Servo Driver Hat | | No | The **8-Channel Servo Driver Hat** is an 8-channel servo driver module designed for use with the M5StickC/C Plus series. It uses a main controller and drives servos using PWM signals via I2C communication. The module includes an embedded power management circuit to programmatically control the servo ON/OFF state. When powered by a rechargeable 16340 lithium battery (700mAh capacity), it can support a maximum load of 1.3A. This module is ideal for robotic and DIY projects. |
| Micro Servo | | No | The Micro Servo SG90 is a small, lightweight motor commonly used in robotics and automation projects. It can rotate approximately 180 degrees and works just like the standard kinds but smaller. It is easy to use and control with a microcontroller like M5StickC Plus. |
| Watering Unit with Moisture Sensor and Pump | | Yes | The Watering Unit, equipped with a Moisture Sensor and Pump, is a versatile device for monitoring and controlling soil moisture levels, simplifying intelligent plant cultivation. |

| | | | |
|---|---|---|---|
| Ultrasonic Distance Unit I2C |  *Figure 27* | Yes | The Ultrasonic Distance is a precise distance sensor with a range of 2cm to 450cm. It uses I2C communication for seamless integration, making it efficient for applications like obstacle avoidance in robotics and fluid-level detection. |

### *4.2.2 Guizzo*

Guizzo, an innovative educational robotic fish developed by ANcybernetics, serves as a remarkable tool designed to seamlessly integrate environmental, STEM-themed activities with the principles of ER, and the detailed information about this robotic fish is expanded in the article from Costa, Screpanti et al. (2023) for further details. In comparison to its counterpart, the PaperFISH kit, Guizzo distinguishes itself with a more robust and complex structure, underwater capabilities, and a higher cost attributed to advanced materials and extensive research and development efforts. This underwater robotic kit offers a unique and engaging learning experience, delving into complex physics principles and marine subjects such as marine biology.

Being a prime example of bio-inspired robotics, Guizzo's design closely mimics that of an aquatic creature, enhancing accessibility and relatability for students and thereby simplifying the learning curve in robotics. The emphasis on bio-inspiration aligns with the broader educational objectives of introducing students to the wonders of the marine world in an interactive and captivating manner.

Guizzo's versatility is not limited to its design; it extends to the incorporation of 3D printing activities, enabling students to customize various components of the robotic fish. This hands-on approach fosters creativity and practical skills, making the learning process informative but also enjoyable and productive.

Researchers at LabMACS have extensively studied ANcybernetics' product Guizzo and its distinctive features, uncovering its educational and scientific potential. Beyond being an educational tool, the kit is a manifestation of a bio-inspired toolkit designed to resemble a fish capable of oscillatory motion for propulsion through water. The simplicity and cost-effectiveness of its architecture make it conducive to widespread distribution in public schools, aligning with the objective of providing a robust and easily producible product for educational purposes.

Guizzo's architecture comprises a buoyant head and a waterproof body, imitating the design elements of a fish. The propulsive system, represented by the fish's tail powered by a waterproof servomotor,

mimics the oscillatory motion of ostraciiform swimmers. This intentional simplicity encourages experimentation with buoyancy, offering students a hands-on exploration of physics principles.

Incorporating advanced electronics, Guizzo employs an M5StickC Plus as its controller, programmable via Wi-Fi, providing an interactive platform for students to delve into programming and robotics. Reed switches enable the remote operation of the controller's buttons, adding a practical dimension to the learning experience.

The power system of Guizzo features a sealed nickel-metal hydride battery pack, prioritizing safety and reliability for educational use. The wireless charging capabilities further enhance the ease of use, ensuring students can conveniently recharge the robot when needed.

Guizzo's design philosophy aligns with the wide range of benefits brought by the implementation of the ER methodology, particularly in marine-themed activities related to the environment and STEM subjects. The project's primary goal is not to create the most efficient or high-performance prototype but to provide a robust, fully functional product that is easy to manufacture in large numbers, aiming for widespread distribution in public schools.

The bio-inspired toolkit, shaped like a fish, propels itself by spinning the tail section hinged to a rigid forebody, mimicking ostraciiform swimmers. Despite being the least efficient among swimming modes, the oscillating tail design is intentionally simple, inexpensive, and easy to seal, fabricate, and maintain, making it suitable for educational purposes, even for untrained primary school personnel.

The forebody section consists of two parts: the head, a hollowed shell resembling a carp, and the body, a waterproof compartment housing the robot controller and its energy systems. The hollowed head shape allows students to practice buoyancy, and the internal surface can be easily accessed for experimentation with the varying mass and mass center positions.

The robot's thruster, comprising the oscillating tail and the flat caudal fin, is driven by a waterproof servomotor in the tail, designed as a thin hollowed shell. Integrated electronics include the M5StickC Plus controller, programmable via Wi-Fi, with reed switches allowing remote operation of buttons, enhancing hands-on learning.

Guizzo's power system involves a nickel-metal hydride battery pack sealed in the body, prioritizing safety for educational use. Additionally, the kit features wireless charging capabilities, facilitating easy recharging by placing it over any commercial wireless battery charger.

Certifications attest to Guizzo's safety and environmental standards, with a Risk Assessment conducted according to current standards, meeting high safety requirements, and bearing the CE marking.



*Figure 28. Guizzo*

Guizzo, as the optimal hardware and software tool for the training course, embodies all the features presented in the curriculum, making it an ideal instrument for promoting environmental awareness, STEM subjects, and ER principles. The FISH Curriculum, tailored for educators using Guizzo, encompasses engineering skills for robotic systems, ocean literacy, and underwater physics, providing a comprehensive foundation for delivering engaging lessons.

Table 4 includes the list of the main components integrated into the kit:

*Table 5. Principal components of Guizzo*

| **Component** | | **Function** |
|---|---|---|
| Central Unit “M5StickC Plus” | | The programmable unit serves as the intermediary, receiving data from sensors and transmitting instructions to actuators. This unit can be programmed through the UIFlow IDE, offering a programming environment reminiscent of Scratch or through Python coding. |

| | | |
|---|---|---|
| Channel Servo Driver Hat | | The Channel Servo Driver Hat is an 8-channel servo driver module designed for use with the M5StickC/C Plus series. It uses a main controller and drives servos using PWM signals via I2C communication. The module includes an embedded power management circuit to programmatically control the servo ON/OFF state. When powered by a rechargeable 16340 lithium battery (700mAh capacity), it can support a maximum load of 1.3A. This module is ideal for robotic and DIY projects. |
| Servo Traxxas |  *Figure 29* | The Traxxas TRX-4 is a servomotor for modeling applications. It comes with a fender protector and a Power HD digital waterproof servo. The actuator inspires reliability and resilience, claiming dust and water-resistant. |

In the future, Guizzo will be integrated with more sensors (cameras, proximity sensors) to enhance its autonomous driving capabilities.

## 4.3 Case Studies of Validation Experiences

The education landscape has undergone a transformative shift in recent years with the integration of ER. These experiences, spanning I.C. “Solari” Summer Camp, RodionPedia Marine Robotics Competition, L.S.S. “Volterra” Workshop and “Nonni & Nipoti 2023”, underscore the dynamic fusion of technology and pedagogy, presenting a paradigm shift in engaging students. The essence lies in immersing learners in hands-on applications, fostering interdisciplinary skills, and promoting critical thinking in a captivating and innovative environment.

These experiences collectively underscore the evolving landscape of educational methodologies. ER moves beyond conventional classroom teaching, immersing students in a dynamic and interactive learning environment. The sequential exploration of activities im Fabriano, Rhodes, Loreto, and Falconara demonstrates the adaptability of these experiences to diverse educational levels and contexts. By fostering curiosity, collaboration, and interdisciplinary skills, ER emerges as a catalyst for preparing students for the challenges and opportunities of the digital age.

### *4.3.1 I.C. "Solari" Summer Camp*

***School:*** Istituto Comprensivo "G. Solari"

***Location:*** Loreto (AN)

***Date:*** August 2021

***Grade:*** Primary School

***RK deployed:*** RoboPisces Basic Toolkit, Guizzo

***Description***

In the summer of 2021, the Istituto Comprensivo "G. Solari" in Loreto (AN) organized a summer camp experience for 25 students (ages 10-13). The collaboration of the school's dedicated staff made it possible for students to make the most of its facilities over six days, investing 5 hours each day in non-formal activities centered around robotics and sustainability. Through non-formal activities, students explored the realms of marine robotics, environmental education, and storytelling. The fusion of these elements aims to consolidate knowledge and skills, demonstrating the potential for experiential learning in nurturing well-rounded individuals. This experience and the outcomes are extensible, as Costa, Screpanti et al. (2023) described.

***ER Impact***

The summer camp curriculum revolved around the FISH curriculum, covering fundamental and advanced marine robotics concepts. For the first three days, students delved into the basics of robotics using the Basic Kits from RoboPisces, as the school was an official partner of the European Project. Subsequently, the focus shifted to marine robotics and environmental education, employing the Advanced Kit Guizzo for three days. The culmination of the camp involved a unique storytelling activity where students shared narratives created using the fish robot and other materials. This activity aimed to organize their newfound knowledge, aligning with the theory of social constructivism.

***Assessment and Questionnaires***

Students were surveyed before and after the camp to gauge the impact of the activities. The questionnaire assessed students' interest, self-efficacy in robotics, and engagement in sustainability themes.



*Figure 30. Children playing with the RoboPisces Basic Toolkit (Silvestrini, 2021).*

### *4.3.2 RodionPedia Marine Robotics Competition*

***Location:*** RodionPedia, Rhodes

***Date:*** July 2022

***Organizers:*** LabMACS and ANcybernetics teams

***Grade:*** Primary and Secondary School

***RK deployed:*** Guizzo

***Description***

The Marine Robotics Competition at RodionPedia, Rhodes, in July 2022 stands as a testament to collaborative learning and innovation. Set against the backdrop of the ICICTE 2022 Conference, the competition brought together students and teachers, highlighting the captivating potential of Guizzo underwater robots. Teams equipped with Guizzo underwater robots and computers for programming embraced the challenge of navigating an aquatic obstacle course. This experience showcased technical prowess and emphasized the unifying power of technology in fostering collaboration and igniting a passion for STEM subjects.

The objective of the competition was to program and navigate Guizzo robots in a water-based challenge. The engagement of the participants, including students and teachers, was guaranteed by the programming activities of their Guizzo robots, refining their strategies after each attempt. At the end of the activity, the teams presented their robotic creations to judges, tackling challenges such as a "drag race," a full underwater circle, and a complex obstacle course. The competition crowned a

victor team based on excellence in these challenges, showcasing mastery in robotic programming and navigation.

***ER Impact***

RodionPedia is a private primary and secondary school. This event showcased the school's commitment to ER and cutting-edge learning methods, thanks to the collaborative efforts of LabMACS and ANcybernetics researchers.

This event highlighted the capacity of robotics, exemplified by Guizzo, to immerse students in educational exploration while ensuring an enjoyable experience. Beyond technical skills, the competition fostered collaboration and innovation among participants.

The RodionPedia Marine Robotics Competition exemplified the convergence of education, technology, and collaborative learning, exemplifying the transformative potential of ER in captivating young minds.



*Figure 31. Teachers competing using Guizzo (Silvestrini, 2022).*

### *4.3.3 L.S.S." Volterra" Workshop*

***School:*** Liceo Scientifico Statale "Vito Volterra"

***Location:*** Fabriano (AN)

***Date:*** October 2022

***Grade:*** Secondary School

***RK deployed:*** L.S.S. "Volterra" Basic Kit, Guizzo

***Description***

The experience at Istituto Tecnico Tecnologico Statale “Vito Volterra” in Fabriano, October 2022, reflects an intentional educational approach. The workshop introduced secondary school students to essential robotics competencies, focusing on marine robotics and environmental awareness. Integrating M5stack components offers a versatile toolkit, enabling students to delve into various facets of coding and robotics, enriching their understanding of STEM disciplines.

***ER Impact***

The curriculum focused on theoretical and practical aspects intending to empower students through the development of computational thinking and establish the student as the focal point of the teaching and learning process. Moreover, it encourages educators to adopt a new role for facilitating innovative and inclusive teaching practices. ER and coding were presented as pedagogical approaches that rely on the conscious, collaborative, and creative use of robotics concepts and tools. This approach has demonstrated its capacity to enhance various skills and competencies among students, including computational thinking and a propensity to engage with STEM subjects.

This initiative highlighted the school's commitment to providing students with a holistic educational experience, bridging robotics education with real-world applications and environmental consciousness.



*Figure 32. Secondary school students working together on Guizzo.*

### *4.3.4 "Nonni & Nipoti 2023"*

***Location:*** Falconara (AN)

***Date:*** July 21, 2023

***Grade:*** Primary School

***RK deployed:*** PaperFISH kit, Guizzo

***Description***

Nonni & Nipoti 2023 was an engaging educational event held in Falconara, featuring diverse activities with a particular focus on the youth. The event kicked off at 4:00 PM with various stands set up in the central square, offering many interactive experiences for attendees. Among these stands was the UNIVPM booth dedicated to robotics, featuring LabMACS and the academic spin-off ANcybernetics.

***ER Impact***

One event highlight was using a water pool, where children of different ages, ranging from primary to lower secondary school, could program robotic fish using tablets and PCs. The sheer amazement on their faces as they observed the fish moving in the water reflected the success of this engaging and educational activity.

Another notable activity involved programming sensors and actuators, such as small robotic pumps, allowing students to witness their effectiveness in a garden behind the central square.

The event provided students with a firsthand experience of active robots, allowing them to interact with the exciting realm of ER. For the older students, particularly those in secondary schools, it served as an introduction to the UNIVPM world and its various innovative departments, including the LabMACS.

Through these hands-on activities, young participants enjoyed a day filled with fun and discovery and gained valuable exposure to the principles of robotics. They witnessed the practical applications of programming and automation in a playful yet educational environment. Nonni & Nipoti 2023 successfully bridged the gap between generations and ignited a spark of curiosity in young minds, fostering an early interest in the innovative world of ER.



*Figure 33. A child and a researcher playing together with some Guizzos (Silvestrini, 2023).*

# CHAPTER 5. FINDINGS AND GUIDELINES

This chapter delves into the heart of our research, presenting a comprehensive analysis of the outcomes derived from four distinct validation experiences, each involving the deployment of Basic and Advanced educational RK. The diverse nature of these experiences offers a unique and multifaceted perspective on the potential applications and impacts of ER. By examining the results of these validations, there are many insights into the efficacy of deploying RK in varying educational contexts. This exploration highlights the educational benefits and provides practical guidelines for harnessing the full potential of ER in different settings.

## 5.1 The Importance of Evaluation Practices

This section delves into the outcomes of the educational experience conducted at Istituto Comprensivo Solari. It's crucial to emphasize that the questionnaires provided valuable insights into the objectives of the activities, enabling the identification of both positive and negative findings, which are detailed below.

***Positive Findings:***

The summer camp at Istituto Comprensivo "G. Solari" in Loreto (AN), supported by Costa, Screpanti et al. (2023), showed numerous positive results. Notably, a significant portion of participants had pre-existing interests in robotics (59%), with the majority finding the activities delightful (88%). The camp

notably increased students' self-efficacy in robotics, rising from the initial 40% to 68%. Moreover, the camp effectively shifted the focus from technology to practical applications, notably enhancing their interest in sustainability efforts. The fish-like robot, employed for education, was trendy, with students expressing delight in working with it (51%) and actively participating in programming tasks (35%). This experience highlighted the bioinspired toolkit's positive impact on fostering student interest, engagement, and motivation during the summer camp. Remarkably, even students with previous experience in digital devices displayed enthusiasm for the fish-like robot, indicating its efficacy in promoting student engagement and learning.

***Negative Findings:***

The camp could potentially attract more students interested in enhancing their robotics skills (25%). A few students did not find the fish robot innovative (12%), suggesting room for further improvements. A small proportion appreciated the different methodologies used (14%), indicating the potential for more distinct engagement.

In summary, the summer camp effectively engaged students, boosting self-efficacy in robotics and fostering a strong interest in sustainability. While most findings were positive, there's potential to attract more students seeking to improve robotics skills, introduce innovative features, and enhance the camp's distinctiveness to engage all participants fully.

## 5.2 The educational efficacy of competition and entertainment

This subsection explores the educational experience at RodionPedia, emphasizing the unique format of a Marine Robotics Competition. This format showcases significant educational potential and offers an engaging approach to learning, fostering student involvement and growth.

***Positive Findings:***

The competition at RodionPedia demonstrated significant educational efficacy. Participants, including both students and teachers, showed strong engagement, displaying a passion for programming and navigating Guizzo underwater robots. Notably, they actively refined their strategies with each attempt, emphasizing a commitment to learning and improvement. The event effectively fostered collaboration and innovation, promoting valuable soft skills alongside technical expertise.

***Negative Findings:***

While the event showcased remarkable positive findings, it is essential to note that no significant negative results were reported. The RodionPedia Marine Robotics Competition successfully demonstrated its potential to foster educational engagement, technical proficiency, and collaboration, underlining the transformative capabilities of ER for young learners.

The RodionPedia Marine Robotics Competition displayed a resoundingly positive impact. Participants, including students and teachers, were highly engaged and demonstrated a genuine passion for programming and navigating Guizzo underwater robots. They actively refined their strategies, emphasizing their commitment to learning and improvement. The event also fostered valuable soft skills alongside technical expertise. Notably, no significant negative findings were reported, underlining the competition's ability to promote educational engagement, technical proficiency, and collaborative learning, affirming its transformative potential for young learners.

## 5.3 Workshops as a practical way to learn ER

The validation experience conducted in Fabriano provides an invaluable case study highlighting the effectiveness of the "Learning by doing" approach when it comes to STEAM education. This hands-on method has proven to be exceptionally effective in helping students grasp theoretical concepts that underpin technical activities. The findings from this experience offer a deep understanding of the interconnectedness between practical and theoretical knowledge, shedding light on the ways in which ER can enrich students' learning journeys.

***Positive Findings:***

The workshop held at Istituto Tecnico Tecnologico Statale "Vito Volterra" in October 2022 demonstrated significant positive outcomes. The integration of ER with marine environmental concepts yielded notable results. Students actively engaged with the provided components from M5stack, showcasing a strong grasp of the ER domain. The course effectively emphasized computational thinking, promoting a proactive approach to STEM subjects and encouraging creative problem-solving skills among the students. Additionally, this initiative reshaped the role of educators, fostering innovation and inclusive teaching methodologies. Evidently, the course successfully equipped students with essential skills, nurturing their enthusiasm for ER and instilling environmental consciousness.

***Negative Findings:***

While the validation experience in Fabriano showcased a host of positive outcomes, one notable challenge emerged. Some students, particularly those without a technical background from non-technical secondary schools, faced initial difficulties grasping ER and electronics concepts. The unfamiliarity with these subjects momentarily hindered their progress. However, this obstacle was overcome with relative ease, as an introductory exploration of electronics fundamentals swiftly bridged the gap in their understanding. Despite the initial challenges, the experience highlighted the adaptability of students and the effectiveness of educational activities in empowering them to acquire new competencies and enhance their STEAM engagement.

In summary, the robotics course at L.S.S. "Volterra" in Fabriano achieved highly positive results. The seamless integration of ER with marine environmental concepts empowered students, fostering computational thinking and a proactive approach to STEM subjects. Furthermore, the innovative teaching methodologies and the reshaped role of educators contributed to the success of this initiative.

## 5.4 ER potential during a public event

The "Nonni & Nipoti" event not only provided valuable insights into the effectiveness of ER but also showcased the extraordinary potential of a public event format. This unique event, designed to bring together students of all ages, emphasized the significance of robotics as a source of enjoyment and knowledge. Beyond the positive and negative outcomes observed during the event, the public format and hands-on activities generated considerable media resonance. Students of varying age groups were drawn to the event, captivated by a new and innovative way of learning, while adults found inspiration in teaching and facilitating these educational opportunities. This format proved to be a powerful means of engaging learners and spreading the importance of robotics in a fun and inclusive environment.

***Positive Findings:***

Nonni & Nipoti 2023, held in Falconara on July 21, 2023, demonstrated the efficacy of ER activities. Young participants from primary to lower secondary school actively participated in programming robotic fish, creating a strong connection between programming and practical application. Their fascination as they observed the fish in motion underscored the success of this educational endeavor. The event effectively introduced older students to the UNIVPM world and its innovative departments, such as LabMACS. Through hands-on experiences, participants enjoyed a day of learning and discovery

while gaining valuable exposure to robotics principles, automation, and programming in an engaging environment.

***Negative Findings:***

One noteworthy aspect of the event format presented a limitation. As students had limited time to engage with the ER experience while passing by the stands, the activity, although entertaining, did not prove to be as engaging as expected. While feedback from students was generally positive, the activity fell short of leaving a lasting mark on the students' learning paths and was more successful as an entertaining experience than an educational one.

In summary, Nonni & Nipoti 2023 served as a successful platform for introducing ER to young learners, sparking curiosity, and creating an engaging bridge between generations. The presence of only one adverse finding further supports the effectiveness of the activities in inspiring a new generation's interest in the innovative world of ER.

## 5.5 Emerging Guidelines

These emerging guidelines collectively form a comprehensive framework for the successful integration of ER. They address key aspects such as teacher readiness, curriculum design, inclusivity, adaptability, continuous improvement, and a focus on student-centered, hands-on learning approaches. These guidelines are poised to shape the future of ER, ensuring a transformative and enriching experience for learners of all backgrounds and levels of expertise.

Teacher Competencies and In-Depth Curriculum:

- Competency Development: Ensure that educators possess the technical competencies necessary to integrate ER into the curriculum seamlessly.
- Training Initiatives: Provide comprehensive training programs and resources for teachers, enhancing both their robotics knowledge and teaching skills.
- Curriculum Design: Develop a curriculum that spans different levels of complexity and depth. Cater to the needs of both novice learners and those seeking advanced knowledge in robotics.

Customized Robotic Kits and Hands-On Learning:

- Adaptable Kits: Design robotic kits that are adjustable and can be customized to meet the diverse needs of different age groups and learning objectives.
- Flexibility: Ensure the adaptability and flexibility of these kits to accommodate students with varying technical proficiency levels.

- Hands-On Approach: Emphasize hands-on learning experiences, encouraging active engagement with robotics activities. Practical application should be a central element of the curriculum.

Interdisciplinary Integration:

- Cross-Subject Integration: Promote the integration of ER across various subjects and disciplines, including mathematics, science, art, and more.
- Inclusivity: Ensure that ER programs are designed to be inclusive and accessible, catering to students with diverse backgrounds and abilities.
- Diversity in Learning Environment: Foster a welcoming and diverse learning environment that encourages participation from students with varied interests and strengths.

Continuous Evaluation and Improvement:

- Ongoing Assessment: Establish a systematic approach to ongoing assessment, allowing for the continuous tracking of student progress.
- Adaptability: Regularly update robotics programs to reflect technological advancements and incorporate the latest educational best practices.
- Comprehensive Evaluation: Implement various assessment methods to evaluate students' robotics skills and knowledge effectively.

Project-Based Learning and Student-Centered Approach:

- Project-Based Approach: Implement project-based learning methodologies, enabling students to design, build, and program robots to achieve specific goals.
- Student-Centered Learning: Place students at the core of the educational process, allowing them to explore robotics at their own pace. Provide guidance and support to facilitate personalized learning journeys.

# CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This thesis addressed the challenges of developing targeted interventions, improving teacher training programs, and promoting an inclusive approach.

The analysis of existing ER programs and the evaluation of outcomes have provided valuable insights that inform strategies for enhancing accessibility and equitable integration of ER in various educational contexts. The innovative integration of marine robotics as an experimental approach has added a unique dimension to the learning experience, successfully bridging the gap between traditional ER and real-world applications. Furthermore, incorporating animal-like, bioinspired robots has contributed significantly to promoting sustainability and environmental awareness among students. The natural user interfaces employed in these educational activities have effectively engaged students and fostered a deep connection between technology, environmental science, and robotics education.

The results from the case studies have shown that these approaches not only enhance students' interest and self-efficacy in robotics but also contribute to reducing the risk of school failure and early school leaving. ER has proven to be a valuable tool for improving students' comprehension of subjects and fostering cooperation, peer learning, and self-efficacy.

Overall, the successful implementation of marine robotics education, coupled with the incorporation of bioinspired robots, highlights the potential of ER experiences to equip students with essential skills and competencies for their future as responsible citizens and job-seekers. This research underscores the importance of fostering STEAM education, digital skills, and ocean literacy by leveraging smart pedagogies and constructionist learning environments. It demonstrates the capacity of ER to introduce vital ideas related to sustainability and environmental consciousness, ultimately promoting a more engaging and impactful learning experience for students across diverse groups.

## 6.1 Addressment of ER challenges

In conclusion, this research has made substantial strides in addressing the multifaceted challenges of ER. As outlined in the introduction, these challenges have hindered the widespread adoption and optimization of ER's potential in educational settings. The following paragraphs present the solutions identified through this research, contributing to a more effective, accessible, and evidence-based implementation of ER.

One of the most pressing challenges faced by ER is its fragmented implementation. To address this, the thesis has focused on creating compelling evidence of the efficacy of learning through robotics. This evidence base can serve as a unifying force, driving the consistent integration of ER into educational programs and curricula. By demonstrating the benefits of ER, we can encourage a more widespread and cohesive approach to its implementation.

In order to solve or ease accessibility in schools of ER tools, the thesis emphasizes the need for financial support and resource allocation to ensure that ER is accessible to all schools, regardless of their financial constraints. By providing the necessary resources and support, we can bridge the accessibility gap and extend the benefits of ER to a broader range of educational institutions.

Moreover, developing comprehensive teacher training programs would solve the lack of preparedness. This solution will equip educators with the skills and knowledge to effectively integrate ER into their teaching methodologies. Enhancing teacher preparedness ensures that ER is employed to its full potential in the classroom.

The lack of empirical evidence, particularly for students aged 11-12, has been a significant hurdle. For this reason, the thesis has emphasized the need for rigorous studies to establish the efficacy and benefits of ER in diverse educational contexts. By conducting robust research and building a solid evidence base, it’s possible to promote ER's acceptance as a valuable educational tool.

In summary, the solutions presented in this research comprehensively address ER's challenges, paving the way for its more effective and inclusive integration into educational systems. With compelling evidence, accessibility, teacher preparedness, early education strategies, research-based practices, quality control, and organized guidelines, ER can fully unlock its potential as a transformative educational tool. By navigating these challenges, we can ensure that ER positively impacts the field of education, offering students engaging and innovative learning experiences.

## 6.2 Methodological Contributions

The methodological contributions in this research play a pivotal role in shaping the study's robustness and validity, and they offer distinct insights:

Starting from research design, deliberate selection of case studies ranging from Basic Kits to Advanced Kits contributes to the comprehensive exploration of educational tool development in the field of ER. This method allows for an in-depth examination of the evolution of ER and highlights the diverse applications of RK in educational contexts. It provides a broader example of how ER tools have

evolved, from foundational to advanced concepts, enriching the understanding of their developmental trajectories.

Moreover, the systematic collection and analysis of feedback data through questionnaires provide a wealth of precise and comprehensive information, particularly regarding the educational potential and quality of the RK. The incorporation of a mixed methods approach, as previously discussed in Chapter 2 and cited by (Scaradozzi, Screpanti et al. 2019), ensures a well-rounded dataset by integrating both quantitative and qualitative methods. This approach contributes to a more comprehensive evaluation of the impact and effectiveness of the RK, enhancing the depth and accuracy of the study's findings.

Finally, this thesis recognizes the essential aspects that well-designed RK should encompass, emphasizing the importance of these elements in promoting effective learning experiences. This methodological contribution not only sets criteria for assessing the quality of RK but also guides their development and evaluation. It underlines the significance of the electronic foundation, nature-inspired design, component diversity, and freedom to create in RK. By identifying these critical elements, the research offers valuable guidance for the improvement and optimization of RK in ER.

These methodological decisions are essential as they not only guide the research process but also provide a comprehensive framework for understanding the evolution of ER, assessing the quality and impact of RK, and promoting effective learning experiences for students.

## 6.3 Limitations and Future Directions

Recognizing the bright potential linked to the incorporation of ER activities via RK in school settings, it becomes essential to confront specific constraints. A prominent one concerns the necessity for continuous investments in teacher training programs. Sustained professional development becomes crucial to maintain educators' proficiency in the ever-evolving field of robotics and their ability to foster meaningful learning experiences. Additionally, the high costs for this kind of activities to be inserted in schools, particularly those with limited resources, underline the importance of concerted endeavors to secure funding and resources for effective ER implementation.

While integrating RK in schools brings significant potential, it also requires exploring future directions. One such direction involves incorporating the bioinspired toolkit into the curriculum, creating opportunities for boosting STEAM learning, enhancing digital skills development, and promoting ocean literacy.

Furthermore, there's a need to innovate the assessment methods related to these robotic kits. Future research could explore the integration of educational data mining and learning analytics, providing more precise and valuable data for evaluation. As explained in Scaradozzi, Cesaretti et al. (2020), this approach aligns with the open-ended tasks that help students develop essential knowledge and skills. By combining the strengths of quantitative and qualitative methods, this innovative evaluation system can effectively support educators and meet the demand for fast and accurate assessment methodologies. Additionally, machine learning-based methods for educational purposes hold promise for the future of school education (Scaradozzi, Cesaretti et al. 2020). These methods offer innovative applications in the field of ER, focusing on identifying diverse problem-solving pathways and analyzing how students learn to utilize sensors during ER activities. Embarking on these future directions can further enhance the integration of RK in schools and the potential for improved educational outcomes.

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